FACTORS CONTROLLING WHEAT PRODUCTIVITY IN THE LOWER MEDJERDA VALLEY, TUNISIA

A STUDY OF AN AGRICULTURAL ECOSYSTEM

by

RODERIC WILLIAM DUTTON

Thesis submitted for the Degree of Doctor of Philosophy
in Geography

School of Oriental and African Studies
University of London
May, 1972

ABSTRACT

This thesis is concerned with the factors governing the cultivation and productivity of wheat on French farms during the colonial period in Tunisia. Particular attention is given to the development region of the Lower Medjerda Valley (LMV).

The thesis begins by setting out the principal hypotheses and discusses the selection of the study area. The importance of the study for Tunisia is made clear in the second chapter which analyses the significance of wheat in the Tunisian diet and economy. The physical features of the LMV and the bearing they have on cereal productivity are then described.

The second part of the thesis first establishes the poor condition of agriculture which the French found in Tunisia and then examines the general impact that the French presence made on this low agricultural base and on the people responsible for it. Finally a detailed analysis is made of the effects of French farming techniques on cereal productivity in Tunisia and on the fertility of the land. The last, post-war, phase of colonisation receives particular attention in order to see whether French farming techniques deteriorated under the pressures of independence and impending land nationalisation.

The last part of the thesis examines the mechanisms by which different climatic elements can affect yield and suggests an objective basis for defining good and bad climatic years. Bearing in mind the mechanisms involved, a quantitative analysis of the relationship between climate and yield is made, using data from the LMV.

The study reveals that although French methods of cultivation did succeed in increasing yields the climate and the soils retained controlling roles. Moreover the fertility of some land was put at risk. Tunisian yields rose on good land but population pressures forced peasants to cultivate and endanger unstable hill soils.

ACKNOWLEDGMENTS

Many people both here and in Tunisia have helped with information and advice to make this study possible. Shortage of space permits me to thank only a few by name.

In the course of my field work in Tunisia I obtained essential information from the Medjerda Development Office with the generous approval of M. M.Ghedira, the then Président Directeur Général. I am indebted to M. W.d'Hulster, Chef du Bureau Technique, to M. M.Fki and to the staff of all other departments of the same office for the time and assistance they gave me.

My thanks are also due to the officials of the Cereals Office in Tunis without whose patient and tireless help I could never have collected the cereal production data which is fundamental to the thesis.

I owe it to two Tunisian students of agriculture, Mournir Hedri and Mohammed Hadjej, that I can claim some first-hand knowledge of agriculture in the Lower Medjerda Valley. They spent three months of the summer vacation with me interviewing farmers and introducing me to every part of the region.

In England I benefited greatly from the knowledge and experience of Dr. D.Boyd of the Department of Statistics at the Rothamsted Experimental Station. But it is to Dr. K.S. McLachlan, my supervisor, to whom I owe a special debt of gratitude for his support and encouragement throughout my period of study at S.O.A.S.

CONTENTS

PART II

PART III

LIST OF TABLES

LIST OF TEXT FIGURES

LIST OF PLATES

Definition of the Term Agricultural Year

In Tunisia the term 'Agricultural Year', used when referring to the effects of rainfall on yield, is defined as running from 1 September to 31 August. But this is misleading when considering cereal crops, which are normally harvested in June, because the rainfall of July and August cannot possibly affect their yield. On the other hand heavy rainfall in August, which occasionally brings to an end the summer drought, may have an effect on the yields of the succeding year. A more natural division of the years, therefore, would be at the end of July; a month which is normally rain-free. It is this division that is accepted for the purposes of this thesis. Where, for example, a date is written, as 1948/49, it refers to the period 1 August 1948 to 31 July 1949.

Transliteration of Tunisian Place Names

The system of transliteration of Tunisian place names used in this thesis aims at internal consistency and the adoption of a current spelling which would be instantly recognisable to all those familiar with recent literature on Tunisia. The majority of the spellings are taken from either the 1956 population census or the 1:50,000 maps; whichever has seemed more appropriate.

Since independence a few towns and villages have been given new names. Mentioned in the thesis are:-

Porto Farina	now called	Ghar el Melah
Ferryville	" "	Menzel Bourguiba
Souk el Arba	" "	Jendouba

- in each case the current name has been used.

GLOSSARY OF FRENCH AND ARABIC WORDS

Auto-consommé	consumed by the producer
Bidonville	shanty-town
Commune	small town, with a mayor
Contrôle	an administrative unit; a term no longer used
Contrôleur civil	administrative head of a contrôle
Colon	colonist
Coup de chaleur	heat-wave
Déclaration d'ensemencement	declaration of area sown
Déclaration de récolte	harvest declaration
Délégation	administrative unit; division of a gouvernorat
Echaudé	shrivelled; shrivelling of wheat grain associated with high May temperatures. Results in reduced size and weight of grain.
Gouvernorat	largest administrative unit in Tunisia; there are 13 altogether
Levée	embankment of a river
Marché toléré	tolerated market; the level of illegal wheat marketing accepted by the Cereals Office given that it could not be effectively banned
Ménage	household
Métayer	farming holding land on condition that a percentage of the produce is given to the owner
Mitadinage	a disease of hard wheat associated with shortage of nitrogen. Yields are reduced.
Passe-partout	master; suitable everywhere
Pis aller	last resource
Raison d'être	the end and justification
Semoule	ground wheat (semolina)
Zone de rachat	area of repurchase
Agir	labourer
Caidat	old term for an administrative unit in Tunisia
Cheikhat	administrative unit; division of a délégation
Djebel	hill, mountain

Fellah	peasant, farmer
Habou (private)	Inalienable land bestowed on a religious centre where the owner's family is still extant; its members farm the land and claim the usufruct.
Habou (public)	As above but where the owner's family has died out leaving the religious centre to manage the land and have full rights over it.
Hamri (terre hamri)	red earth
Haras	stud farm
Khammes	see Métayer
Melk	land in full private ownership
Mokaddem	foreman
Ouakaf	farm manager
Qar'at	marsh, pond
Sebkhet	salt marsh, pond, lake
Wadi	seasonal stream, river

PART I

BACKGROUND

CHAPTER 1

INTRODUCTION

1.1 Aims and Hypotheses. The principal aim of this thesis is to make a close examination of the interrelationship between a selected group of farmers in Tunisia, the productivity of the land they cultivated and the climate. The study concerns the way in which large areas of land were brought under permanent cultivation, for perhaps the first time since the Roman era, by the French and Italian colonists. It will be argued that before the arrival of the colonists most of the land, with some notable exceptions, was extremely under-exploited. In practice the farming methods neither used the natural advantages of the soil nor sheltered the crops from the worst dangers of the climate. The colonists worked to improve the methods of farming practice and adapt them both to the climate and soil in an effort to improve both the fertility of the land and, hence, their crop yields.

The colonists certainly used the soil much more intensively than before. This carried with it the twin dangers of losing the soil by erosion and exhausting the fertility of the soil by over-useage. For this reason the evidence available will be closely examined to see whether the colonists overstepped the boundary between under-using and overexploiting their land.

Some attention will be given to the indirect effects of the presence of the colonists on the land farmed by the Tunisians. It will be argued that the gulf between the results of the traditional farms and the so-called 'modern' farms, run by the colonists and a small number of Tunisians, was not as great as is commonly thought. Also that the main reason why the peasants extended farming into the hills, where much damage was done by erosion, was not the presence of the colonists but the demographic pressure exerted by the growing population.

The crop chosen for examination is wheat. This is for several reasons. Firstly it was an important crop in Tunisia long before the French arrived which makes a comparison with the pre-colonial situation possible. Secondly wheat remained for the French a crop of primordial importance and played a major role in the diet and economy of the country. Thirdly although the role of wheat in the economy has changed since the war it still occupies some 25% of the agricultural land and is the principal food product grown. Understanding how it grows is thus of economic as well as purely academic importance. Fourthly wheat is a relatively shallow-rooted annual crop and so its yield is likely to reflect the climate of the year in which it is grown and the quality of the surface soil. The other major agricultural crops in Tunisia, olives and vines, are deep-rooted perennials and are less responsive to annual variations of rainfall and temperature. Their roots tap reserves of water and nutrients from the subsoil.

The ways in which rainfall and temperature can affect wheat yields will be examined at some length and an attempt made to see how successfully the colonists came to terms with the climate. It will be argued that the methods of cereal cultivation adopted overcame some of the worst problems posed by the climate but that nevertheless the climate continued to play a limiting role. In order to understand this role the last part of the thesis will be concerned with a quantitative evaluation of the correlation of yield with a number of climatic factors.

Below, these points are put more formally as hypotheses:

1. The colonists improved the fertility of the land they farmed and came much nearer than previously to the border between under-using and overexploiting the soil, without causing undue damage to it.

2. By evolving and adopting methods of wheat farming which took the Tunisian climate into consideration the colonists overcame some of its worst defects and made better use of what advantages it offered.

3. The climate retained a strong controlling effect on yield of wheat. Climatic constraints were primarily responsible for maintaining the system of extensive cereal farming.

4. The gulf between the productivity of the colonial farms and the Tunisian farms was not as wide as has been thought. It was the growth of the Tunisian population and advances in agricultural technology, rather than the presence of the colonists, that increased the rate of Tunisian underemployment and forced Tunisian peasants to farm the poor hill soils.

1.2 Discussion of the Study Area. To examine these hypotheses this study will concentrate on the achievements of colonial cereal farming with a special reference to a study of 126 individual French and Italian farms in the Lower Medjerda Valley (LMV) from 1948/49 to 1962/63. The reasons for selecting this study area are discussed below.

Individual Farm Study. A study based on individual farm data was made possible because each year the farmer had to complete a Déclaration d'Ensemencement and a Déclaration de Récolte and return it to the cereals office (STONIC: Section Tunisienne de l'Office National Interprofessionel de Céréales). The forms gave, respectively, the area and production of the following crops:- Hard Wheat, Soft Wheat (ordinary), Soft Wheat (type Florence), Barley, Oats, Flex, Broad Beans, Peas, Chickpeas, Lentils. The forms also gave the name and area of the farm and the name of the owner if different from the farmer - so making identification easy.

French and Italian Farms. There were several reasons for the choice of French and Italian, rather than Tunisian, farms. Firstly, at the STONIC, the colonial forms were filed by farmer whereas the Tunisian forms were filed by year and administrative sub-region. This meant that it was practically impossible to trace any one Tunisian farm back through more than two or three years. Much more Tunisian land was leased by the year which meant no continuity of records or farm management.

Secondly it is likely that the colonial records would be much more accurate than the Tunisian ones. In fact many of the Tunisian forms were incomplete - giving some indication of area but not of production - or the figures conflicted. This was very rarely true of the colonial farms because the colonists were much more literate, used to completing forms and less suspicious of authority. Moreover there were only a small number of colonists (compared with the number of Tunisian peasants) whose farm area and boundaries had been explicitly determined by the land registration office, so that the STONIC inspectors could readily check their records on the farm.

Whilst a Tunisian peasant might consume most or all of his cereal production (making it very difficult to check his forms of declaration) the large colonial farmer worked in a cash economy, marketing almost all he produced. Large cereal crops could only be marketed through official channels which were controlled by government inspectors. An added incentive to do this was that the colonists could thereby obtain short term loans. On the other hand there is no doubt that the Tunisian small farmer marketed some of his produce through channels known only to the extended family system or through the black market - known to the inspectors as the *marché toléré*.

Thirdly the colonists shared a broadly similar technical standard which responded more quickly to advice given in the agricultural publications and proffered by the advisory service. The problems and successes of cereal cultivation were annually discussed in a lecture given by the director of the *Service Botanique et Agronomique de Tunisie* (SBAT: Now known as INRAT, the *Institut National de Recherche Agronomique de Tunisie*) to the *Société des Agriculteurs*. The continuity of standards, in the post-war period, can be assessed by the stability of the percentage of fallow land in successive years, by the ratio of wheat to secondary cereals and by the national useage of fert-

-ilisers.

The stability, or the reduction of the areas planted with fruit trees, olives and vines in the years as land nationalisation approached (see ch. 7.3 & 7.4) indicates the degree of security with which the colonists faced their future in Tunisia. Reduced long-term investment in fruit and vines was probably reflected in reduced efforts to maintain the long-term fertility of the soil.

Fourthly the colonists came much nearer to obtaining maximum yields within the limitations imposed by the climate and soils than did the Tunisians. Therefore a study of Tunisian, traditional techniques would be irrelevant to the question. Also as the colonists were working near the limit of what the climate permitted the response of yield to good or bad climatic years was more marked. This is true in spite of the fact that Boeuf (1932) used peasant yields for correlation with rainfall because, as he says, the peasants did not conserve water from one year to the next by the use of fallow so that their yields reflected more accurately the rainfall of the agricultural year in question. However this objection to using colonist data may be overcome by taking into consideration the rainfall of the fallow (see ch. 9.1, pp. 285-288) year before the crop.

Lastly the evaluation of the French farms made at the time of the departure of the colonists (1958 to 1964) give details about the area of uncultivable lands, and the area under fruit trees. By combining this information with the data from the STONIC the area of fallow may be calculated. They also give some information concerning the quality of the soil and occasionally comment upon the ability of the farmer and climatic hazards faced in particular years.

From the evaluations and the plans - not all of which exist - made when the colonial farms were grouped into cooperatives in 1967 it is possible to locate exactly the farms within the LMV. To locate the Tunisian farms would be impossible: many of them have never been surveyed or registered.

The Lower Medjerda Valley. The LMV (see Fig. 1, p. 10) has long been one of the major wheat producing regions of Tunisia. With the plains of Béja and Mateur, the Great Plains of the Middle Medjerda Valley, and the Zaghouan/Pont du Fahs region it includes practically all the good wheat land. The LMV is also the site of the largest and most intensively capitalised agricultural development projects in Tunisia under the aegis of the Office de la Mise en Valeur de la Basse Vallée de la Medjerda (OMVVM). Only a small percentage - at the most 10-15% - of the land will be covered by the growing irrigation network leaving the greater part of the LMV under wheat and other dry-farmed cereals.

The study is not only an examination of the association between cereal yields, climate and farming techniques, but a study of the real progress of the OMVVM in improving yields of cereal crops; economically the most important crop in the area. The 'real' progress will be taken as a change in yield not caused by climatic variation. With this in mind it should be noted that the plans up to 1980 show a steady annual increase in yield and make no mention of fluctuations due to climate.

Even on the irrigable land one important crop will be irrigated wheat; the new Mexican wheats which yield best under irrigation. Conclusions drawn from the study of climate and yield should help define the ideal mode of irrigation.

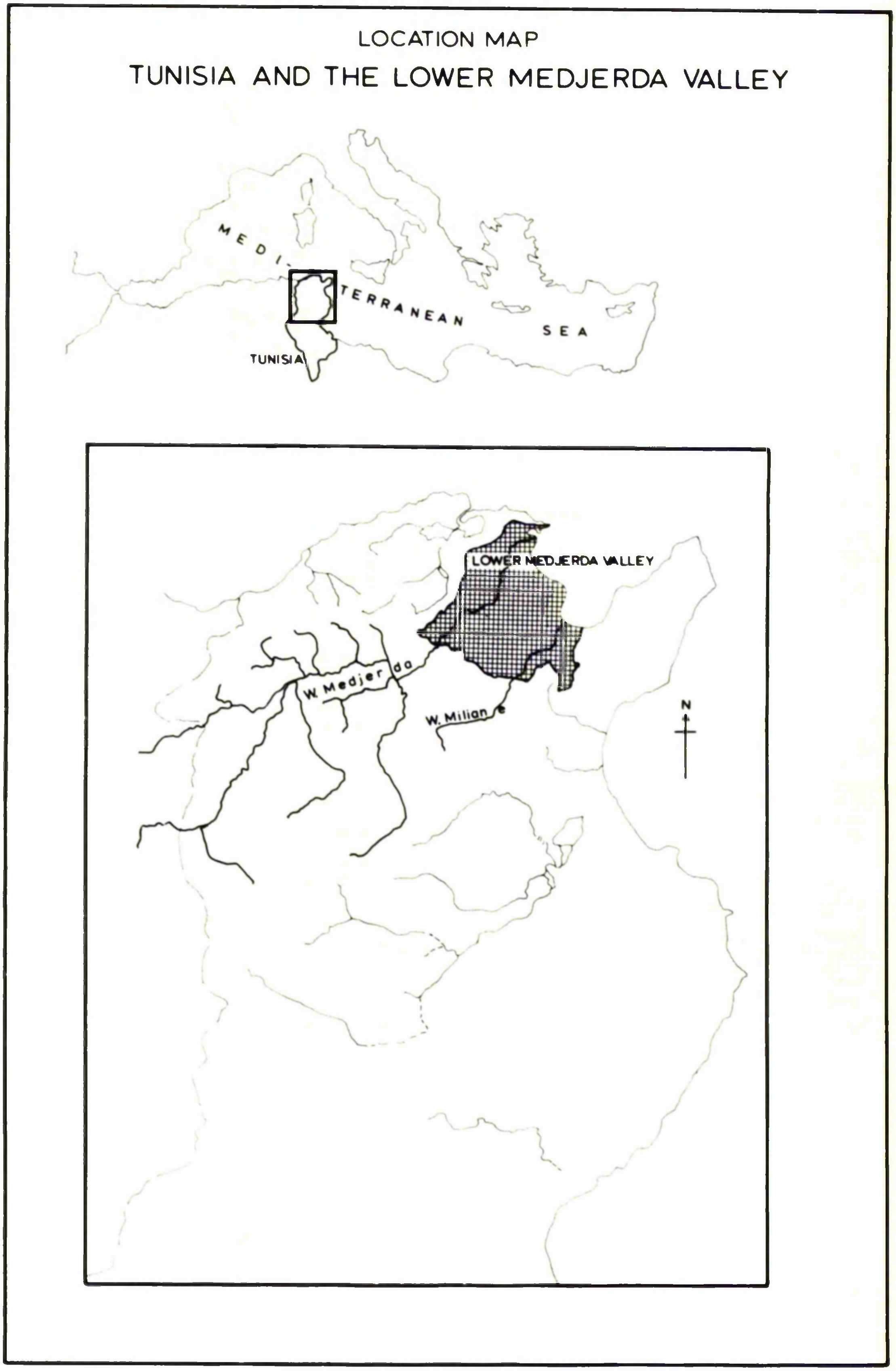
A further and very important reason for doing the study in the LMV is that the LMV has probably the best climatic records of any comparable area in Tunisia. Apart from the fact that the meteorological office at Tunis-Carthage airport, the Bureau de l'Inventaire et de Recherche Hydraulique (BIRH) at Tunis-Manoubia and the main agricultural research station at Ariana with their long and detailed climatic records lie within the LMV, the BIRH, often with the help of colonial farmers maintained a network of rainstations throughout the LMV.

Some twenty rainstations returned almost complete daily records to the BIRH throughout most of the period in question. The weakest part of the record is after 1960/61 when many of the observers, who were French farmers, began leaving the country.

The daily rainfall of fifteen stations (three of which lie beyond the LMV boundary) was on computer cards at the time of data collection, duplicates of which were obtained for the years 1946/47 to 1962/63. For the remaining stations only the monthly totals are known. Some of the rainstations were on the French farms which fall within the scope of this study while others were sited between groups of colonial farms.

The temperature record is much less detailed. A complete record of monthly mean temperatures and temperature extremes for the whole period was taken from the airport, Tunis-Carthage. Less complete records from two inland stations just beyond the LMV southern boundary, at Medjez el Bab and Bir M'Chirga, show that the inland region has a slightly more continental range of temperature.

Fig. 1


LOCATION MAP
TUNISIA AND THE LOWER MEDJERDA VALLEY
MEDI-TERRANEAN SEA
TUNISIA
LOWER MEDJERDA VALLEY
W. Medjerda
W. Milian
N

There was only one complete record of insolation; the monthly mean sunshine hours from Tunis-Manoubia. But as there is far less variation of sunshine hours than of rainfall in different sub-regions of the LMV the record from Tunis-Manoubia will be applicable for the whole of the study area.

The only other climatic data available were isolated indications of humidity and evaporation.

The 126 Farms Selected. The 126 colonial farms are the full complement of the 21 Pre-cooperatives and one State Farm into which they were grouped in 1967; three years after the nationalisation of all colonial land. Where in this thesis the name 'Farm Group' is used it refers to the colonial farms which together were later to form a single Pre-cooperative or State Farm in 1967. Altogether 52 Pre-cooperatives (Fig. 2, p. 12) and 10 State Farms were formed from the land nationalised in the LMV. most of the State Farms are mixed research farms.

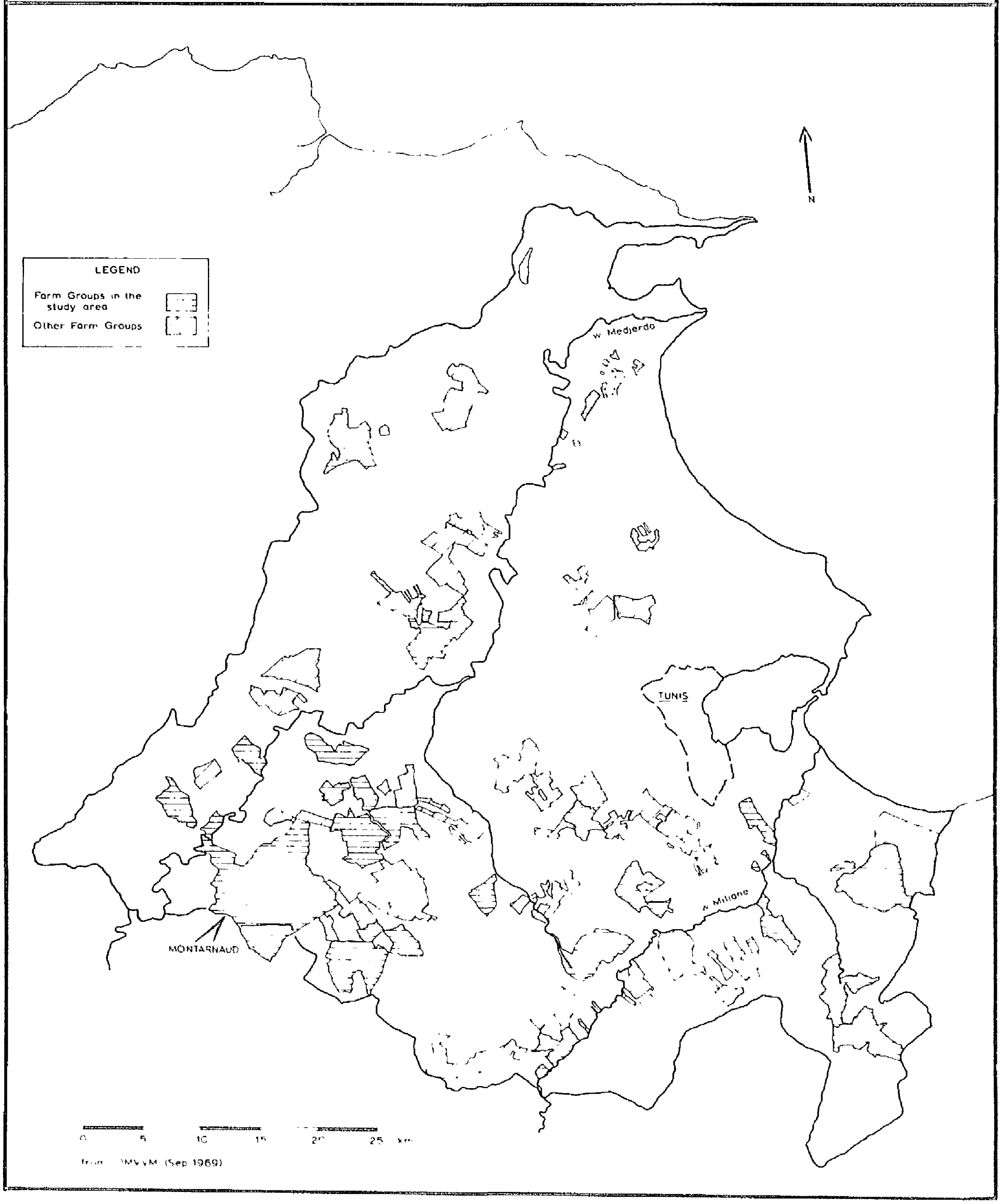
The 22 Farm Groups in the study were not chosen at random but selected because they combined several essential qualities. These were, an even distribution throughout the region, large area under annual crops, and proximity to suitable rain stations. Some of the Pre-cooperatives had to be excluded because they were formed from habou land not leased to the French farmers (e.g. Douimis/Tahouna) or from land only recently purchased by the colonists and not effectively farmed (e.g. Bach Hamba; purchased after drainage of the plain of Mabtouha in 1951).

By taking the full complement of ex-colonial farms in each Pre-cooperative Farm Group it will in the future, be possible, by combining the yields of each farm within the Farm

Fig. 2

PRE CO-OPERATIVES (FARM GROUPS) IN THE LOWER MEDJERDA VALLEY

INCLUDING THE STATE FARM OF MONTARNAUD



Group to make a comparison with the yields since the Pre-cooperatives were formed. As yet only the yields for the years 1967/68 and 1968/69 are available. The reason why only one State Farm is included in the study is that on the other State Farms no comparable data exists for the post-nationalisation period and the experimental/commercial status of these farms would make a true comparison impossible.

1948/49 to 1962/63. The study years 1948/49 to 1962/63, were determined by several factors. Firstly the start in 1948/49. The STONIC was established in 1936/37 so individual farm records only start from this date. But as the records are traced back in time from the 1950's they become increasingly difficult to follow because of change of owner and/or tenant; the records being filed under the name of the farmer. Only three important farms had continuous records and ownership back, respectively, to 1938, 1940, and 1945; the farms of Montarnaud, Planche and Cattan. For some farms the record does not begin until after 1948/49.

According to two observers the post-war resurgence of investment in agriculture was only under way by 1948 (see ch. 7.2) so that the country did not regain its normal equilibrium of cereal production until the year 1948/49, lost because of the war and the coincident years of drought.

The final year of the study, 1962/63, was the last full agricultural year before nationalisation of colonial land in May 1964. In fact some colonists began leaving the country in the late 1950's (see ch. 7.4, p.241) and there was a major exodus after the Bizerte crisis of 1961 so that the record for the years 1961/62 and 1962/63 is less than 50% complete.

During the period 1948/49 to 1962/63 farming practice amongst the colonists remained fairly stable; with some evidence of a decline in standards from the outset of the 1960's. There were no major innovations in techniques, with the possible exception of increased use of nitrogen fertiliser (see ch. 7.4, pp. 238-239), no important new varieties (see ch. 6.2, pp. 148-157), and no war-time crises, factors which had characterised the preceding decades.

The shift in emphasis from Florence wheat to hard wheats in the immediate post-war period had taken effect by the late 1940's. A study of a single 200 ha. farm (Terre, 1958) indicated the turning point to be 1947.

1.3 Review of the Literature. No study of the effect of French and Italian colonists on the evolution of agriculture in Tunisia can begin without paying due tribute to M. Jean Poncet. In three major works, 1961(A), 1961(B) and 1963, and many articles he has charted the course of agriculture throughout the colonial period covering most aspects of the subject - historical, geographical and economic - but paying particular attention to the effect of European farming methods on the soil. Poncet emphasised the dangers of soil erosion and loss of soil fertility when these methods were used for cereal farming, but he pays less attention to understanding the sum of the problems, technical and climatic, which these methods were attempting to overcome. In particular he pays very little attention to the uncertainties of the Tunisian climate, except where mentioning the possibility of droughts or storms seems to strengthen his argument. He went so far as to believe that cereals should be replaced by other crops when in 1961(A) (p.402) he wrote, 'only the appeal of a stable and regular market, a market of fruit and vegetables... would allow the end of these extensive and denuding crops, and the anarchy of farming which demineralised badly protected soils'. Fertiliser and green manure was not the answer, he added; they were only a temporary palliative.

This argument , however, fails to take a number of important factors into consideration. Firstly the climate and the very inadequate resources of irrigation water upon which early vegetables depend; secondly the primary importance of wheat to the Tunisian economy and diet, and thirdly the quality of the land, which is only locally suited to a wider variety of fruit and early vegetables. But water is the key, as will be illustrated below, and without it intensification of agriculture is not possible. The point is illustrated in Plate 21 (p. 190).

The source of most information about research done into improving cereal varieties and methods of cultivation is the SBAT which devoted much attention to wheat farming. The position up to the end of the 1920's is carefully documented by Boeuf (1932) in his monograph on wheat. Subsequent work has been published by a number of researchers at the SBAT. Perhaps the contribution by Yankovitch (1956) added most to an understanding of the effects of wheat cultivation on the mineral balance of the soil. Poletaef (1946 & 1953) reassessed the value of current ploughing methods on soil fertility and yield, and Montlaur (1941) made the first serious attempt at evaluating the relationship between climate and yield. More recently Ferhat (1962) has studied the effect of temperature and various regimes of water on yield. Apart from these individual contributions it is well to mention the journal published by the Agricultural Society, La Tunisie Agricole, which contained many articles about cereal cultivation including the annual addresses given to the society by the Director of the SBAT analysing the most important features of the previous cereal year. In this connection the articles by Valdeyron andby Séguéla contain valuable information.

In Tunisia very little work has been done either to quantify the relationship between climate and yield or even to establish what the salient climatic factors are. In this respect the value of the work by Boeuf (1932), Montlaur (1941), Ferhat (1962), Hyslop and Dahl (1970), and a single farm examination of yields from 1937 to 1956 (Terre, 1958) is assessed at the beginning of chapter ten (ch. 10.1, p. 308 ff.). Similar work abroad, though not of direct value because of differences of climate, soil, varieties and methods of cultivation, is reviewed in the same chapter.

CHAPTER 2

THE ROLE OF WHEAT IN THE DIET AND ECONOMY OF TUNISIA.

2.1 Introduction. Before preceding to an examination of wheat production and productivity it is essential to estimate the importance of wheat to Tunisia. This should throw into relief the value of obtaining a better understanding of the complex factors which affect wheat yield. Chapter 2 will, therefore, study the role played by wheat in the diet and economy of Tunisia; concentrating on changes since the Second World War and future prospects.

2.2 The Area and Production of Wheat. Ascertaining figures for productivity of hard and soft wheat in Tunisia is a difficult task because there is reason to believe that the official statistics underestimate both area and yields. In the discussion which follows it will be assumed for reasons outlined in chapter 1 (p. 5 ff.) that the data obtained from the STONIC for area and production of the European farmers is accurate. The evolution of these since 1911 will be given, followed by an attempt at a more accurate estimation of yields by Tunisian farmers.

European Farms. The area of soft wheat grown by the French increased steadily up to the end of the 1920's as more land was brought under cultivation. The yields during this period fluctuated widely from year to year (Fig.3a, p. 20) but showed no overall change. However at the end of the 1920's, and the early 1930's yields increased sharply due, mainly, to the generalisation of deep ploughing and fallow (see ch. 6.4 & 6.5) and to the introduction of the high yielding variety, Florence x Aurore (F/A) (see ch. 6.2). The high yields encouraged a great expansion of area under soft wheat from 54,000 ha. in 1929 to 138,000 ha. in 1940. Yields fell slightly during this period but were broadly sustained by the good climate, in spite of expansion onto land unsuited to F/A. The rainfall was above, but near, the annual mean (see Figs. 12/14, p. 57-59). The crash came in the 1940's when the combination of the war and a series of extremely dry years cut both the area sown and the yield. The decade 1943 to 1952 saw a recovery of both yield and area though neither reached their pre-war maxima. The reduction in area was because the export market for F/A had gone (see ch. 2.4, p. 31 ff.) and the STONIC price for hard wheat considerably raised. The lower

AREA AND PRODUCTION OF WHEAT BY EUROPEANS IN TUNISIA
1911 - 1962

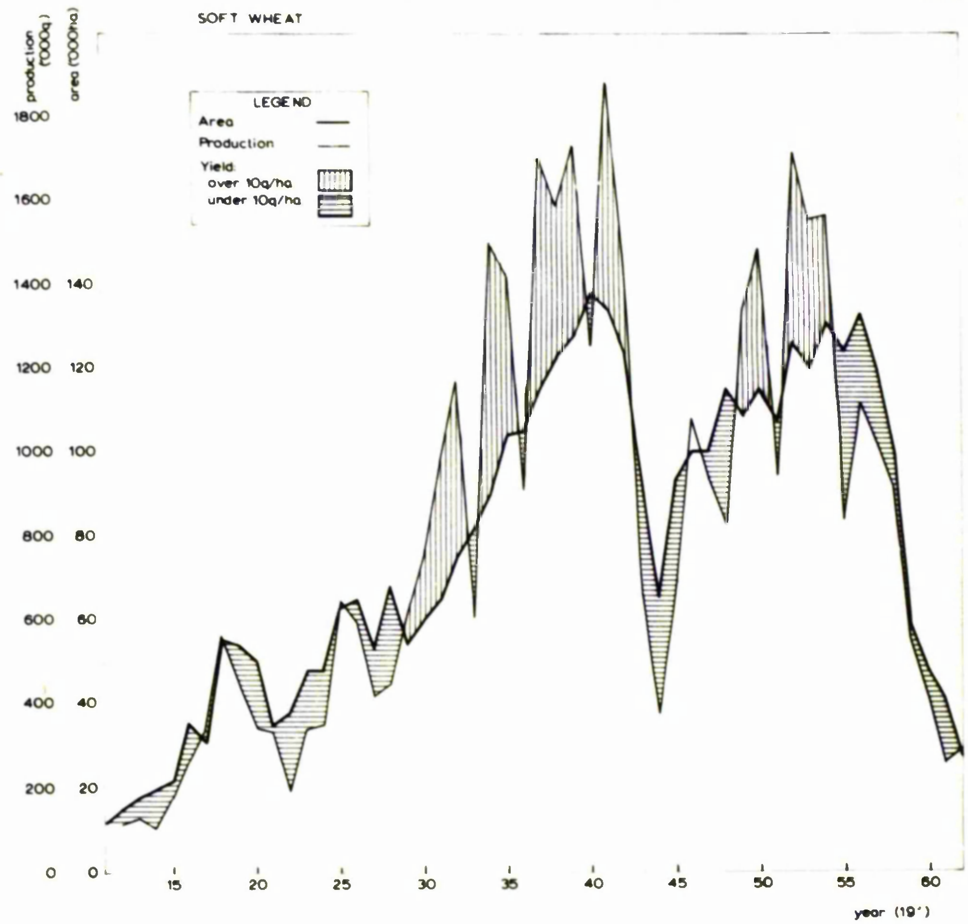


Fig. 3a

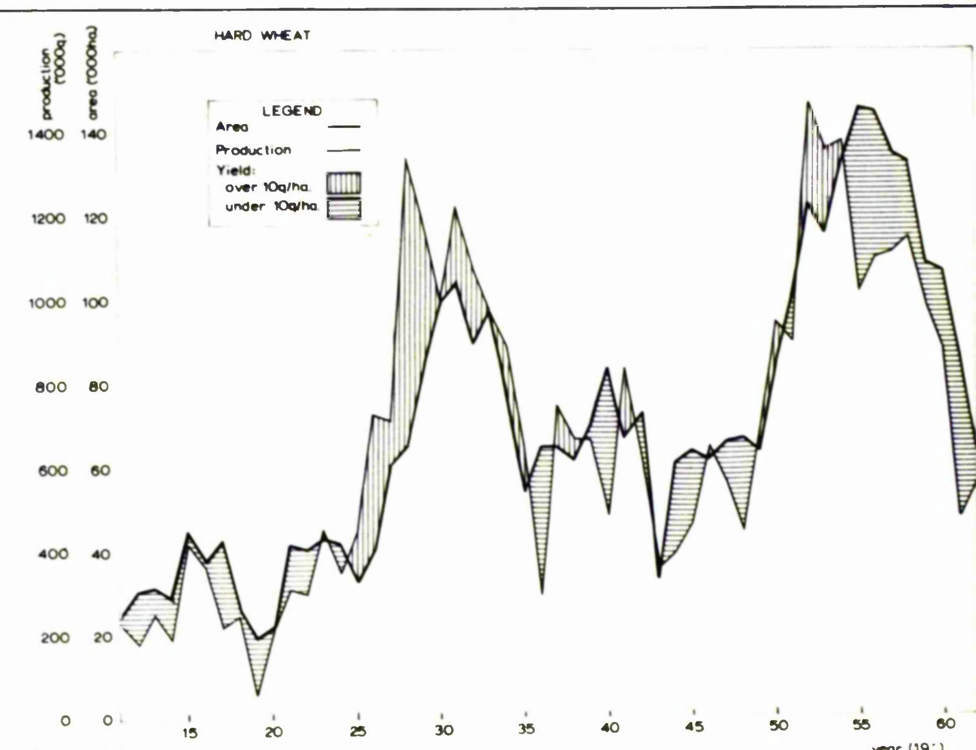


Fig. 3b

yields may be explained, at any rate in part, becaude the climate from being to dry had become to wet.

The area under hard wheat (Fig.3b, p. 20) followed a rather different course. It remained static at about 35,000 ha. from 1911 to 1925. Then in the mid-1920's yields rapidly increased as a result of improved varieties (see ch. 6.2, p.148ff.) and the use of fallow. In consequence the area sown also expanded from 33,000 ha. in 1925 to a maximum of 105,000 ha. in 1931. The area was then sharply cut back, to about 65,000 ha. Farmers prefered the new, higher yielding soft wheat, F/A. This very demanding variety was grown on the best land leaving the worst land to the hard wheat, a factor which must account for its lower productivity in the 1930's. Interestingly enough they sustained this level of productivity better than the soft wheats in the driest years of the 1940's.

Hard wheat did not share in the post-war expansion until 1950. The area then increased rapidly as the price of hard wheat relative to soft wheat rose and the market for F/A closed. Yields also increased but fell from 1955 onwards due, at least in part, as with the soft wheats, to adverse climatic conditions.

Because, during the war, both yield and area sown fell for hard wheats and soft wheats alike total wheat production dropped very sharply from the 1930's to the 1940's.

Tunisian Farms. According to figures published by the STONIC the area of hard wheat sown by the Tunisians remained more or less static from 1911 to 1950, with a slight increase in area in the wetter 1930's and a decrease in the dry 1940's. After 1950 there was a steady increase in area to a maximum of 1,049,000 ha. in 1960 due partly to the departure of the French and to the increased price of hard wheat. The trend after 1960 is, surprisingly, downwards in spite of the complete departure of the French in 1964. This can only be a result of poor collection of statistics when the personnel in the STONIC changed and as the farm community reacted against the policy of complete imposed cooperatives due for completion in 1969.

Ignoring these latter years, and concentrating on the period 1950 to 1962 an attempt will be made to review the published Tunisian wheat yields. These have already been considerably adjusted upwards from the declared figures both by decreasing the declared area and increasing the declared production according to undisclosed criteria. The greatest reduction in area was in 1956, from the declared figure of 1,372,211 ha. to 820,000 ha., and in 1955; 1,264,260 ha. to 690,000 ha. Because of these discrepancies it was decided to estimate production and yield by an alternative method.

This involved, Table 1, a knowledge of the wheat consumed by the population of Tunisia, the net imports or exports, the amount of grain used for seed and the production by the European farmers.

The consumption of hard wheat was assessed (Tunisia, 1968) in 1965-1968 at 89 kg/head out of a total of 147 kg/head of cereals. In 1949/53 an FAO census (Kool, 1963, p.22) estimated 167 kg/head of cereals. By assuming a slightly higher proportion of hard wheat to soft wheat in 1950 (more cous-cous and less bread) and a steady rate of change this gave a hard wheat consumption of 106 kg/head in 1950.

The total production is given by the quantity consumed, the import/export of wheat and pasta (semoule) and the seed

Table 1. Statistics of Tunisian Hard Wheat Production based on Import/Export Data and Internal Consumption.

Year (19')	Population (000')	Consumption: Per Head (ql)	Consumption: Total (000't)	Net Export (000't)	Total Area (000'ha)	Seed (000't)	Total Prod. (000't)	European: Area (000'ha)	European: Prod. (000't)	European: Yield (ql/ha)	Tunisian: Area (000'ha)	Tunisian: Prod. (000't)	Tunisian: Yield (ql/ha)	Published Tunisian Yield
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
			2x3				4+5+7			10/9	6-9	8-10	13/12	
62	4217	94.0	396.4	+31.0	1042	104.2	531.6	63.7	56.1	8.8	978.3	475.5	4.9	
61	4141	95.0	393.4	+0.8	1034	103.4	497.6	87.4	48.5	5.6	946.6	449.1	4.7	2.0
60	4067	96.0	390.4	+141.8	1025	102.5	634.7	107.2	88.3	8.2	917.8	546.4	6.0	2.2
59	3994	97.0	387.4	+69.0	1017	101.7	582.9	108.7	99.3	9.1	908.3	483.6	5.3	3.3
58	3922	98.0	384.4	+130.0	1008	100.8	615.2	133.0	114.6	8.6	875.0	500.6	5.7	3.1
57	3852	99.0	381.4	+97.4	1000	100.0	578.8	135.3	111.5	8.2	864.7	463.3	5.4	2.7
56	3783	100.0	378.3	+4.9	973	97.3	480.5	144.6	115.7	8.0	828.0	364.8	4.4	1.3
55	3724	101.0	376.1	+102.7	945	94.5	573.3	145.8	101.6	7.0	799.2	471.7	5.9	0.9
54	3666	102.0	373.9	+182.4	918	91.8	648.1	132.5	138.3	10.4	785.5	509.8	6.5	2.1
53	3608	103.0	371.6	+190.3	891	89.1	651.0	116.3	136.0	11.7	774.7	515.0	6.7	2.9
52	3552	104.0	369.4	+97.6	864	86.4	553.4	122.5	147.0	12.0	741.5	406.4	5.5	3.8
51	3496	105.0	367.1	+63.8	836	83.6	514.5	100.0	90.0	9.0	736.0	424.5	5.8	1.0
50	3441	106.0	364.8	+149.3	809	80.9	595.0	85.0	94.4	11.1	724.0	500.7	6.9	3.6
							Mean Yields 1950 to 1961:			9.08			5.73	2.34

sources: population - calculated from the censuses of 1946, 1956 and 1966

consumption per head - calculated from the 1949/53 census (Kool, 1963, p. 22) and the 1965/68 census (Statistique, 1968).

net exports - Statistiques du Commerce Extérieur de la Tunisie, and the Annuaire Statistique de la Tunisie.

total area - calculated from 1949/50 and 1961/62 agricultural censuses (Plan, 1962).

European production data - STONIC

Tunisian yield (published) - STONIC

required for the following crop - 1ql/ha. By deducting the wheat grown by the Europeans the production by the Tunisians is established though it must be remembered that these production figures are valid only for the trend and the mean; individual years are not accurate because the total hard wheat production was computed from exports as well as production. Exports, totalled by calendar year, might refer to the harvest of one of two years.

The population has been calculated from the censuses of 1946, 1956 and 1966 assuming, for simplicity, a constant rate of growth between census years.

The calculated mean hard wheat production by the Tunisians, Table 1, for the period 1950-61, is 469.7 thousand metric tons. This is twice the published mean of 238.0 thousand metric tons.

The area of hard wheat grown by the Tunisians has been calculated from the figures given in the agricultural censuses of 1949/50 (Tunisie, 1950) and 1961/62 (Plan, 1962), and the European area deducted from the total. The total area rose from 809,000 ha. to 1,042,000 ha. with a period of more rapid growth in the first years. Using these figures the mean yield, 1950-1961, was 5.7 ql/ha.; more than twice the published mean of 2.3 ql/ha.

According to the 1961/62 census more than than 40% of this area lies in the centre and south of the country - south of the Dorsale - in a much lower rainfall where the yields are much below average and extremely irregular. A conservative estimate of Tunisian hard wheat yields in the north would put them between 6.0 ql/ha. and 7.0 ql/ha. The European yields for the same period were 9.1 ql/ha.; not far in excess of the Tunisian yield.

The doubling of Tunisian yields is supported by other observers. Firstly Pissaloux (1955, p.567) in establishing the Tunisian consumption of calories at 2,420 to 2,580 per person, which closely corresponds with the FAO estimate of 2,480 at the same period, assumed the true mean yield, European and Tunisian, to be 7.0 ql/ha. The calculated combined mean, above, is 6.2 ql/ha. with the trend downwards as the area increased. In the first six years it was 6.7 ql/ha.

Secondly, following Kool (1963, pp.54-55) the cost of growing wheat under the traditional system was, in 1963, 24.5 dinars per hectare. To break even the farmer would have to produce 5.8 ql/ha. But Kool (1963, p.58) like many other commentators accepting the official statistics, wrote: 'The _fellah_ farm, from the economic viewpoint, is thus permanently in deficit which does not prevent the _fellah_ from pursuing their traditional activities'.

Kool's paradox is resolved if the mean yield is doubled because the peasant is then showing a small profit on wheat.

The explanation for the STONIC underestimating production is that, contrary to the law, many of the small farmers did not declare all that they produced thereby leaving themselves free to consume it, or sell it illegally in the local market where they might obtain a higher price and avoid paying taxes.

The extent of this illegal marketing, which the French referred to euphemistically as the _marché toléré_, was impossible to assess or control. It is likely to have grown since independence; certainly in 1970 (Purvis, personal communication) the _marché toléré_ price was six to seven dinars per quintal in the Tunis region, instead of the official price of 4.6 D/ql.

The 1965/68 consumption census sought to measure the amount of auto-consumption, defined as food eaten but not bought, and concluded (Statistique, 1968, p.153) that in Tunisia as a whole 17% of the cereals were never marketed; a figure rising to 22% in the rural areas.

The above discussion is not intended to produce an exact figure for Tunisian yield but to indicate the order of inaccuracy of the published statistics. In conclusion it must be said that any study based upon them is liable to be extremely inaccurate.

Soft wheat, according to the STONIC, was first grown by Tunisian farmers after the First World War. After a slow start the area under soft wheat rapidly expanded from the late 1920's to reach a peak in 1940; a growth from 5,000 ha. to 50,000 ha. This expansion occurred at the same time as the increase in area on the European farms and was, no doubt, due to the same causes. It is likely that the modern Tunisian farmers showed more interest in soft wheat than the peasants, with a view to benefiting from the export market along with the colonists. Certainly the published Tunisian soft wheat yields were higher than those of the hard wheat; fluctuating between 6 ql/ha. and 9 ql/ha. from 1925 to 1935.

Both area and yield declined in the 1940's. During the 1950's the area increased rapidly, exceeding 100,000 ha. in some years. In the early 1950's yields rose to their pre-war level but dropped, like all other yields, from 1955 onwards.

It is likely that the published soft wheat yields were more accurate than the hard wheat yields because they were produced by the modern Tunisian farmers. But considerable underestimation is likely, particularly after independence and in the 1960's.

2.3 Wheat Area and Total Agricultural Land; Now and Future Plans.

The two nationwide agricultural censuses of 1949/50 and 1961/62 give the most accurate picture available of the area of wheat within the context of the total agricultural area of Tunisia. The total area of agricultural land, excluding non-productive land, dropped slightly from 1949/50 to 1961/62, Table 2, and the

Table 2. Evolution of Crop Areas in Tunisia 1949/50 to 1961/62: ('000 ha.). source: Pissaloux, 1955, p. 550 and Plan, 1962, p.89.

Crop		1949/50		1961/62
*Arable Land		3,422.6		3,518.0
Permanent Natural Grassland		102.3		3,250.0
Pasture		3,558.9		
Vines and Fruit Trees		929.6		992.0
Total Agricultural Land		8,013.4		7,760.0
Forest and Woodland		680.1		1,240.0
Total Productive Land		8,693.5		9,000.0
*Arable Land				
Cereals (winter)		2,042.0		1,810.0
Hard Wheat	809.0		1,042.0	
Soft Wheat	335.0		148.0	
Barley	907.0		585.0	
Oats and others	51.0		35.0	
Vegetables (dry)		94.0		80.0
Market Garden		20.4		31.0
Forrage Crops		37.0		35.0
Oil Producing & Industrial Crops		15.6		8.0
Arable Land in Production		2,248.4		1,963.0
Fallow		1,194.2		1,555.0
Total Arable Land		3,442.6		3,518.0

percentage of this land under arable rose slightly from 43% to 45%.

The total area of wheat remained static but the area under hard wheat grew at the expense of the soft wheats. The total cereal area declined and the area under fallow increased. But the change in ratio of cereals to fallow may be deceptive because south of the Dorsale, where, in 1961/62, 60% of the hard wheat, half of the soft wheat and most of the barley was grown (Plan, 1962, p. 36) the area sown and the fallow area fluctuate very widely. In a poorish climatic year, such as 1961/62, the fallow area is above average. However, in round figures, one can say that cereals occupy 25% of all agricultural land in Tunisia and the greater part of this area is accounted for by hard and soft wheat. By area hard wheat is the single most important crop in Tunisia.

According to current planning policy in Tunisia the area under cereals is to be reduced overall although the area under soft wheat is to be considerably increased; Table 3.

Table 3. Planned Evolution of Cereal Area in North Tunisia: 1961/62 to 1971/72. ('000 ha.)

source: Plan, 1962, p. 36 & Wheat, 1970, p. 2

Cereal Crop	1961/62	1971/72
Hard Wheat	620.5	178.0
Soft Wheat	79.7	425.0
Secondary Cereals	218.8	147.0
Total	919.0	750.0

In the LMV the only recent census of the cereal area, in 1968/69, estimated that of the 252,500 ha. of cultivated land 85,000 ha. (OMVVM, 1970, p. 3 & p. 9) were occupied by cereals; with 52,000 ha. under hard wheat and 9,000 ha. under soft wheat. This area, based on crop suitability maps as well as a partial census, may be very misleading. So too may be the figures in the four year plan prepared for the OMVVM development of the non-irrigable area, 1969-1972. According to this the current area of wheat, 48,000 ha. is to be reduced by 1979/1980 to

27,000 ha. (OMVVM, 1969, p. 53) while at the same time increasing total production by nearly 50%. The table of estimated production year by year shows an even and steady increase in yield from 8 ql/ha. to 15 ql/ha. for hard wheat and 10ql/ha. to 25 ql/ha. for soft wheat. This is dangerously optimistic, particularly for the hard wheats, making no allowance for the effects of climate on yield and aiming for a mean considerably above what the better French farmers even achieved. It is probable that if the planned reduction in the area of hard wheat is achieved, itself not likely in the near future, production will drop accordingly.

The situation with regard to soft wheat is rather more hopeful because of the recent successful introduction of high yielding varieties of Mexican soft wheats.

The Mexican Wheat Programme began in 1967/68 when yields from 32 experimental farms in northern Tunisia (Wheat, 1969B, p. 5) averaged 26.4 ql/ha.; 5 ql/ha. above the control Tunisian wheat. The areas sown in the following two years were:

1968/69	12,000 ha.
1969/70	54,000 ha.

The planned area of 141,000 ha. for 1969/70 was not achieved because of the confusion and uncertainty caused by the reversal of the cooperative policy in September 1969.

According to the Plan the area under Mexican wheat will have extended to 425,000 ha. by 1971/72 (Wheat, 1970, p. 2) and production will be sufficient to cover the country's wheat requirements. Meanwhile new Mexican varieties of hard wheat are to be introduced.

In 1969/70, the first year of full scale Mexican wheat cultivation, yields were very good (average about 20 ql/ha.) in spite of mediocre climatic conditions and a very poor standard of cultivation practice resulting from the excessive rains of October and December 1969 and the confusion when the cooperative policy was reversed.

If as the area under Mexican wheat expands the yields are maintained at about 20 ql/ha. the deficit of soft wheat should indeed be made good. However it must be remembered that the Mexican wheats, even more than F/A, are extremely demanding; they yield well only if the cultivation practice is of a high standard. In 1969/70 some farms returned yields of well under 10 ql/ha.

There is also the danger, as with F/A, of these wheats exhausting soils of medium quality; soils which will have to be used if the planned area of 425,000 ha. is achieved.

One advantage of the Mexican wheats is that they were developed, initially, to be grown under irrigation. Room is being found for them within the irrigation perimeters in Tunisia where they are yielding, at their best, up to 40-50 ql/ha.

2.4 Foreign Trade and the Internal Market.

Foreign Trade. Until 1915 Tunisia was a net importer of wheat. Then for each successive five year period, 1916/20 to 1936/40, Table 4, she was a net exporter; most of the wheat going to France. The export potential was greatly increased by the variety F/A, which, though bred in France, was improved and developed in Tunisia. In France it did not yield well but in Tunisia it yields and industrial qualities were excellent. This made it highly prized by French millers which ensured a good and stable export market to France.

F/A did not create the export market - Tunisia had been a net exporter of bread wheat for some 15 years before it was grown as a cash crop - but captured and secured it from the older varieties and from foriegn competition. Up to the Second World War (Bigourdan, 1947, p. 8) 60% of all wheat exports were F/A. The increase in exports, 1926/30 onwards, Table 4, was due

Table 4. Export of Wheat from Tunisia: 1916/20 - 1940/45. ('000 metric tons).

source: Séguéla and Jacquard, 1953

Period	Wheat Exports
1916/20	29.4
1921/25	53.7
1926/30	105.0
1931/35	159.1
1936/40	102.0
1941/45	-40.9*

*Soft Wheat only

to F/A.

But the war-time conditions and the poor climate saw a sudden reversal of the trend; a net import of 40,900 metric tons of soft wheat from 1941/45.

Even if Tunisia had maintained her pre-war level of production the export market was closing. France was growing (Valdeyron, 1953, p. 131) more and better quality bread wheats. At the outbreak of war France's production of soft wheat roughly equalled its needs. This fact was stressed by the SBAT at the end of the war: 'It therefore seems prudent to foresee the possibility of replacing the export of Force Wheats by that of Hard Wheats' (Boeuf, 1946, p. 108). France could not grow hard wheats because of its climate, so for export purposes the colonists should concentrate on growing hard wheats.

Moreover as the home market had remained firmly based on hard wheat and was likely to rise with the population Boeuf (1946), and other agronomists, emphasised the need to make hard wheat the major cereal crop of the modern agricultural sector. This prompted the SBAT to begin extensive trials of the hard wheat varieties already known in Tunisia to test their strengths and weaknesses. This work was reflected in the gradual increase in area under hard wheat - which passed 50% of the total wheat area on European farms for the first time in 1951 - in the size of the hard wheat harvests and, finally, in the export market. By 1950 Tunisia had become an exporter of wheat once more (Fig. 4, p. 33) but this time hard wheat predominated. In fact the very small export of soft wheat was soon turned to a

Table 5. Export of Wheat from Tunisia: 1950/55 - 1966/70 ('000 metric tons).

source: Stat. du Comm. Ext. de la Tunisie.

Period	Hard Wheat	Soft Wheat	Total
1951/55	537.4	24.4	561.8
1956/60	562.6	-454.5	-91.9
1961/65	227.6	-975.3	-747.7
1966/70	-234.6	-1253.3	-1487.9

Fig. 4

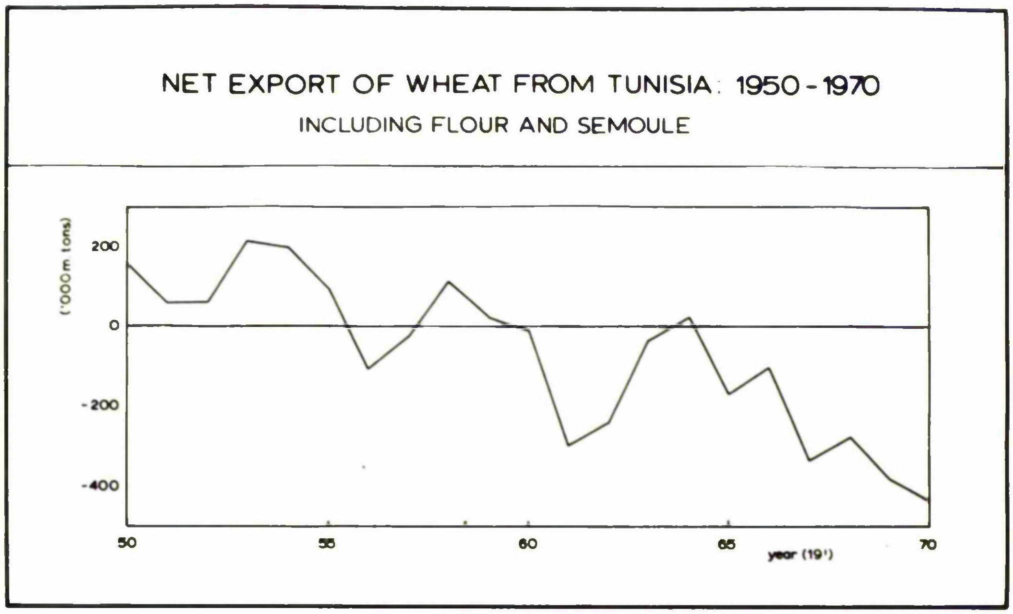
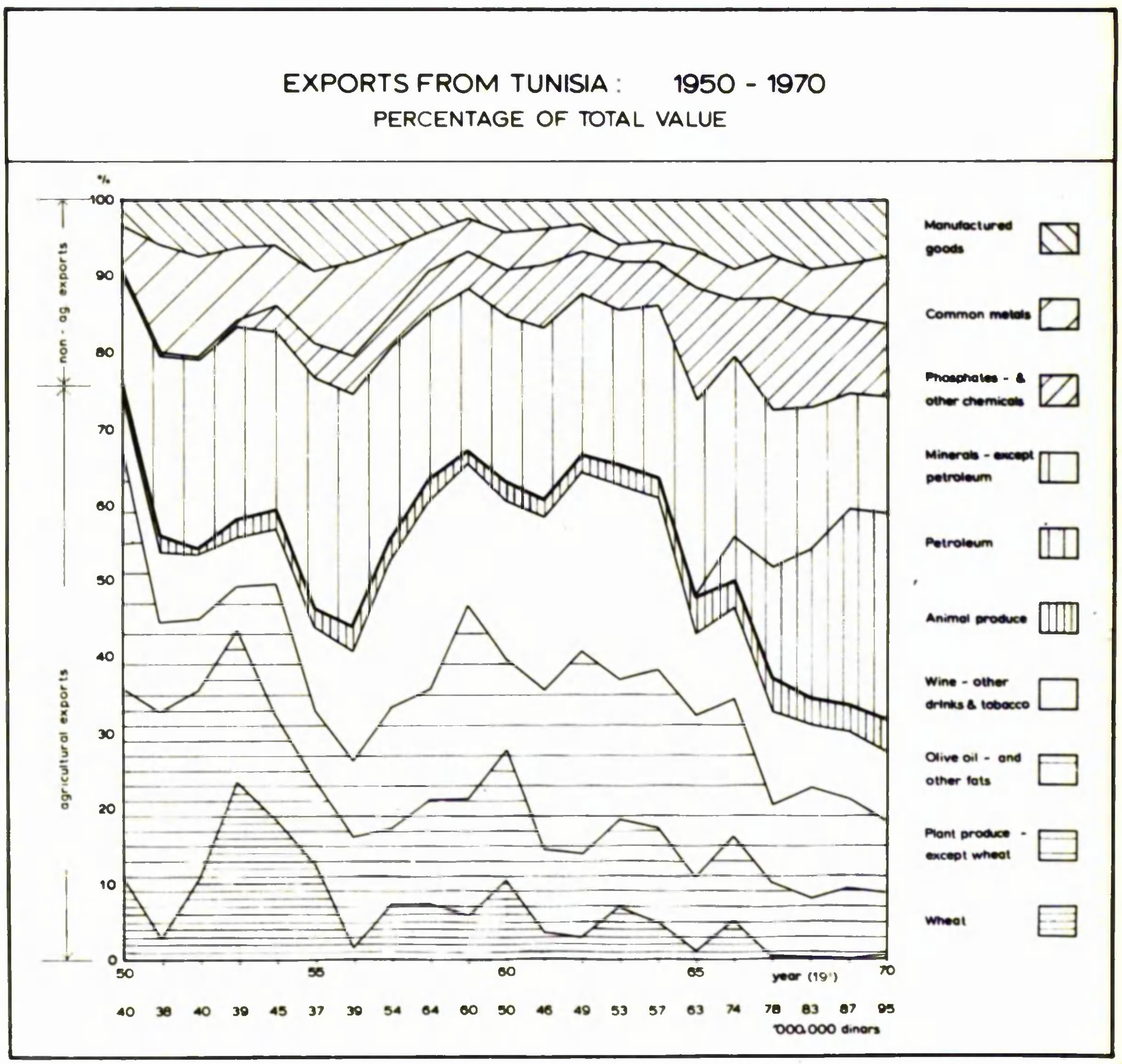

NET EXPORT OF WHEAT FROM TUNISIA: 1950-1970
INCLUDING FLOUR AND SEMOULE
('000m. tons)
200
0
-200
-400
50
55
60
65
70
year (19')

Fig. 5


EXPORTS FROM TUNISIA : 1950 - 1970
PERCENTAGE OF TOTAL VALUE
%
100
90
80
70
60
50
40
30
20
10
0
non - ag exports
agricultural exports
50
55
60
65
70
year (19')
40 38 40 39 45 37 39 54 64 60 50 46 49 53 57 63 74 78 83 87 95
'000.000 dinars
Manufactured goods
Common metals
Phosphates - & other chemicals
Minerals - except petroleum
Petroleum
Animal produce
Wine - other drinks & tobacco
Olive oil - and other fats
Plant produce - except wheat
Wheat

to a permanent and growing deficit; Table 5.

In 1954 a Franco-Tunisian agreement (Bulletin, 1959, p. 3) fixed the price of wheat, theoretically, at the same level in the two countries for four years. This allowed a reasonable return for the farmer in Tunisia and a continued export market to France. France, now with a growing North African labour force, required an increasing volume of hard wheat imports. But the devaluation of the franc in December 1958 - not followed by Tunisia - made Tunisian wheat 17% more expensive in France. This problem was overcome by a subsidy to the exporters. But the main constraints on exports were the increasing local consumption of wheat in Tunisia and declining productivity; Tunisia became a net importer of wheat, Table 5, from 1956/60 onwards.

However in the future even if the production of hard wheat rises above home demand Tunisia will find exporting more difficult. To begin with France, which in 1950 was considered incapable of growing hard wheat because of the incidence of <u>mitadinage</u> due to the wetter climate, produced in 1958 some 4,000 metric tons (Chamary, 1969, p. 95) of more resistant varieties. By 1968 the output had accelerated to 300,000 metric tons; 3-4% of the total French wheat harvest. This is used to make pasta products and the cous-cous for the migrant North African workers. Total requirements are about 600,000 metric tons; a figure which should soon be attained making further import of hard wheat from North Africa unnecessary.

Before the Second World War a decline in wheat exports significantly affected the balance of trade because in a market dominated by agricultural exports wheat had a prominant role. Immediately post-war the situation was similar but the structure of Tunisian exports has radically altered (Fig. 5 , p. 33) in the past 20 years; particularly since the mid-1960's.

In 1950 agriculture still retained its pre-war dominance over other exports. Olive oil was the most important single export commodity in the agricultural sector and remains so today. The production and export of wine did not regain its pre-war importance, because of replanting after the vineyards had been devastated by phylloxera, until the late 1950's. It then formed, Table 6, 15-20% of total exports until the departure of both French farmers and vintners in 1964, and new French restrictions on importing wine.

The part played by plant products in total exports has steadily decreased, both absolutely and relatively, since 1950 (with one important reverse in the trend in the late-1950's) in spite of diversifying crops. While, for example, the total value of plant exports has fallen, the value of exported vegetables, citrus fruit, almonds and dates has risen. On the other hand the role of wheat as an export crop has declined from a mean of 12% of total value, 1950 to 1955, virtually to nothing. Indeed as has been shown above, Table 5, the position has been reversed; Tunisia has become a net wheat importer of considerable magnitude.

Today mineral products earn for Tunisia more than 40% of her export earnings; crude oil alone accounted for 25% in 1970. The role of chemical and other manufactured products is gradually increasing.

This analysis shows that today Tunisia is in no way dependent upon wheat to earn foreign currency; indeed production must be greatly increased to cover the demands of the home

Table 6. Tunisian Exports by Class and Percentage of Total Value: 1950 to 1970.

source: Statistique du Commerce Extérieur de la Tunisie.

Class	'50	'51	'52	'53	'54	'55	'56	'57	'58	'59	'60	'61	'62	'63	'64	'65	'66	'67	'68	'69	'70
Live Animals and Animal Products	1.3	2.1	2.8	2.3	2.5	2.8	3.3	2.9	2.8	1.7	2.6	2.3	2.5	2.6	2.6	4.5	3.5	4.4	3.3	3.4	4.1
Plants and Plant Products	36.0	32.8	35.6	43.5	32.2	23.8	16.2	17.3	21.1	21.3	27.7	14.5	14.0	18.5	17.3	10.6	16.0	10.0	7.9	9.1	8.9
Hard Wheat	10.8	3.7	10.0	19.4	16.6	11.4	1.2	7.0	7.1	5.7	10.3	3.4	2.9	6.8	4.7	0.5	4.9	0.1	0.0	0.0	0.1
Soft Wheat	0.0	0.0	0.5	4.1	1.7	1.1	0.3	0.2	0.1	0.1	0.1	0.1	0.0	0.0	0.1	0.5	0.1	0.0	0.0	0.1	0.5
Oils and Fats	31.0	11.8	9.4	5.7	17.5	9.2	10.2	16.5	14.7	25.6	12.0	21.0	26.5	18.5	20.9	21.6	18.3	10.3	14.6	12.1	9.1
Olive oil (crude)	29.0	10.1	8.3	5.2	15.3	7.9	8.2	14.6	14.2	24.2	11.4	20.7	24.4	16.9	19.2	18.6	16.0	7.2	11.3	9.6	7.8
Processed Food; Drink and Tobacco	7.3	9.4	8.5	6.7	7.2	10.9	14.3	19.1	24.9	17.5	21.0	23.1	23.8	25.8	23.0	10.7	12.1	12.4	8.6	9.0	9.5
Wine	3.8	4.6	3.4		3.5	6.7	6.8	13.9	20.0	12.4	14.4	17.0	14.9	18.3	14.8	4.2	5.3	6.2	3.8	3.4	4.5
TOTAL AGRICULTURAL	75.6	56.1	56.3	58.2	59.4	46.7	44.0	55.8	63.5	66.1	63.3	60.9	66.8	65.4	63.8	47.4	49.9	37.1	34.4	33.6	31.6
Mineral Products	14.5	23.2	24.7	25.0	23.1	29.9	30.6	24.7	21.7	21.0	21.6	22.2	20.9	20.1	22.3	26.4	29.4	35.2	38.4	40.9	42.5
Chemical Products	0.3	0.5	0.3	0.9	3.6	4.8	4.8	4.4	5.4	5.0	5.9	8.3	5.5	6.3	5.5	14.6	7.6	14.8	12.3	10.1	9.6
Common metals and Metal Products	6.3	14.3	13.3	9.6	8.0	9.2	12.5	8.8	5.1	4.3	4.9	4.7	3.4	2.4	2.9	4.9	4.0	5.5	5.8	7.0	8.7
Other Manufactured	3.3	5.9	5.4	6.3	5.9	9.4	8.1	6.3	4.3	3.6	4.3	3.9	3.4	5.8	5.5	6.7	9.1	7.4	9.1	8.4	7.6
GRAND TOTAL (%)	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
TOTAL(000,000 D)	39.8	37.5	40.1	39.1	44.5	37.4	39.3	54.2	64.4	59.6	50.3	46.3	48.7	52.9	57.3	62.9	73.7	78.4	82.8	87.0	95.3

market and reduce imports. While wheat exports have declined to nothing since 1950 total exports have risen from 40 to 95 million dinars.

The wheat breeder is therefore freed from the need to consider export requirements when breeding new varieties. F/A although an excellent export wheat, was never as popular in Tunisia as in France. The price paid for popularity in France was a tendency to exhaust the Tunisian soils.

Internal Market. At the beginning of the century the wheat market in Tunisia was almost entirely for hard wheat for making cous-cous and pasta products; consumption of bread was very limited. As the European population grew so did the demand for soft (bread) wheats. The educated Tunisian town dweller also increased his preference for bread. To begin with it was the European farmers alone who catered for this need but by the end of the 1920's many Tunisian farmers were growing soft wheat as well.

The responsibility for marketing the wheat, particularly the hard wheats, was in the hands of middle men who often doubled as money lenders thereby keeping an economic control over the livelihood of many of the poorer Tunisian farmers who were permanently indebted to them.

From the late 1930's the government in Tunisia became directly involved in the marketing of cereals. A Cereals Office (the STONIC) was set up to which all farmers, Tunisian and European, had to send declarations of area sown and the harvest of all the annual crops, particularly the wheats, barley and oats. The whole harvest of hard wheat, soft wheat, and barley had to be marketed through one of the recognised agencies (except for the needs of home consumption, livestock and seed) for which the farmer received a fixed guaranteed price. The price was adjusted from year to year allowing price differential to encourage one crop and discourage another. From 1944 to 1951, Table 7, this moved rapidly to the advantage of hard wheat against soft wheat and to the disadvantage of barley.

Into the post-war period the home demand had remained firmly based on hard wheat and as was forecast by Boeuf (1946, p. 108) would rise with the increase in population. But a change had occurred in the market for bread wheat. The millers no longer wanted wheat with a 'W' higher than 150 but were looking for wheats like Baroota whose milling and bread making qualities were highly regarded.

In 1950 the export market for hard wheat, (see ch. 2.4, p. 32) was expanding while that for soft wheat was closing. The home demand for hard wheat was stable and, it was forecast, was likely to rise. At the same time the home demand for bread wheat, though stable was moving away from soft, force wheats. In consequence the area sown with F/A was passed by the hard wheats in 1950 and by the other soft wheats in 1955. In 1954, encouraged by the trend in the STONIC prices, hard wheat occupied more than 50% of the total wheat area for the first time.

Running parallel with the official internal market was an unofficial, illegal, market whose extent was difficult to calculate. On the declaration of harvest each farmer had (and has) to give his total production and the amount he wished to sell. The difference represented the cereal needs for his family, his livestock and for sowing. However it was very difficult to

Table 7. Guaranteed Price for Main Cereal Crops in Tunisia: 1936-1968 (millimes-francs/quintal).

source: STONIC

Year	Hard Wheat	Soft Wheat	Barley	Differential Hard Wheat : Soft Wheat	Differential Hard Wheat : Barley
1936	145	140		5	
1937	170	178		-8	
1938	201	200		1	
1939	207.5	197.5		10	
1940	230	215	160	15	70
1941	305	290	180	15	125
1942	390	375	245	15	145
1943	435	420	315	15	120
1944	500	420	425.5	80	74.5
1945	700	600	525	100	175
1946	1165	1013	764	152	401
1947	1495	1300	1000	195	495
1948	2645	2300	1840	805	345
1949	2875	2500	1522.5	375	1352.5
1950	2990	2600	1570	390	1420
1951	3960	3445	2134	515	1826
1952	3960	3445	2172	515	1788
1953	3960	3445	2172	515	1788
1954	3910	3400	2040	510	1870
1955	3910	3400	2040	510	1870
1956	3967	3449	2187	518	1780
1957	3967	3450	2408	517	1559
1958	4468	3596	2158	872	2310
1959	4200	3450	2000	750	2200
1960	4200	3450	2000	750	2200
1961	4200	3450	2000	750	2200
1962	4200	3450	2000	750	2200
1963	4200	3450	2000	750	2200
1964	4200	3450	2000	750	2200
1965	4200	3450	2500	750	1700
1966	4200	3450	2500	750	1700
1967	4800	4300	2800	500	2000
1968	4800	4300	2800	500	2000

check whether there was an additional quantity of wheat sold privately or given in exchange to members of the family now emigrated to the towns; a practice common in an extended family society. Private sales avoided the complexities of the market procedure, evaded tax and, in poor years at least, realised a price above the government price. On the other hand smaller farmers without family capital or access to official sources of loans, frequently had to morgage their harvest to middle men to obtain short term working loans at very high interest rates.

The STONIC knew that such markets existed but, knowing that it would be uneconomic to stop them, sought only to limit their field of action.

It has been suggested that auto-consumption accounted for 17% of cereals consumed in Tunisia (Statistique, 1968). It is likely that auto-consumption and the unofficial markets accounted for something in the order of 50% of Tunisian production if the reassessment of Tunisian yields in chapter 2.2 is accurate.

2.5 Wheat in Personal Expenditure and Diet. Between 1965 and 1968 a detailed study of 7,147 family units (ménages) was undertaken in Tunisia (Statistique, 1968) with the double objective of studying both family and personal expenditure and food consumption. The population was considered by region - north-east, north-west, centre, south - and by degree of urbanisation - large towns, communes, rural - in an attempt to locate precisely inadequacies of diet.

It was found that the mean annual budget per person was

Table 8. Structure of Total Annual Expenditure per Person in Tunisia. 1965/68.

source: Statistique, 1968, p. 291

	Millimes	% Expenditure
Food	35,956	50.3
Clothing	9,403	13.2
Home	13,770	19.3
Health	3,098	4.3
Transport	2,017	2.8
Pastimes etc.	7,236	10.1
	71,480	100.0

71D 500 of which half, Table 8, was spent on food. Of this proportion of total expenditure 32.8%, Table 9, was spent on cereals alone. The expenditure on cereals consumed, Table 10, is least in the towns and greatest in the rural areas. The inhabitants of the large towns consume three times as much soft wheat as hard wheat, reflecting the shift from cous-cous to bread as the staple wheat product for the urban populace, while the rural population still relies heavily on cous-cous and other hard wheat products.

People in rural areas consume more wheat than in the towns although total expenditure on food in the large towns (52D 295) and the communes (33D 568) is greater than in the rural areas (30D 413). This suggests, as will be shown below, a greater

Table 9. Structure of Personal Annual Expenditure on Food in Tunisia, 1965/68.
source: Statistique, 1968, p. 199

Commodity	Millimes	% Food
Cereals	11,805	32.8
Vegetables, Potatoes	4,891	13.6
Fruit	1,536	4.3
Oils, Fats	3,781	10.5
Meat, Poultry	5,248	14.6
Eggs	382	1.1
Fish	776	2.1
Milk, Milk Products	1,249	3.5
Sugar, Sugar Prods.	1,775	4.9
Tea, Coffee, Drinks	2,337	6.5
Condiments	1,038	2.9
Divers	1,138	3.2
	35,956	100.0

inbalance of diet in the rural areas, but part of the explanation of lower rural expenditure on food is that the country people do not buy all that they eat; they can either grow it or receive it as a gift or as payment for work done. In rural Tunisia the

Table 10. Structure of Cereal Consumption in Tunisia: 1965/68 (kg/person/year).
source: Statistique, 1968, p. 154

Type of Cereal	Large Town	Commune	Rural	Total
Hard Wheat	30	80	114	89
Soft Wheat	98	40	30	44
Barley		9	22	14
Other	1	1	1	1
	129	130	167	147

cereals consumed but not bought (auté-consommé) is 22% of the total amount eaten.

The diet of the average Tunisian is, thus, rich in cereals with all the inherent advantages and disadvantages with which this is normally associated. The presence of cereals in relatively high quantities ensures that a certain number of essential dietetic requirements are catered for - perticularly calories, proteins, vitamin B1 and iron - but leaves the diet short of calcium and vitamin B2. Table 11, shows the relationship between dietetic requirements and the degree to which they are covered in the urban and rural areas of Tunisia. They are discussed, by foodstuff, below, to emphasise the strengths and weaknesses of the Tunisian wheat-based diet.

Calories. The calory coverage is good in each section of the community but it is unevenly distributed according to income. The poorer families, rural and urban, suffer, in general, a calory deficit. Even in rural Tunisia, where the consumption of wheat is highest, 18% of the population suffer a 20% calory deficit, and 4% a 50% calory deficit. From region to region there is surprisingly little variation in the rural calory deficit. The south, however, does have the largest share with the north-east, including the LMV, in second place.

The calory shortage is very important; not to be overlooked when planning for future development of agriculture. According to Triemolière (quoted in Statistique, 1968, p. 408) a calory deficit of 20% can cause emaciation, reduce a person's endurance and his ability to work. A deficit of 50% is extremely grave, especially for children; leading to deformity and stunted growth.

The excessive proportion of calories originating from cereals is partially corrected in the family units where individual

Table 11. Dietetic Requirements and Their Coverage by Locality, in Tunisia. 1965/68.

source: Statistique, 1968

Locality		Calories	Protein (gm)	Calcium(mg) NCR	Calcium(mg) BN	Iron (mg)	Vitamins A(I.U)	Vitamins B1(mg)	Vitamins B2(mg)	Vitamins PP(mg)	Vitamins C(mg)
Large Towns	Needs	2250	62.1	1000	500	11.0	4225	1.14	1.50	11.0	60
	Ration	2550	67.7	408	408	15.1	5490	1.68	0.86	11.6	65
	Surplus%	+13.3	+9	-59	-18	+37	+30	+48	-44	+5.5	+8
Comm-unes	Needs	2250	62.1	1000	520	11.0	4225	1.14	1.50	11.0	60
	Ration	2230	59.8	297	297	13.7	3930	1.64	0.64	9.8	47
	Surplus%	-	-4	-70	-42	+24.5	-7	+44	-57	-11	-22
Village	Needs	2250	62.1	1000	520	11.0	4225	1.14	1.50	11.0	60
	Ration	2315	63.7	308	308	14.3	3270	1.78	0.65	10.3	39
	Surplus%	+3	+2.6	-69	-41	+30	-23	+56	-57	-6	-35
Dispersed	Needs	2250	62.1	1000	580	11.0	4225	1.14	1.50	11.0	60
	Ration	2413	67.3	315	315	14.7	3040	1.96	0.67	11.7	36
	Surplus%	+7.2	+8.4	-68	-39	+23.5	-28	+72	-55	-3	-40
Total	Needs	2250	62.1	1000	520	11.0	4225	1.14	1.50	11.0	60
	Ration	2365	64.8	336	336	15.0	4050	1.76	0.72	10.5	44
	Surplus%	+5.1	+4.3	-68	-35	+38	-4	+54	-52	-4.5	-29

expenditure rises above 125D/year; about 14% of all family units. As expenditure rises above this point the consumption of cereals decreases from a maximum of 170 kg/year to about 150 kg/year. The calory intake curve is of similar shape with a peak of 3,330 calories at an expenditure rate of 150D/year.

Proteins. There is a slight overall excess of protein in the diet (+4.3%) although there is a slight deficit in the communes. Again the majority of the protein originates from cereal (72.7%) and all except 14.4% from plants. The dependence upon plant protein falls steadily as total expenditure rises. Poor families suffer because animal protein is much more expensive than plant protein.

Calcium. Calcium is of fundamental importance in the diet; it is the essential element for maintaining the growth and condition of bones and teeth. Unfortunately in Tunisia more than 50% of family units have a 50% calcium deficit. This fault is directly attributable to the cereal based diet because cereals are poor in calcium. Commodities rich in calcium include milk, milk products and, to a lesser extent, fresh vegetables and fruit yet in Tunisia only 24.1% of the calcium in the diet originates in milk products, because milk, butter and cheese are very scarce. About 36% comes from cereals.

Iron. Once again, because the diet is based on cereals which are rich in iron, iron is in excess in the Tunisian diet; 65% of it being provided by cereals.

Vitamins. The one vitamin whose requirements are amply covered is B1 (a vitamin concentrated in cereal grains) which explains, considering the extra quantity of wheat consumed in rural areas, the 72% excess in the rural diet and the smaller excess in the towns.

On the other hand vitamins A and C, found principally in fresh fruit and vegetables, are in excess in the town diet although nationwide they are in deficit; reflecting the small quantities of fruit and vegetables grown and consumed in rural Tunisia.

Vitamin B2 is found mainly in animal products. Shortage entails great dangers including loss of weight and stunted growth. Because the diet is poor in animal products it is poor in B2; an overall deficit of 52%, worst in the rural areas.

Conclusion. There can be no doubt that the Tunisian diet is over-dependent on cereals and, for that reason, is unbalanced. Because the country produces so little fruit, vegetables and milk products there is a national shortage of calcium and the vitamins A, B2, PP, and C. But although the production of livestock, fruit and vegetables, for internal consumption, should be increased, this cannot be at the expense of cereals. As it is the consumption of cereals per head has gone down as a result of the increasing population; it was 167 kg/year in 1949/53 but only 147 kg/head in 1965/68. Although cereals in 1965/68 accounted for only 60% of the calories consumed as opposed to 65% in 1949/53 the overall excess of calories in the diet fell from 10.2% to 5.1% thereby leaving many poorer families in permanent calory deficit.

The rapidly growing population will absorb the excess of calories, vitamin B1 and iron and make more acute the shortage of calcium and the other vitamins. In this situation it would be extremely hazardous to cut down the area under wheat or to reduce the emphasis on improving wheat productivity. If the diet is to be balanced it must be by increasing the availability of other foodstuffs. However in Tunisia it will never be easy to increase the production of milk, animal products, fruit and vegetables because where in Tunisia their production is economically viable they are grown in conjunction with irrigation, and the possibilities for expanding irrigation are limited.

Most of the land will remain under a dry-farming regime and in this situation wheat must remain a priority crop. Therefore a clear understanding of the relationship between the productivity of wheat and its physical environment is of great importance to Tunisia

CHAPTER 3

THE PHYSICAL CHARACTERISTICS OF THE LMV.

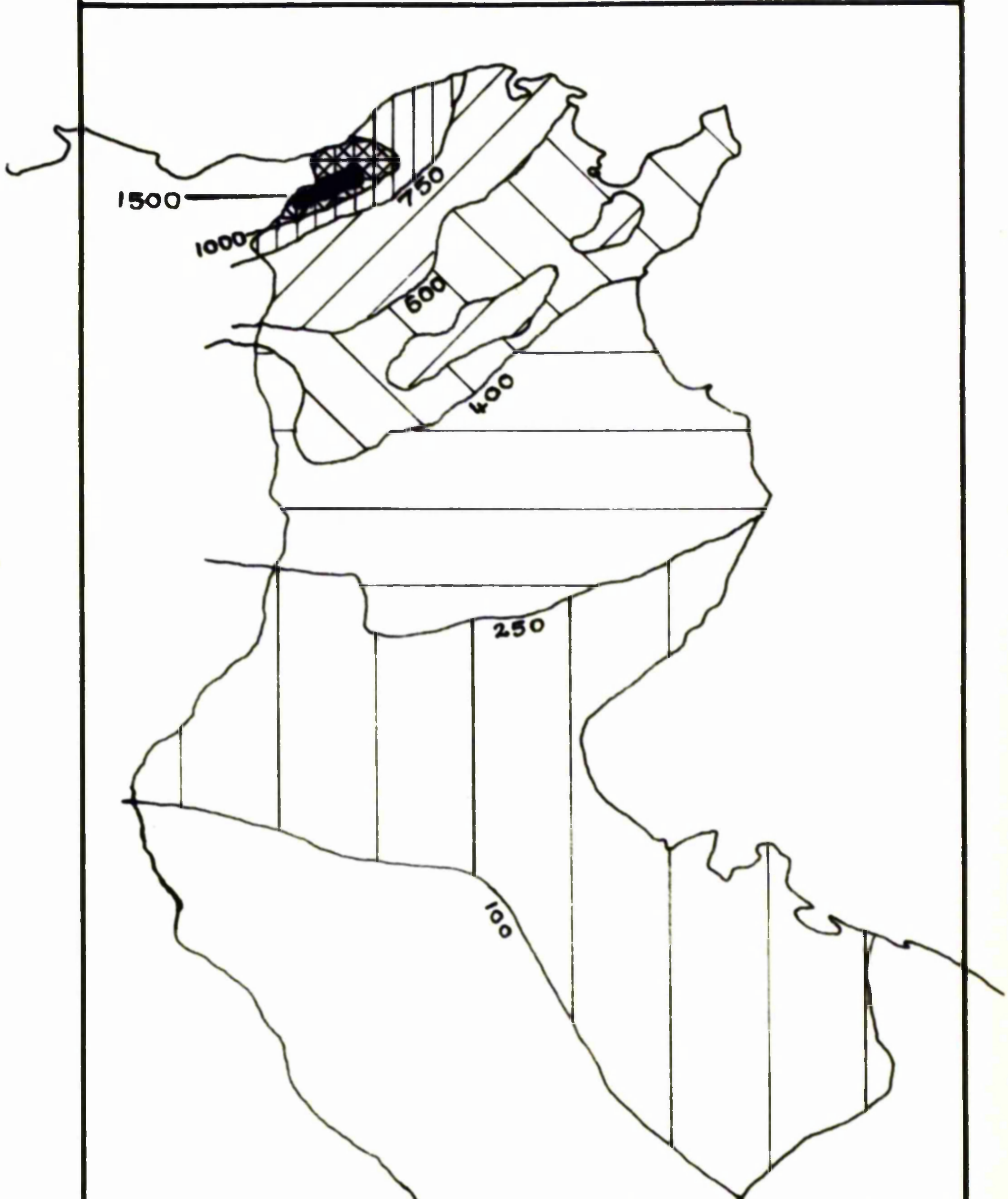
3.1 The Climate of the LMV. For a small country Tunisia has a great range of climatic type, from wet Mediterranean in the north-west to Saharan in the south (Fig. 6 , p. 49) which greatly restricts the areas suitable for cultivation of the different cereals. Only to the north of the Dorsale, a barrier of hills running across the country from Thala to south of Hammamet , are the yields of wheat acceptable to good. The LMV is an important part of the northern wheat area.

The LMV is low-lying and borders the Mediterranean giving it a moderate range of temperature and rainfall (400-500 mm.) which makes it suitable for cereal cultivation. The distribution of rainfall is, however, less favourable than in the High Tell (Isnard, 1952) which receives 46% of its total rainfall in spring: at Thala the wettest month is March with 55 mm. and all the months between December and May receive about 50 mm. In the LMV too much rain is concentrated in winter and too little in spring. There is an important annual and seasonal fluctuation of the major climatic elements which is discussed below.

Rainfall. There is a more detailed record of rainfall in the LMV than of the other features of the climate. A number of rainstations in different parts of the valley returned daily records of rainfall to the BIRH. These records are fairly complete and, in some cases, extend over 50 years or more. Records from eight stations were chosen to give a general picture of rainfall throughout the LMV. These stations were chosen because they evenly cover the entire area and because they are reasonably

Fig. 6

ANNUAL RAINFALL IN TUNISIA



isohyets at: 100, 250, 400, 600, 750, 1000, 1500 m.m.

after Lasserre

complete for the 50 year period, 1911-1960. Gaps in the records were calculated with reference to the other records. A comparison between the stations, Table 12, shows that the coastal region received the highest rainfall but the total decreased considerably inland and to the south. The plot of these records (Fig. 7 , p. 51) shows that most of the LMV - including all the cereal growing areas - received less than 500 mm. of rain

Table 12. Mean Rainfall in the LMV 1911-1960. (mm.)
source: data from BIRH.

Region	Station	Autumn	Winter	Spring	Summer	Annual
Coastal	Ghar el Melah	180.5	257.0	114.1	21.1	572.6
	Ariana (Bot.)	154.1	201.7	114.6	23.4	493.8
	Creteville	161.5	195.7	116.3	20.8	494.5
Central	Mabtouha	135.3	195.8	104.7	15.3	451.1
	Bordj Toum	120.3	204.9	109.2	11.6	445.9
	Bordj Chakir	139.2	177.0	109.2	23.5	448.8
Southern	Ain Asker	130.3	153.9	101.0	23.1	408.6
	Montarnaud II	121.9	135.7	95.6	20.4	373.7

annually. Most of the area in which cereal crops predominate received between 375 mm. and 450 mm. of rainfall annually.

The seasonal maps for autumn and winter (Figs. 8 & 9, pp. 52-53) show that most of the rain is brought by the eastward procession of cyclones across the Mediterranean. The prevailing winds are north-east to north. In spring (Fig. 10, p. 54) more of the rainbearing winds come from the west. But the most important feature of the spring rainfall is its uniformity throughout the valley.

The monthly distribution of rainfall throughout the year (Fig. 25, p.286) is broadly similar for each station with a minimum in July, practically none at all, and a maximum in January. A secondary peak occurs in November in the case of Creteville and Montarnaud II. Much more important from the point of

Fig. 7

RAINFALL IN THE LOWER MEDJERDA VALLEY

MEAN ANNUAL RAINFALL 1911-1960

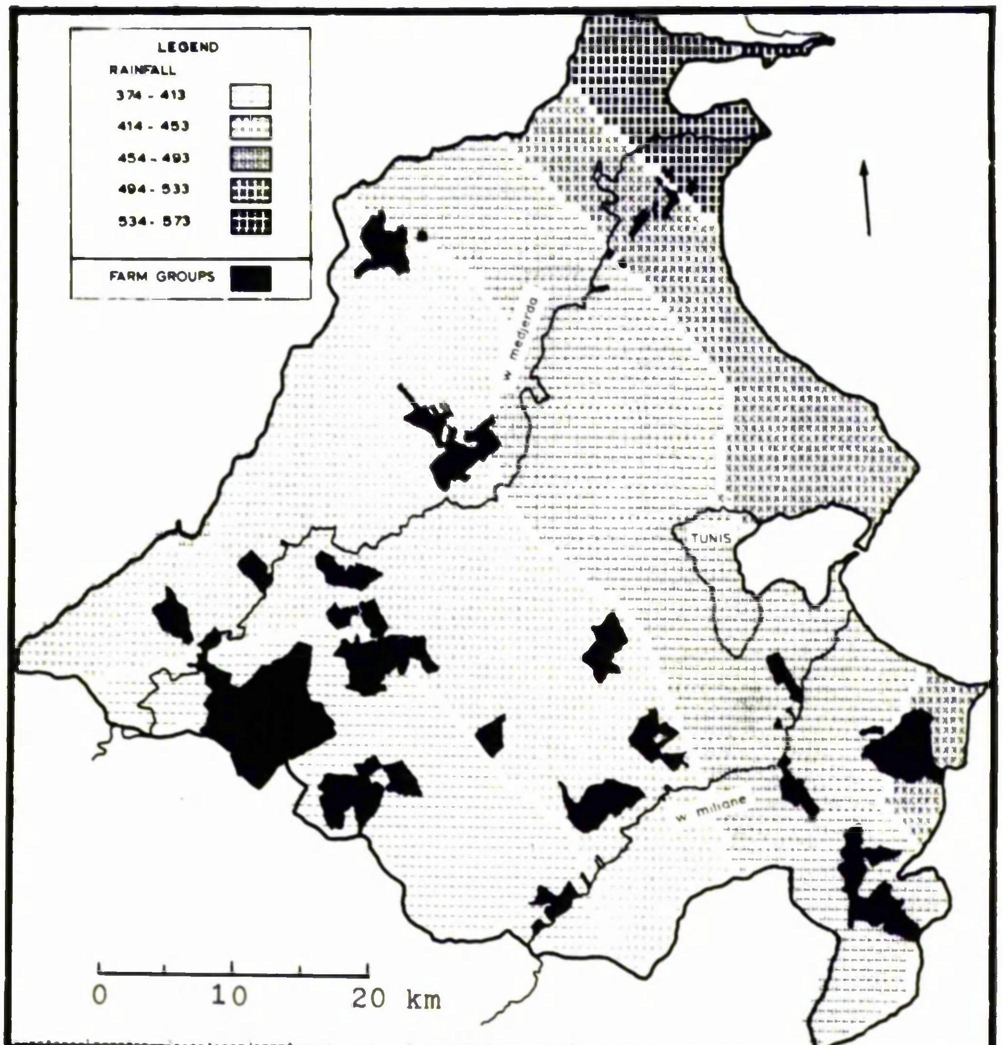


Fig. 8

RAINFALL IN THE LOWER MEDJERDA VALLEY

MEAN AUTUMN RAINFALL 1911 - 1960

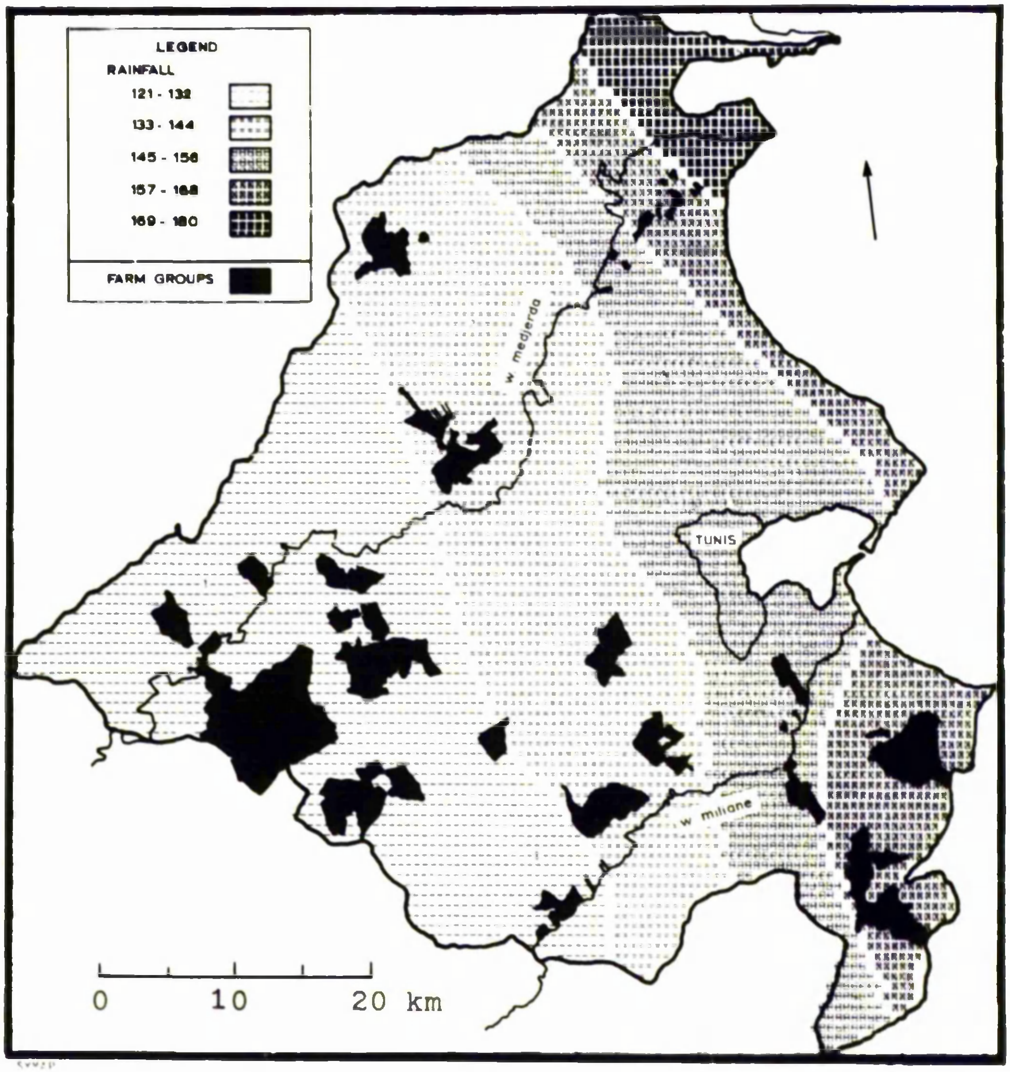


Fig. 9

RAINFALL IN THE LOWER MEDJERDA VALLEY

MEAN WINTER RAINFALL 1911 - 1960

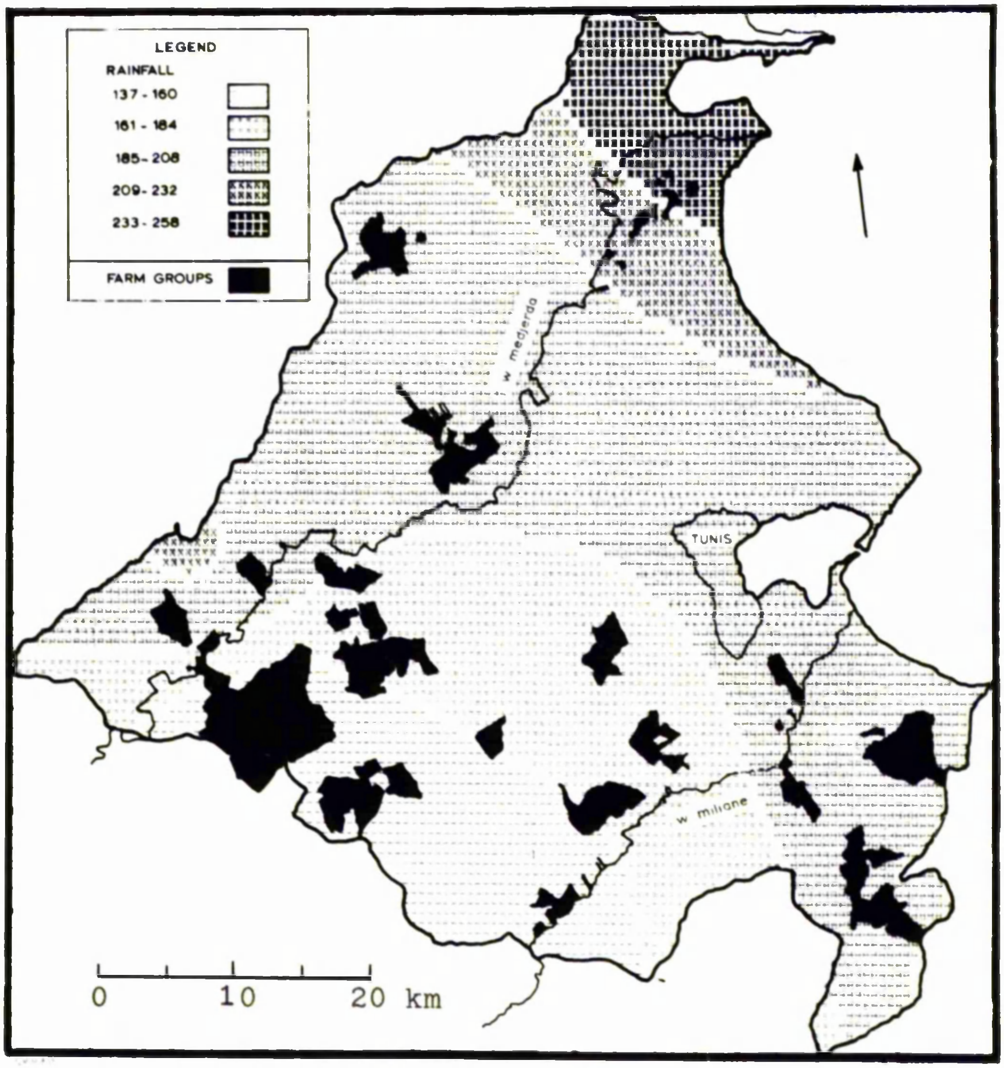
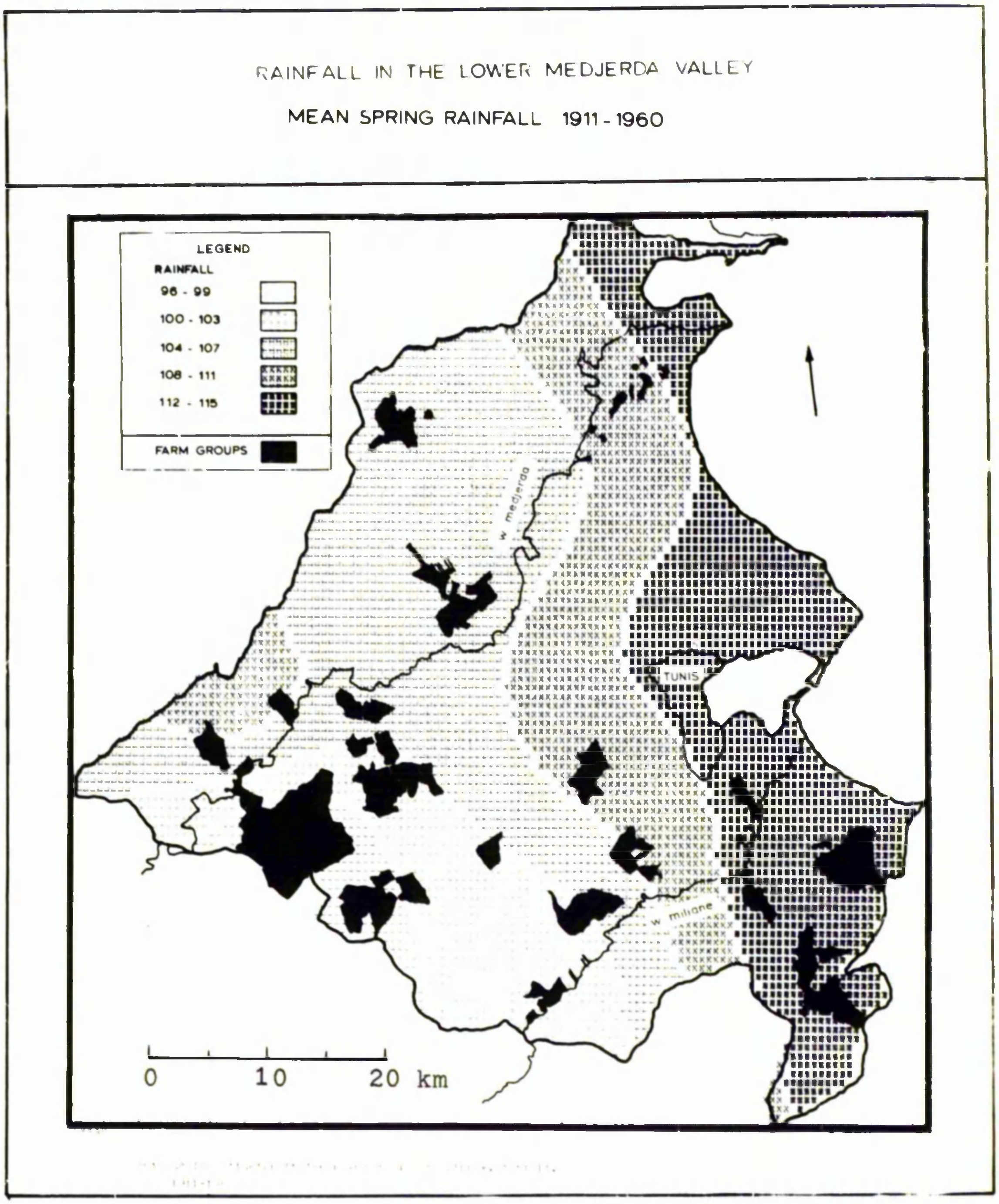


Fig. 10


RAINFALL IN THE LOWER MEDJERDA VALLEY
MEAN SPRING RAINFALL 1911 - 1960
LEGEND
RAINFALL
96 - 99
100 - 103
104 - 107
108 - 111
112 - 115
FARM GROUPS
w medjerda
TUNIS
w miliane
0
10
20 km

cereal crops there is a further peak in March at Montarnaud and Ain Asker which partially compensates for the low winter rainfall at these southern stations.

For the months from May to September there is surprisingly little variation in rainfall in different areas of the LMV compared with the rest of the year. Analysis of variance between the stations shows that the null hypothesis of no variation is upheld for the months March, April, May, June and September. At the 1% level there is only significant variation for the months of January, February, November and December and for the year as a whole.

A great annual fluctuation of rainfall is a common feature of Mediterranean climates. The LMV is no exception to this rule (Fig. 11, p. 56). Over a 49 year period of agricultural years means for the eight stations can only be established, within 95% confidence limits, to plus or minus 8-10% of the 49 year mean. Much more significant for the farmer is the high degree of variation of the 5 year and 10 year means from the true mean. Taking the agricultural year - 1 Aug. to 31 July - the eight stations show a broadly similar rainfall pattern over the period 1911/12 to 1959/60 (Figs. 12-14, pp. 57-59) with high rainfall in the 1930's and the 1950's and low rainfall during the 1940's. There is little regional variation. At each station the difference between the highest and lowest 10 year means is as high as 30% and 40% of the 50 year mean. In most cases, Table 13, these are successive, or partially overlapping, periods in the 1940's and 1950's. The effect that this has on agriculture is dramatic. A farmer adapting his techniques to the medium rainfall of the 1920's and 1930's would find them quite

Fig. 11

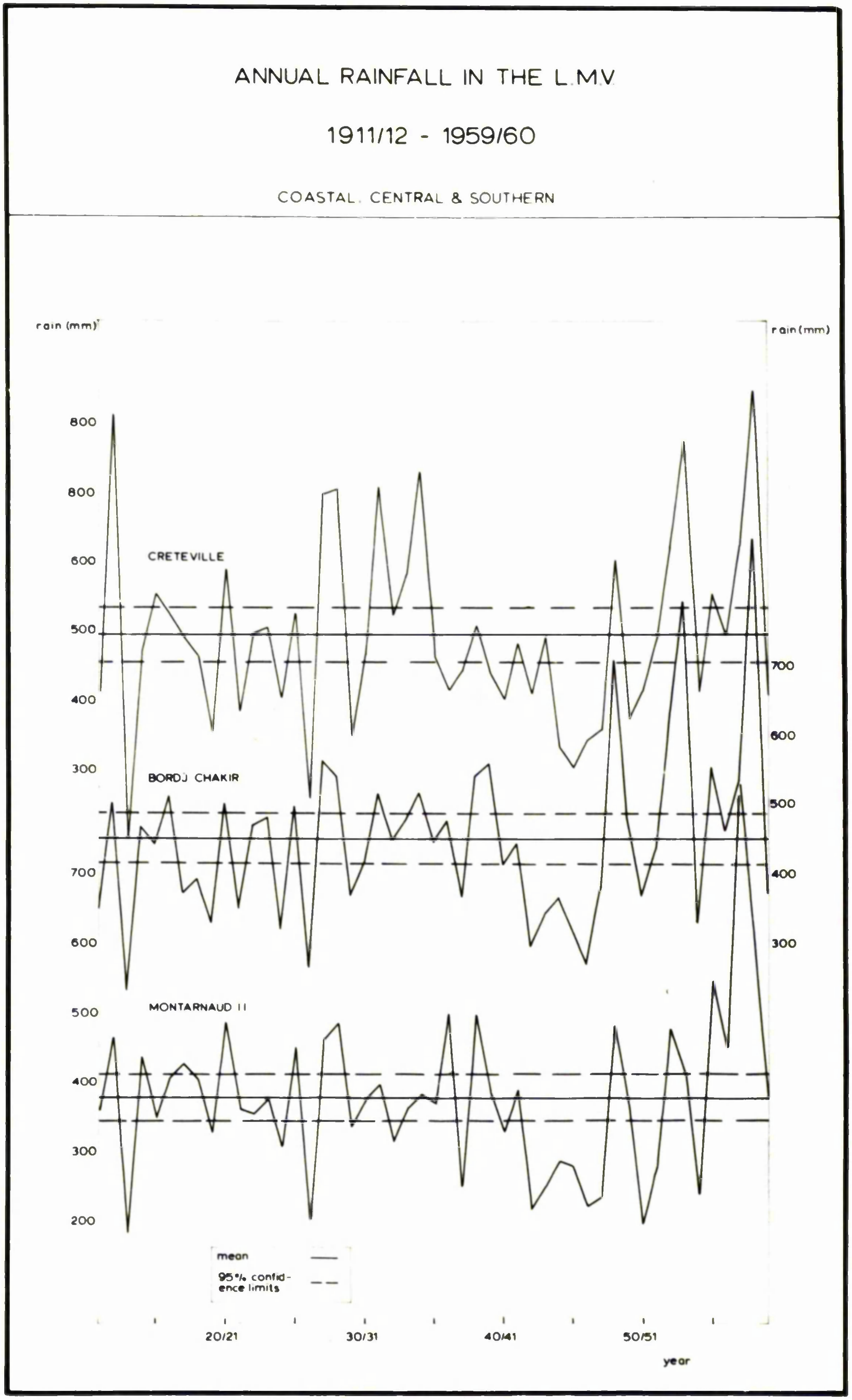
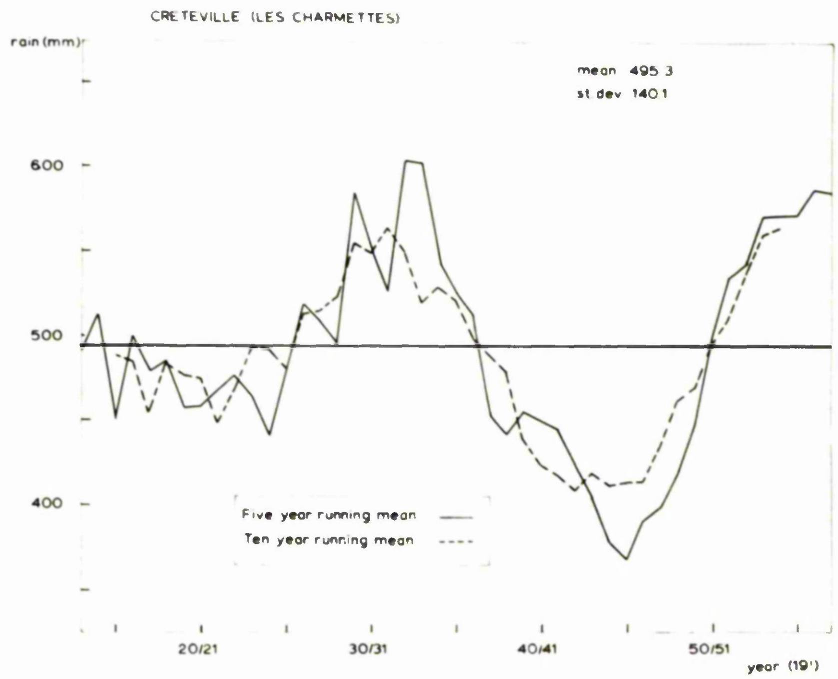

ANNUAL RAINFALL IN THE L.M.V.
1911/12 - 1959/60
COASTAL, CENTRAL & SOUTHERN
rain (mm)
rain (mm)
CRETEVILLE
BORDJ CHAKIR
MONTARNAUD II
800
800
600
500
400
300
700
600
500
400
300
200
700
600
500
400
300
mean
95% confidence limits
20/21
30/31
40/41
50/51
year

Fig. 12

RAINFALL IN THE L.M.V. 1911/12 - 1959/60

COASTAL BELT



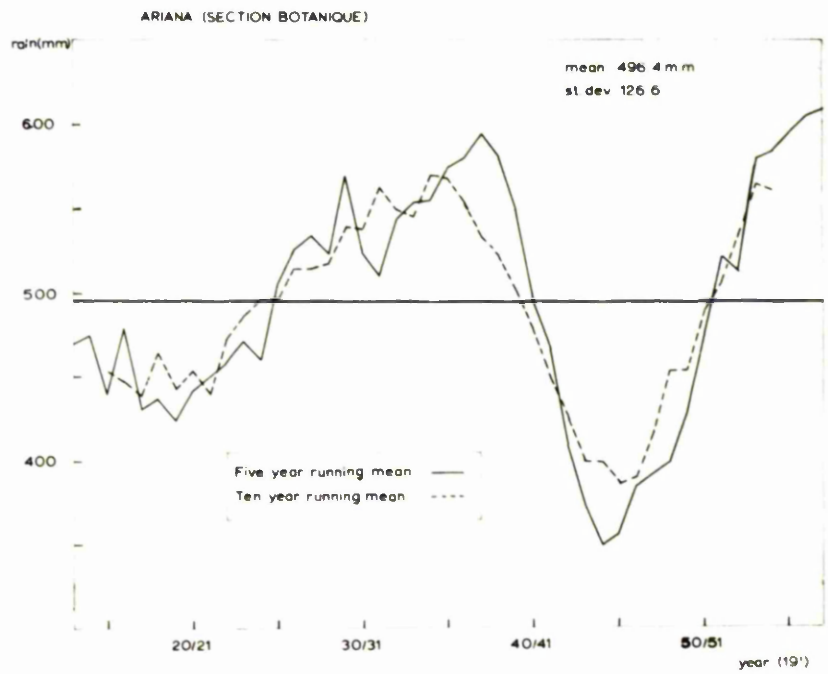
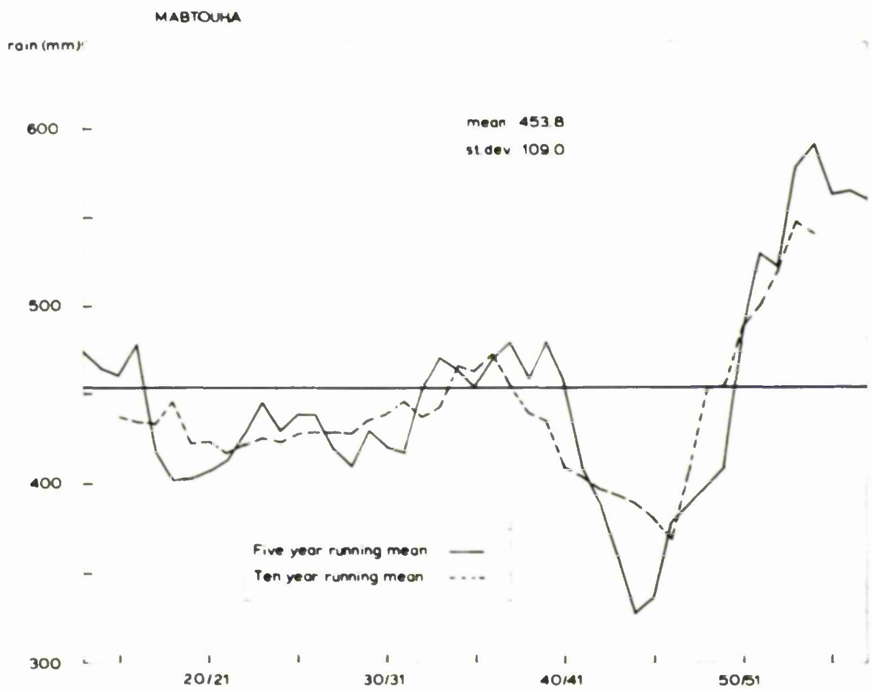


Fig. 13

RAINFALL IN THE L.M.V. 1911/12 - 1959/60

CENTRAL REGION



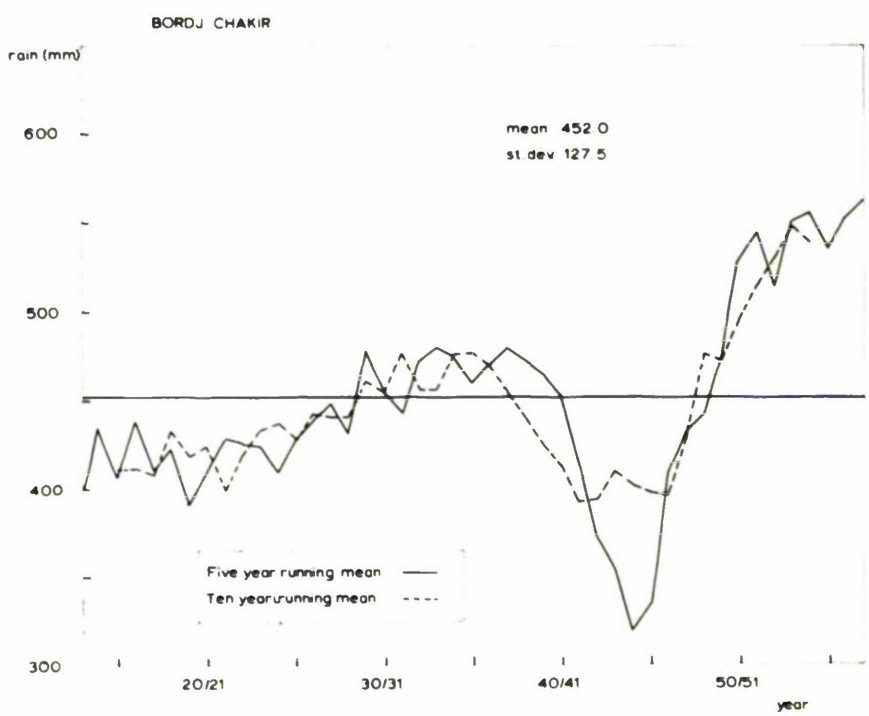
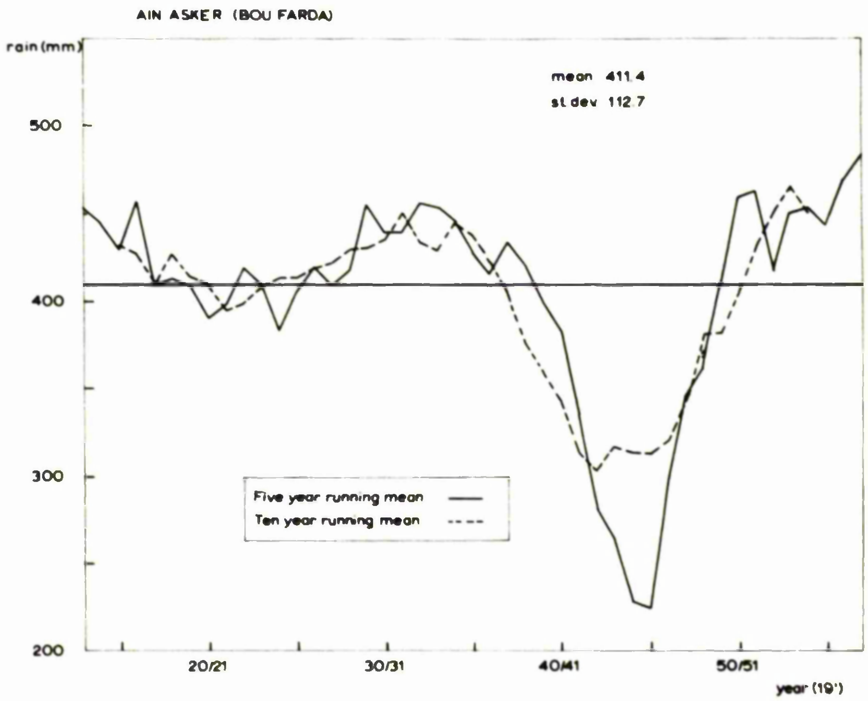


Fig. 14

RAINFALL IN THE L.M.V. 1911/12 - 1959/60

SOUTHERN



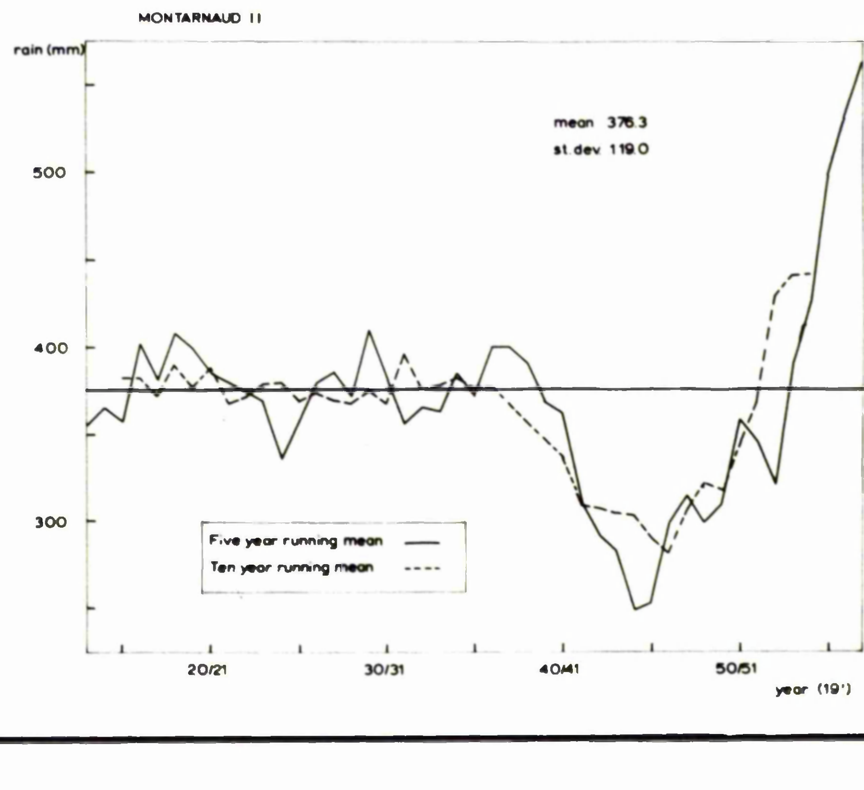


Table 13. Rainfall in the LMV.: Minimum and Maximum 5 and 10 Year Means, 1911/12 - 1959/60.(mm)

source: data from BIRH.

Station	Mean 1911/60	Min. 5 yr. mean Period(19')	Min. 5 yr. mean Rainfall (1)	Max. 5 yr. mean Period(19')	Max. 5 yr. mean Rainfall (2)	Difference (2-1)
Ariana(Bot.)	496.4	42/43-46/47	350.9	55/56-59/60	609.1	258.2
Ain Asker	411.4	43/44-47/48	224.7	55/56-59/60	482.9	258.2
Mabtouha	453.8	42/43-46/47	327.7	52/53-56/57	592.8	265.1
Ghar el Melah	575.4	13/14-17/18	441.1	55/56-59/60	739.5	298.4
Creteville	495.3	43/44-47/48	367.5	30/31-34/35	603.3	235.8
Bordj Chakir	452.0	42/43-46/47	319.1	55/56-59/60	562.2	253.1
Montarnaud II	376.3	42/43-46/47	249.9	55/56-59/60	563.7	313.8
Bordj Toum	448.2	43/44-47/48	307.2	27/28-31/32	563.8	256.6
		Min. 10 yr. mean		Max. 10 yr. mean		
Ariana(Bot.)	496.4	41/42-50/51	387.3	49/50-58/59	563.8	176.6
Ain Asker	411.4	38/39-47/48	304.0	49/50-58/59	466.4	162.4
Mabtouha	453.8	42/43-51/52	368.8	49/50-58/59	548.4	179.6
Ghar el Melah	575.4	13/14-22/23	479.6	50/51-59/60	661.5	181.9
Creteville	495.3	38/39-47/48	408.5	50/51-59/60	564.7	156.2
Bordj Chakir	452.0	37/38-46/47	392.2	49/50-58/59	548.5	156.3
Montarnaud II	376.3	42/43-51/52	280.2	50/51-59/60	442.2	162.0
Bordj Toum	448.2	41/42-50/51	362.9	27/28-36/37	505.2	142.3

unsuited to the arid 1940's or the wet 1950's.

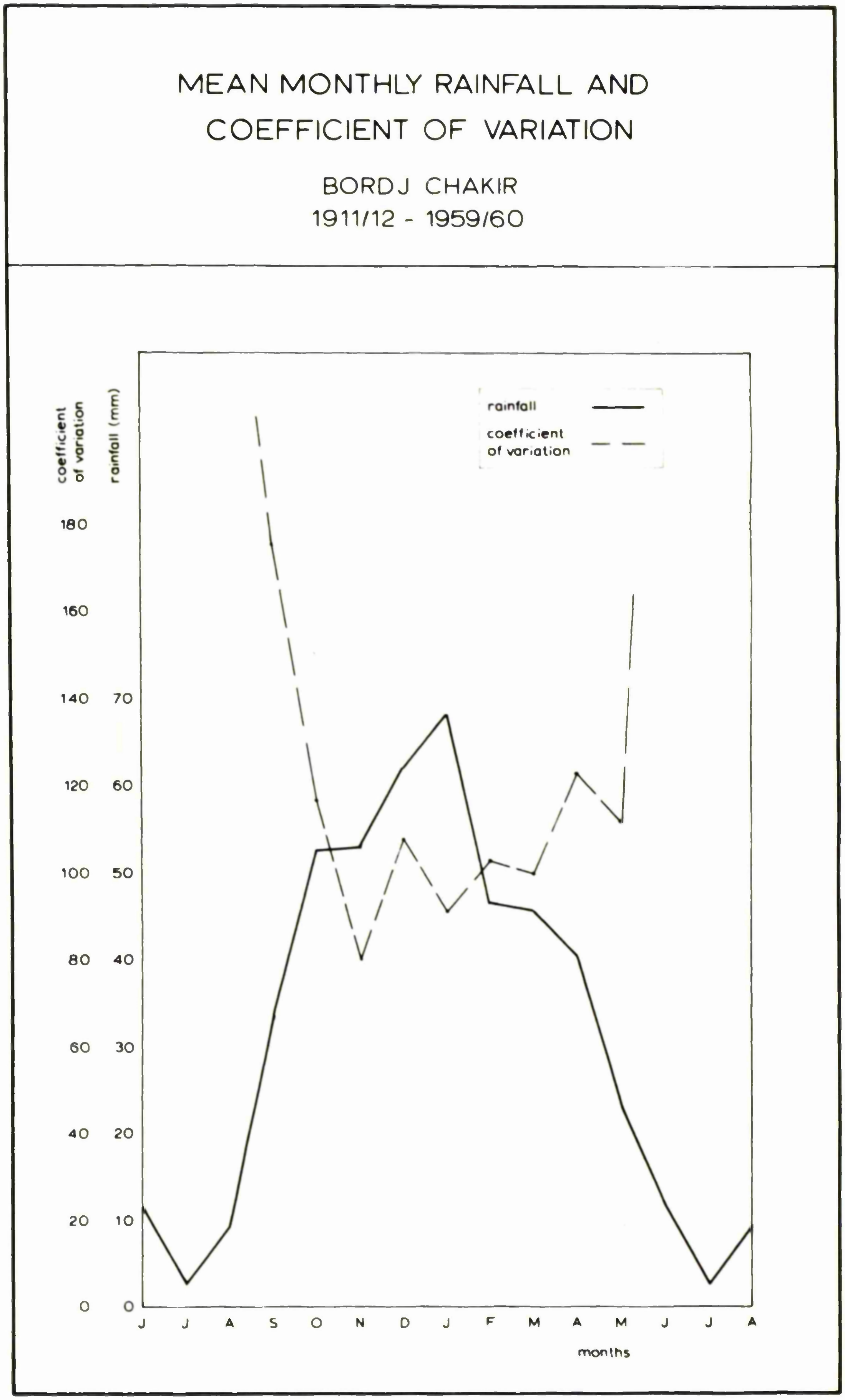
The problems posed for the research worker are equally great. It is rare that a researcher occupies a position or conducts an experiment for more than 10 years but this might not be long enough. Conclusions reached at the end of the 1940's would be radically different from those reached at the end of the 1950's unless great care was taken to set the results of the decade into a much longer rainfall context. Failure to do this was a major cause of the pessimistic view of colonial cereal cultivation (to be discussed in detail in ch. 6) taken by some authors in the 1950's; the yield trend tended to be steadily down from 1930 to 1950.

A last point of interest to agriculture is that the coefficient of variation (Fig. 15, p. 62) is higher for the months of September and October than throughout the winter. This means that the rain is most uncertain in autumn and varies between wider extremes. This can be very serious because following the dry summer a very dry or very wet autumn will delay or prevent sowing. Also a heavy storm falling on dry land has a much greater erosive potential than if the land were wet.

Temperature. There is much less variation in annual and monthly temperature from year to year (Fig. 24, p.254) than rainfall. The true mean at Tunis-Carthage lies in a range of only 4-5% of the 30 year mean, within 95% confidence limits.

The coldest month is January, with December, January and February the coldest season. The hottest month is July. Comparison of Tunis-Carthage with Bir M'Chirga shows that there is a small degree of continentality at the southern end of the LMV where it is hotter during June, July and August but slightly

Fig. 15


MEAN MONTHLY RAINFALL AND
COEFFICIENT OF VARIATION
BORDJ CHAKIR
1911/12 - 1959/60
coefficient of variation
rainfall (mm)
rainfall
coefficient of variation
180
160
140 70
120 60
100 50
80 40
60 30
40 20
20 10
0 0
J J A S O N D J F M A M J J A
months

colder during the rest of the year. The slightly cooler winters will depress the rate of germination, tillering and head formation if they have any significant effect at all. During the crucial ceiling phase in May, when hot weather can damage the maturing grain, the temperatures are more or less identical.

Extremes of temperature can be as important as the means. Temperatures below 0°C. are rare in the LMV. When they occur in winter they do no damage to the cereal crops. But occasionally they occur as late as April, during the critical phase of heading when they have a disasterous effect on yields. The degree of frost, and therefore the extent of damage to the head, is higher in the southern LMV as in April 1956; discussed more fully in chapter 8.2 (p. 268ff.).

Temperature maxima in May can stop, or hinder, the development of the grain (see ch. 8.3, p. 275ff.) if they reach 30°C. during the ceiling phase. The effect is exaggerated if, as often happens, Table 50,(p. 278), the high temperatures are accompanied by sirocco conditions when the low relative humidity increases the rate of evapotranspiration.

<u>Wind</u>. The wind direction is very variable. It is affected by the Atlantic anticyclone, by the easterly passage of cyclones over the Mediterranean (a few of which pass south of the Atlas mountains) from autumn to spring and by the strongly continental conditions to the south in the Sahara.

About 50% of all winds (Bonniard, 1925) are north and north-west. These bear the rain though in spring rainbearing winds reach the valley from the north-east making the coast rather wetter than the interior and ensuring a relatively even distribution of spring rainfall throughout the LMV. The north-west winds can be violent; causing flooding from the sea, uprooting trees and eroding top soil. In winter they can flatten wheat during the tillering phase.

In the late dry season slightly cooler and more humid winds blow from the north and north-east and east.

Evenly distributed throughout the year, and forming about 10% of all winds, come south and south-east winds bringing dry sirocco air. They penetrate into the LMV (Monchicourt, 1904) through low gaps in the hills. In May they dry the air and can cause a sudden increase in temperature lasting from two to four days. Frequently the daily maxima are over 30°C. The effect on the maturing grain (see ch. 8.3, pp. 275-279) can be extremely harmful.

Other Precipitation. Both snow and hail are extremely rare in the LMV. Neither interferes with cereal cultivation. On the other hand dew might play a more important role. Certainly in nearby Malta (Mitchell and Dewdney, 1960) and Libya (Willimott, 1960) the probable importance of dew was mentioned although there was no experimental confirmation of this. In Israel (Duvdevani, 1957) it has been shown that on the coastal plain 10 mm. to 25 mm. of dew can fall in the six months April to September with the heaviest falls occurring in August. Foliage could be wet for three to five hours after sunrise and, it was proved, moisture could seep through the foliage into the plant and act as a secondary water source.

Assuming the situation in the LMV to be similar to the plain of Sharon the importance of dew is likely to be greatest when the rainfall is least and the dewfall heaviest; that is to say August and the other summer months. This is after the grain harvest has taken place. But it is possible that in the early part of a dry May heavy dewfalls could have a beneficial effect on wheat yields. Unofrtunately this point will have to await future examination because no data on dewfall has been recorded in Tunisia.

3.2 The Medjerda River. In a study concentrating on the problem of dry-farmed cereals a description of the path and regime of the Medjerda river has, nevertheless, to be given. This is because the river's lower valley lies across the study area (Fig. 16, p. 77) where it has played an important manifold role in shaping farming practice and development. The Medjerda is relatively very important to Tunisia's hydrology. It flows continuously throughout the year, which makes it unique in Tunisia, and carries half of the country's total volume of surface water, Table 14, which flows to the sea or the inland drainage basins. The dominant position of the Medjerda basin is made more imp-

Table 14. Drainage Regions in Tunisia.
source: Tixeront, 1957

Region	Volume of Water/Annum (milliard cu.m.)
Medjerda Basin	1.00
Ichkeul Basin	0.25
Bizerte and Tabarka Basins	0.25
Rest of Tunisia	0.25/0.50

ortant by the fact that the country is chronically short of water, particularly in the dry Mediterranean summer months, so that the water borne by the Medjerda has long been coveted for irrigation.

In consequence a project to control and use the river for irrigation (Ptes. 1 & 2, pp. 67-68) was begun in 1948 under the direction of the OMVVM (Dutton, 1968). But of the total development area, extended to 300,000 ha. in 1967, only about 10% will be irrigated when the project is completed leaving the rest of the agricultural land to be developed within the limitations imposed by the climate and the soil. So the river is the raison d'être of the OMVVM whose major interest in terms of

Pte. 1. The OMVVM Irrigation Project: Reservoir at el Arroussia

source: Dutton, spring 1970

Water dammed at el Arroussia, above, is distributed along two primary canals either side of the Medjerda river to supply the irrigable zone of the LMV.

Pte. 2. The OMVVM Irrigation Project: Irrigated Melons at Saida

source: Dutton, spring 1970

Water is carried to each field in tertiary canals. It is then the farmer's responsibility to make earth canals which conduct equal amounts of water to each plant in the field.

area will remain cereal crops.

The presence of the river has affected cereal cultivation in several ways which make a study of its regime worthwhile. Firstly the LMV is a sedimentary plain; its topography and soil structure are profoundly influenced by the river and the sea. Soil profiles (see ch. 3.3, p. 78 ff.) show alternating strata of fluvial and marine deposits including a high concentration of soluble salts. Each flood causes the deposition of further silt eroded from the Middle and Upper valleys of the Medjerda and its tributaries.

Flooding was a common hazard in the LMV endangering the crops and land of the farmers near the river. The OMVVM (Dutton, 1968) has practically ended the danger of flooding by damming the river and shortening its bed. The water is now harnessed for irrigation which has intensified agriculture in the irrigated areas which in turn has meant a move from dry-farmed cereals to irrigated fodder and market garden crops. There is also scope for irrigated cereals now that Mexican wheats have been introduced into Tunisia so the quality of the water (its concentration of soluble salts) and its suitability for irrigating cereal crops on the LMV soils has to be examined.

The Drainage Basin. The drainage basin of the Medjerda river is the largest in Tunisia, draining much of the wettest area of the country. The river bed is about 460 km. long (Bonniard, 1934) including meanders and drains 22,000 sq.km. The Upper Valley of the river, receives a rainfall of 600 to 1,000 mm. a year. The river descends rapidly to Ghardimaou, only 200 m. above sea level, where it enters Tunisia and begins the course of its Middle Valley through the Great Plains of

Jendouba and Bou Salem, where the rainfall is only 400-500 mm. a year. The flat and fertile land of the Great Plains is composed of sedimentary deposits from a lake which existed until the river cut through the mountain bridge at its eastern end. The river descends slowly and has cut deep and wide meanders into the plain. Erosion is rapid. Because of the depth of the meanders serious flooding is rare except at the western end of the Great Plains where the Medjerda has built up its bed.

In the Middle Valley the Medjerda is joined by all its major tributaries. The drainage basin to the north includes only the southern part of the Tell Septentrional. Most of this region, the wettest in Tunisia, drains to the north so that the left bank tributaries are small, Table 15, which is a double loss because their water has a very low salt content. The largest tributaries are from the south, notably the Mellegue, where they drain a lower rainfall from a much larger catchment area. This region contains secondary gypsum clays rich in soluble salts which are leached into the rivers in sufficient concentration to become an irrigation hazard (Dutton, 1968, pp. 36/37). The mean annual salt concentration 1951/52 to 1964/65 was 1.8 gm/li.

Beyond Teboursouk the only major tributary is the Silyana. From here to the sea the Medjerda is enlarged only by minor wadi carrying storm water from the neighbouring hills. The Chafrou is the largest of these. The Medjerda descends very gradually from Medjez el Bab to the sea, its course lengthened by innumerable meanders. The river here is rich in silt and salts (Dutton, 1968, Graph I, pp.12/13). From Medjez el Bab to Tebourba the river valley is steep-sided and well defined but from Tebourba to the sea, a distance of 50 km., the Medjerda travels

80 km. while it descends only 23 m. across a flat alluvial plain. Erosion gives way to deposition of silt so that the river has raised its bed on levées two or three metres above the plain. In consequence, of the wadi in the LMV, only the Chafrou (Fig. 16, p. 77) empties into the Medjerda. The other

Table 15. Analysis of the Medjerda and its Tributaries.
source: Plan, 1968

Name	Point of Measurement	Catchment Area(sq.km.)	Mean Annual Flow(10^6m.^{3})	Mean Salinity(gm/li)
Medjerda	Ghardimaou	1,490	171.0	0.8
Melliz	confluence	235	19.0	3.0/8.0
Raria	"	320	67.0	slight
Mellegue	"	10,643	190.0	2.3
Tessa	"	2,412	65.0	3.5
Bou Heurtma	"	?	85.0	0.4
(water table)	-	-	103.0	?
Medjerda	Bou Salem	16,361	700.0	0.8/2.7
Kassab	confluence	264	68.1	0.4
Béja	"	340	28.0	0.4
Zarga	"	302	19.0	high
Khalled	"	458	24.6	high
Silyana	"	2,227	83.0	2.5
(water table)	-	-	27.4	?
Medjerda	Medjez-el-Bab	20,030	950.0	1.0/3.5

wadi, from a catchment area of 1,050 sq.km., flow into the qar'at.

The bed of the Medjerda river is unstable because the general level of the plain on its left bank is lower than on the right bank where at least three ancient beds of the river are clearly visible. There is a natural tendency (Pimienta, 1953) for the mouth of the river to be displaced northwards. The last time that this occurred was in 1898-1900 when the river opened a mouth into the lagoon of Ghar el Melah after extensive flooding when 1/3 of the villagers of Aousdja died from malaria.

On the left bank of the river the lowest plains are Utique and Mabtouha. The latter is the main collecting basin for flood water when the Medjerda overflows its banks from as far upstream as Tebourba. Up to 1954 the farms in this region were exposed to the full danger of flooding but after this the work done by the OMVVM (Pte. 3 , p. 73) to control flooding and improve drainage freed the farms from this danger in all but exceptionally wet years such as 1958/59 and 1969/70.

The Water: Volume. The mean annual volume of water in the Medjerda measured at Medjez el Bab 1932-1955 was 950 x 10^6cu.m., Table 16, but with a range extending from a minimum of 318 x 10^6cu.m. to a maximum of 1,740 x 10^6cu.m. The monthly means, as well as the wide divergence between minimum and maximum values, show how closely the river regime reflects the

Table 16. The Medjerda River: Volume of Water at Medjez el Bab; 1932-1955 (10^6cu.m.).

source: BIRH, 1951/55

	S	O	N	D	J	F	M	A	M	J	J	A	YEAR
max.	117	218	361	545	960	545	404	311	14[illegible]	62	24	69	1,740
min.	4	3	4	12	29	53	22	11	10	4	3	3	318
mean	31	55	57	108	223	172	131	78	42	23	10	19	950

Mediterranean distribution of rainfall with a January maximum and a July minimum. In addition the day to day variation in flow of the river closely reflects the daily rainfall pattern. A depression passing over the catchment area can cause the depth of water at Medjez el Bab to rise up to 5 m. or more in a few hours, which greatly increases the likelihood of flooding. Once the peak is passed the tail of the flood is long spread out and suitable to be dammed for irrigation.

The close association between rainfall and water carried in the Medjerda means that most water is available for irrigation when there is least for it, in winter, while during the long

Pte. 3. Chaouat; Colonial Farm Village and Cereal Land

source: Air survey of Tunisia 1962/63

The whole area was colonised by French and Italian farmers. Most of the land, divided into large fields, was cultivated with the Fallow-Wheat rotation. The lower slopes of the djebel Chaouat, near the village, were contoured.

The drainage canal built by the OMVVM (crossing the picture) made the land secure from flooding after 1954.

dry summer irrigation is most difficult.

The Water: Salinity. Some of the tributaries of the Medjerda, Table 15, have a concentration of soluble salts in excess of 2 gm/li. Even when these waters are mixed with the tributaries of low salt concentration (Plan, 1968) the mean (1951 to 1965) is 1.8 gm/li. The annual, and monthly, concentration of soluble salts has a strong inverse association with volume of water, and therefore the rainfall. In the dry years, Table 17, 1954/55 and 1960/61, the salt concentration rose to 2.2 gm/li. and 2.1 gm/li. respectively so that water for irrigation was not only in short supply but of the poorest quality.

Table 17. The Medjerda River: Salinity (gm/li.) and Volume of Water (10^6 cu.m.). 1951/52-1964/65.

source: Plan, 1968

Year	Salt	Water	Year	Salt	Water
51/52	1.8	910	58/59	1.6	1,040
52/53	1.7	1,145	59/60	2.0	500
53/54	1.7	1,340	60/61	2.1	310
54/55	2.2	330	61/62	1.9	690
55/56	1.8	920	62/63	1.6	860
56/57	2.1	480	63/64	1.8	840
57/58	1.8	1,020	64/65	1.5	1,120

The salt concentration is highest in summer which exascerbates the problem of using the water for irrigation. Even cereals, which do not require irrigation after April, would suffer in dry years.

Water: Erosion and Deposition. The river erosion map of Tunisia (Cote, 1964) shows that the Medjerda valley lies for its entire length within the zone of most rapid erosion. Several factors encourage very rapid erosion (Bonniard, 1934) following winter storms. Important amongst these is the incomplete vegetation cover, particularly at the end of the long dry summer, which means that run-off of rain water is unimpeded when the stormy autumn rains begin.

The Medjerda in flood has a proportion of solid matter to water of 25:1,000 (Pellegrin, 1955). The total sediment each year is about 20 x 10^6 cu.m. which would cover 2,000 ha. to a depth of one metre. If this were deposited on the flood plain it would have a beneficial effect on soil fertility but 90% of the eroded material is washed into the sea. The rest is either deposited on the bed of the river or carried onto the flood plain by destructive floods which occur during the agricultural season and are quite unpredictable. Where river water is used for irrigation silt tends to block the irrigation canals.

Erosion impoverishes the Middle and Upper Valleys. Most of the eroded material is carried into the sea where it is rapidly enlarging the river estuary. Utique, which was a port in the 7th. century, is now 16 km. from the sea. Sediment deposited on the river bed has built it up above the plain level, increasing the possibility of flooding. About 75% of this sediment is fine (under 0.02 mm. in diameter: Pimienta, 1954) which renders it impermeable and therefore difficult to irrigate.

3.3 The Topology, Geology and Hydrology of the LMV.

The Medjerda Delta. The delta region includes the river valley from Tebourba/Djedeida to the sea; which forms its eastern boundary. The northern and western boundaries are formed by a series of hills rising to 394 m. The south-western boundary (Fig.16,p.77) is formed by the *djebel* Ammar, the *djebel* Naheli and the *sebkhet* Ariana.

The delta is composed of a series of flat plains broken by a few low hills. The plains of Mabtouha and Utique, both on the left bank of the Medjerda, are the lowest points. They are separated by an eastward projection of the western hills, the *djebel* Menzel Roul, on which was built the port of Utique; now distanced from the sea by 16 km. of alluvium.

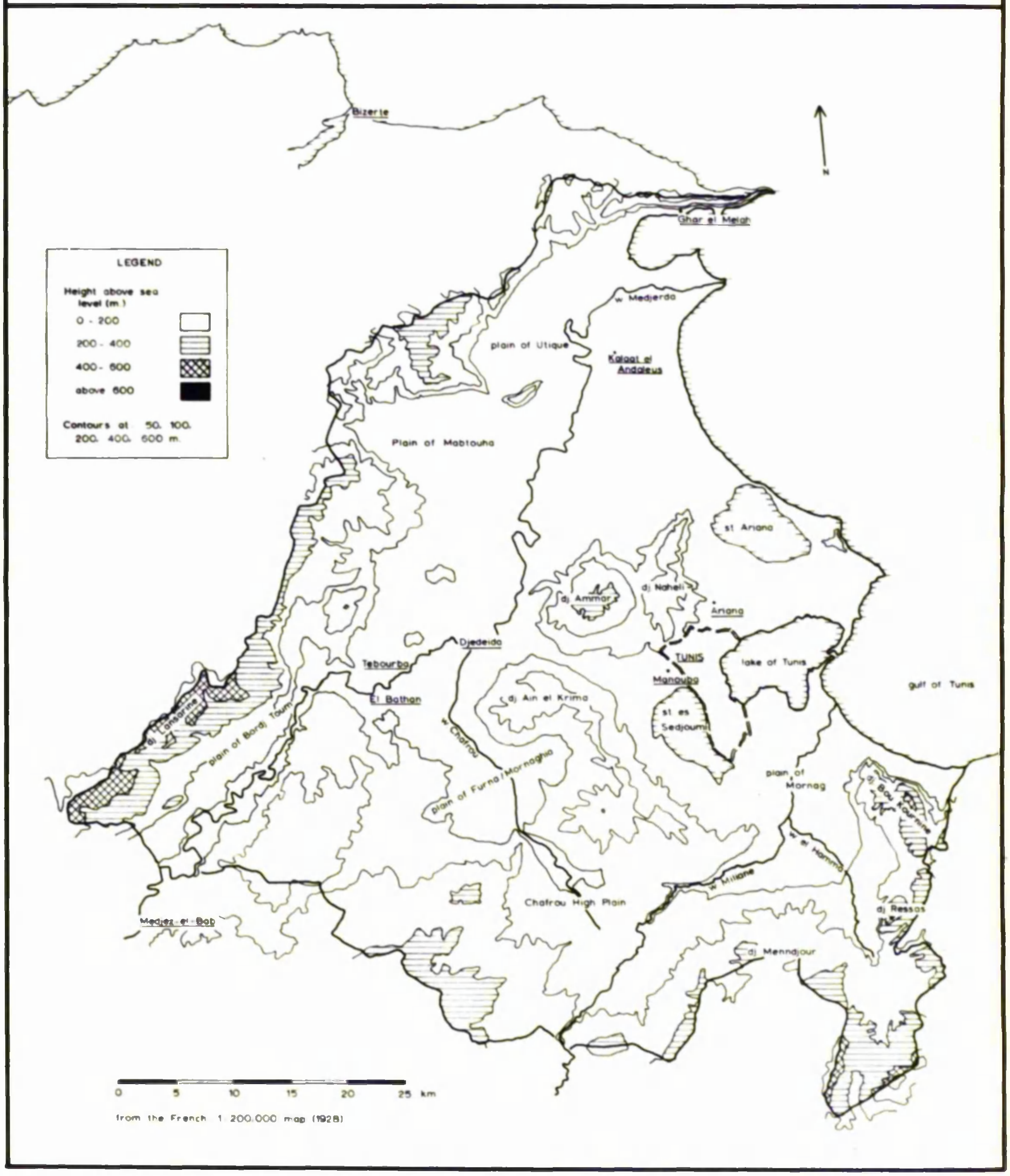
At Djedeida the river bed is eight metres below the plain but the final 15 km. of the river's course are above plain level; raised on natural *levées*.

The Medjerda is probably less important today than during the pliocene. The pliocene deposits (GRONTMIJ, 1961) east of the present delta were at times raised by tectonic movements during the quarternary. The pliocene of *djebel* Ain el Krima, *djebel* Naheli and Gammart are made of clays and sands deposited entirely by the Medjerda.

During the quarternary there have been four or five cycles of marine advance and regression. The last, during the last 2,000 years, has seen the retreat of the sea from Djedeida to the present coast line. In the course of this retreat the lower part of the river slowly moved its bed north to Ghar el Melah. It finally moved slightly south again to its present position and the sea has turned the mouth at Ghar el Melah into a lagoon.

Fig. 16

TOPOGRAPHY OF THE LOWER MEDJERDA VALLEY



The whole of the littoral, but particularly the lake of Ghar el Melah, the marsh region of Bou Ammar and the sebkhet Ariana, is unstable sinking as rapidly as it is being built up by sedimentation. The instability, coupled with the salinity of the soil, makes the land very difficult to reclaim for agriculture. At best it is fit for rough pasture land.

In contrast to the littoral some regions have been raised. The hills of Kalaat el Andaleus and Utique and the small rounded hills south of Protville are uniform clays deposited in the sea but transported by the Medjerda in a period before the quarternary.

All the alluvium of the delta originates from the Medjerda catchment area but the marine deposits, whether clay or sand, tend to be uniform and without stratification. The river deposits are very varied. In general the finest, which are the least permeable to rain or irrigation, are nearest the sea.

The last marine transgression is seen in the soil profile at 15-18 m. by Djedeida but at only 2 m. near Kalaat el Andaleus. This is important for cereal farming because the heavy concentration of salt in the marine levels has been forced by compression into all other levels, especially where they are coarse. The upper level of terrestrial alluvium is relatively salt free - except where the water table comes very close to the surface - but none of the ground water can be used for irrigation because it all contains more than 3.0 gm/li. of soluble salts (Droque, 1966A). A deep bore at Kalaat el Andaleus to 368 m. found no fresh water but the bore did not reach the terrestrial pliocene which may contain fresh water. This terrestrial pliocene in the hills outcrops as pliocene sandstone which border the plains to north and west. But this stratum has to small an impluvium to hope that the pliocene below the plains will contain much water.

A little pure ground water has been tapped all along the fringe of hills to the north and north-west of the delta. It is this which has made possible the long-established tradition of irrigation in the villages of Ghar el Melah, Aousdja, Zouaouine and Zana/Utique. But deepening the wells could take them down to the saline stratum. At Kalaat el Andaleus and Chaouat water has been found in quarternary sandstones but the quality is only medium to poor (2.0 gm/li.). Drawing heavily on the supply would bring more saline water from the surrounding areas.

<u>The Medjerda Valley: Bordj Toum</u>. Bordj Toum lies near the centre of an alluvial plain extending from Medjez el Bab to Tebourba (Fig. 16,p.77) on the left bank of the Medjerda river. The plain inclines north-west towards the <u>djebel</u> Lansarine (Pte. 4,p. 80) which rises to 596 m.

Most of the alluvial deposit in the valley is pliocene which outcrops in the north-western part of the plain, against the hill slopes. These deposits tend to be coarser; more permeable than the quarternary alluvium through which the river now runs. The hill crests of the <u>djebel</u> Lansarine are largely triassic and contain saline deposits.

In the plain the water table has been raised by the barrage at el Arroussia. Because of this the permeable pliocene underlying the quarternary alluvium should be richer in water which may be pumped from wells. But once again (Drogue, 1966C) the water is saline; 3.0 gm/li.

<u>The Medjerda Valley: Right Bank, Medjez el Bab to Tebourba</u>. Geologically the right bank of the Medjerda from Medjez el Bab

Pte. 4. Plain of Bordj Toum from the Djebel Lansarine

source: Dutton, summer 1969

The contouring, and tree planting, of the djebel Lansarine was done by the OMVVM.

The Medjerda river is in the middle distance.

to Tebourba is characterised by a cover of continental pliocene broken only by a thin layer of quarternary alluvium in the northern plains of el Mansoura and Saida. There is no equivalent to the wide inclined plain of Bordj Toum. The hills rise sharply from the Medjerda flood plain.

The most important features are two ranges of hills, parallel to each other and to the Medjerda, running south-west to north-east; and forming the flanks of a synclinal basin. On the hills are outcrops of oligocene sandstones (GRONTMIJ, 1961) which in the syncline are covered by pliocene deposits up to 30 m. thick. The western flank of the djebel Assoud anticline plunges under the Medjerda river.

The Medjerda valley is straight and narrow, although the river meanders, following a series of recent faults. At Tebourba the river turns east along a system of east-west folds, of which the Manouba syncline is the eastern extension. The pliocene of the djebel Ain el Krima is layered horizontally in its central part but plunges northwards beneath the alluvium of the Manouba syncline.

East of Medjez el Bab the upper cretaceous limestones lie on the surface and incline to the north. On the djebel they are replaced by oligocene strata of sandstones and marl with sandstone forming 50% of the profile in regular strata 2 m. thick. Elsewhere the superficial rock is formed from complex and irregular strata of sands, marls and clay which are either pliocene or quarternary in origin. South of el Bathan is a 6.5 m. stratum of pliocene/quarternary gravels.

Aquifers are found in the oligocene sandstone as well as the more recent rocks. But the sandstone has a limited impluvium and the aquifer forms only 50% of the stratum. The water from this stratum is extensively used already (note the market garden produce and the vines of the Furna region) and will not yield much more except, possibly, by deep boring through the pliocene in the syncline, between the parallel ranges of hills, to the underlying sandstone. The estate of Montarnaud, on which a deep bore has produced copious water, occupies most of this region.

The pliocene and quarternary have only very weak aquifers. In the Saida/Manouba area the contained water is medium to very saline - up to 3.0 gm/li. or more. The water table is very high and the natural drainage poor.

Penetration of the Ain el Krima is weak because the strata are horizontal. Most of the water floods down the wadi Melah to the Saida plain carrying with it much eroded material.

The Chafrou Valley: 1. Plain of Furna/Mornaghia. The plain of Furna/Mornaghia (Fig. 16, p. 77) has its long axis cut by the Tunis/Medjez el Bab road, from Mornaghia to Furna, and its short axis cut by the middle valley of the wadi Chafrou.

The central part of the plain is covered with quarternary alluvium lying on continental pliocene sediments of similar nature. These outcrop at the edge of the central plain. In the hills flanking the plain are seen cretaceous and tertiary deposits in which the strata are very varied and not well defined. Strata and lenses of limestone, marl and sandstone are present. In general a calcareous crust of recent origin is found round the border of the plain. This has to be broken, by deep subsoiling, to obtain the best results from all crops; annuals as well as vines and fruit trees.

Near Bordj el Amri water is pumped from cretaceous limestones. Elsewhere only the pliocene and quarternary deposits are important as aquifers. In general the strata of sands and gravels capable of acting as water reservoirs are not important because of their limited extent and slight thickness. But in the lowest part of the plain, where the water table is very high, some wells are used for irrigation although the water contains up to 2.5 gm/li. of soluble salts.

The Chafrou Valley: 2.The High Plain. The High Plain lies over 50 m. above sea level for the most part. It is quarternary in origin, consisting of alluvium 20-30 m. thick. Similar conditions prevail in the Miliane valley which borders the High Plain to the East.

A superficial calcareous crust lies under the plain (GRONTMIJ, 1961) though not in the central part. The alluvium is moderately sandy with a sandier stratum at 5-10 m. deep. The hills contain some limestone and sandstone strata which are potential aquifers though the yield of water is low. The water pumped from a number of wells in the plain is saline; up to 3.0 gm. per litre.

The Manouba/Sedjoumi Syncline. The Manouba/Sedjoumi syncline drains naturally into the extremely saline sebkhet es Sedjoumi. The main structural feature of the region is the synclinal trough running east-west. Part of the trough is filled with pliocene continental deposits which appear at the surface to north and south. The centre is filled with quarternary deposits brought by the Medjerda which used to flow east from Djedeida to the gulf of Tunis. During the pleistocene a land slip near Oued el Lill cut off the mouth of the Medjerda (Pimienta, 1953) which turned north to begin depositing its present flood plain. The plains of Chebaou/Ville Jaques may be considered as a valley of a stream flowing into the Medjerda; the alluvium is much less thick.

Because the alluvium is continental it is very varied with both horizontal and vertical alternation of lenses and benches of clay, marls and sand. A calcareous crust, sometimes near the surface is found over much of the plain.

Within the alluvium are layers of sand rich in pure water, especially near Manouba, from which water has long been pumped (Pte. 5, p. 85) for irrigation. The degree of salinity decreases down to about 150 m. deep and then rises. Near the sebkhet the salinity rises to 150 gm/li. or even 200 gm/li.

The Miliane Valley: The Plain of Mornag. The middle course of the Miliane valley is separated by only a narrow south-west to north-east divide from the Chafrou valley. Further downstream the Miliane is narrowly separated from the drainage basin of the sebkhet es Sedjoumi. The river then flows through the lower part of the plain of Mornag before reaching the sea near Rades. Its major tributaries, of which the most important is the el Hamma draining the eastern and southern parts of the Mornag plain, are all on its right bank. The river plain is bordered to the east by the mountainous peaks of the djebel Bou Kournine and the djebel Ressas (795 m.) and to the south, between the Miliane and the el Hamma, by the djebel Menndjour.

The triassic is well represented but the hills are characterised by pliocene deposits. Hill crests may be oligocene sandstone which features predominantly on djebel Menndjour. The river valleys and the Mornag plain consist of pliocene alluvium overlain by quarternary deposits of similar structure.

The area is rich in ground water. The sandstone strata of

Pte. 5. Intensive Farming near Manouba

source: Air survey of Tunisia 1962/63

Intensive farming at Manouba benefits from the proximity of the large market in Tunis. Long-used local resources of irrigation water have now been supplemented by the OMVVM from the Medjerda river.

djebel Menndjour form an excellent aquifer. The water, of good quality, drains northwards under the southern part of the Mornag plain. Wells and deep bores have revealed important reserves of good quality water in the quarternary and tertiary alluvial sands of the east central part of the Mornag plain at Ouzra, Nassen, Cebala and Creteville. Further north and west the water becomes progressively more saline.

The rest of the region is under exploration. It seems likely that other sources of saline-free water will be discovered.

3.4 The Soil of the LMV. The classification of the soils of the LMV has received a great deal of attention because of the importance of the OMVVM and because of the projected expansion of irrigation in the LMV. Under the four main heads of, 'heavy', 'medium', 'light' and 'sandy' the soil potentiality maps of the LMV (SOGETHA, 1968) distinguished 48 separate soil types. Finieltz (1953), on the other hand, distinguishes only seven soil types falling mostly into two groups; the red soils and the grey soils.

Below is a general classification of soil types based on the above studies and the work undertaken by a Dutch company (GRONTMIJ, 1961) on behalf of the OMVVM. Mention is made of the soils' suitability for growing cereal crops but it must be remembered that this assessment depends upon rainfall. To obtain a high yield from a sandy soil a high rainfall evenly distributed throughout the growing season would be required. However the heavy and fertile clay soils would suffer from a high rainfall but tolerate a less even distribution.

Brown Soils. The brown soils, usually found on hills, are calcareous, rendinza in character. They are normally badly eroded, skelatal and of poor quality for growing cereals.

Red Soils. The red soils (hamri) are found on hill slopes. Where the slopes are steep the soil tends to be eroded exposing the tuff subsoil and many stones at the surface. The hardpan is firm, thick and superficial.

Where the land is flatter, with less tendency to erosion, the soils are deep and mature. The level of contained calcium is is small (or even absent) but there is often a hardpan though it is deeper, softer and less thick than in the more steeply inclined slopes. The soils are silt-clay to clay-silt in type, well drained and structurally stable. They are described by the potentiality maps as either medium or light.

For cereal crops they have the advantage of being well drained and of suitable type. They are easily worked without giving large clods. But they are short of humus and they heat rapidly thereby losing their moisture and exposing the cereals to drought. Where the hardpan is firm and superficial the roots do not develop properly which exaggerates the dangers of water shortage in a hot, dry spring.

At the base of the hills are soils of mixed character formed from alluvial soils and colluvions or eroded hill soils.

Red soils are widely spread in the LMV. According to the French farm evaluations most of the farms outside the delta region of the LMV have at least some, '<u>terre hamri</u>'.

<u>Grey Soils</u>. The grey soils, found in the plains, are generally less stable than the red soils. Over a short distance, both horizontally and vertically, their structure and texture can change rapidly.

The lighter soils, which may even be sandy, can be very calcareous. In this case a superficial (20-30 cm.) or medium depth (30-60 cm.) hardpan is a common feature though it is not normally very thick. Where the hardpan is thin or absent these lighter soils can give very satisfactory yields of wheat if the sand is not displaced by wind. They conserve moisture fairly well, if the mineral particles are not too large, and readily yield it to the plants. Excess water easily drains through them. Such soils are not very fertile unless fertiliser is regularly applied.

The heavier, clay, plain soils (clay-silt to clay) do not form a hardpan although the concentration of calcium is still fairly high. The soils are of great depth and very compact; sometimes saline or alkaline at depth. They are usually well provided with mineral elements and even humus in the wetter areas making them very fertile, so long as they are neither too wet nor too dry. Under these conditions wheat will give high yields. When the soil moisture content is very high or low the soil is difficult to work, needing mechanisation and prompt action when the conditions are nearest to ideal.

Where the alluvial plain soils are superficially saline their usefulness in agriculture depends on their texture, depth and degree of salination. At best they can grow pasture, cereals and hardy annuals which can be irrigated so long as the degree of salinity of both soil and water are taken carefully into consideration.

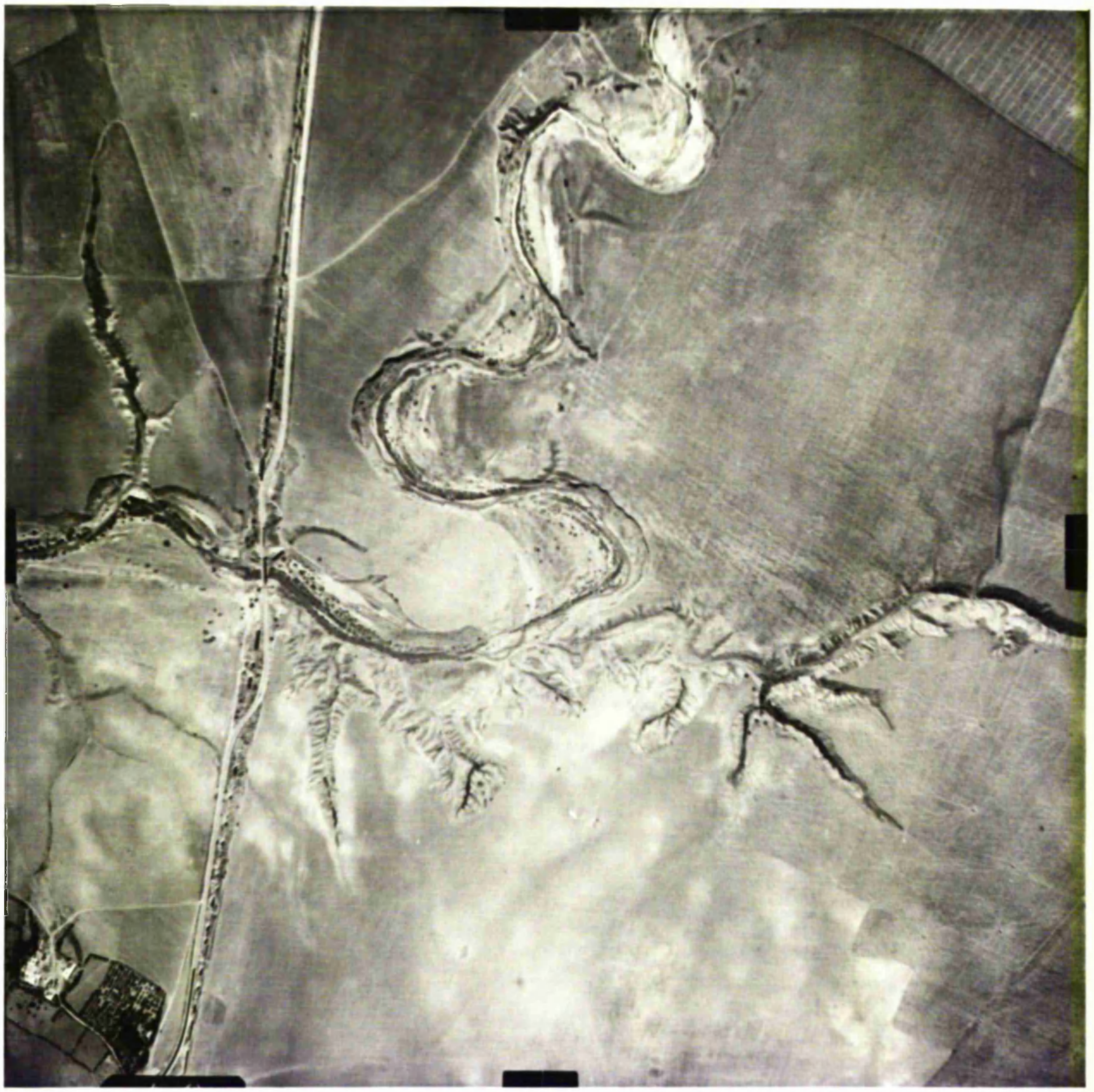
In the LMV the grey soils are widespread along the valleys of the Medjerda, Chafrou and Miliane and in the Medjerda deltaic plain. In the delta the heaviest soils do not lie nearest the river - the *levées* contain a high percentage of larger particles - but in the lowest-lying areas. Near the sea and in the very low-lying plains of Utique and Mabtouha the soils are compact and halomorphic. Their natural vocation is rough pasture.

3.5 The Natural Vegetation of the LMV. The LMV lies in the Punic section of the Mauritano-Mediterranean vegetation type (Poncet, 1956) characterised by the association of Thuya, the Aleppo pine and the Jujube tree. In addition there are thousands of hectares of halophytic plants around the mouth of the river, along the coast and in some inland march areas.

As a result of Man's intrusion (Poncet, 1956) most of this natural vegetation has been destroyed except in inaccessible places and on infertile hills. But some herbs of the natural vegetation type still remain.

The loss of the permanent natural cover of herbs, shrubs and trees has only been partially replaced by agriculture. Vines, fruit trees and market gardens cover a small area while most of the agricultural land is evenly divided between cereal crops and fallow, with the area under fallow somewhat reduced in recent years (see ch. 7.4, p. 244 ff.). Marginal pasture lands have been eaten into by mechanisation and replaced by cereal crops and fallow. This has usually happened on hill slopes leaving them with a greatly reduced protection against rain and wind. In short the replacement of the natural vegetation by agricultural crops and fallow has significantly increased the tendency towards erosion; see Pte. 6, p. 91. The loss of trees has removed an essential barrier against flash-flooding.

Pte. 6. The Wadi Miliane South of Mohammedia



source: Air survey of Tunisia 1962/63

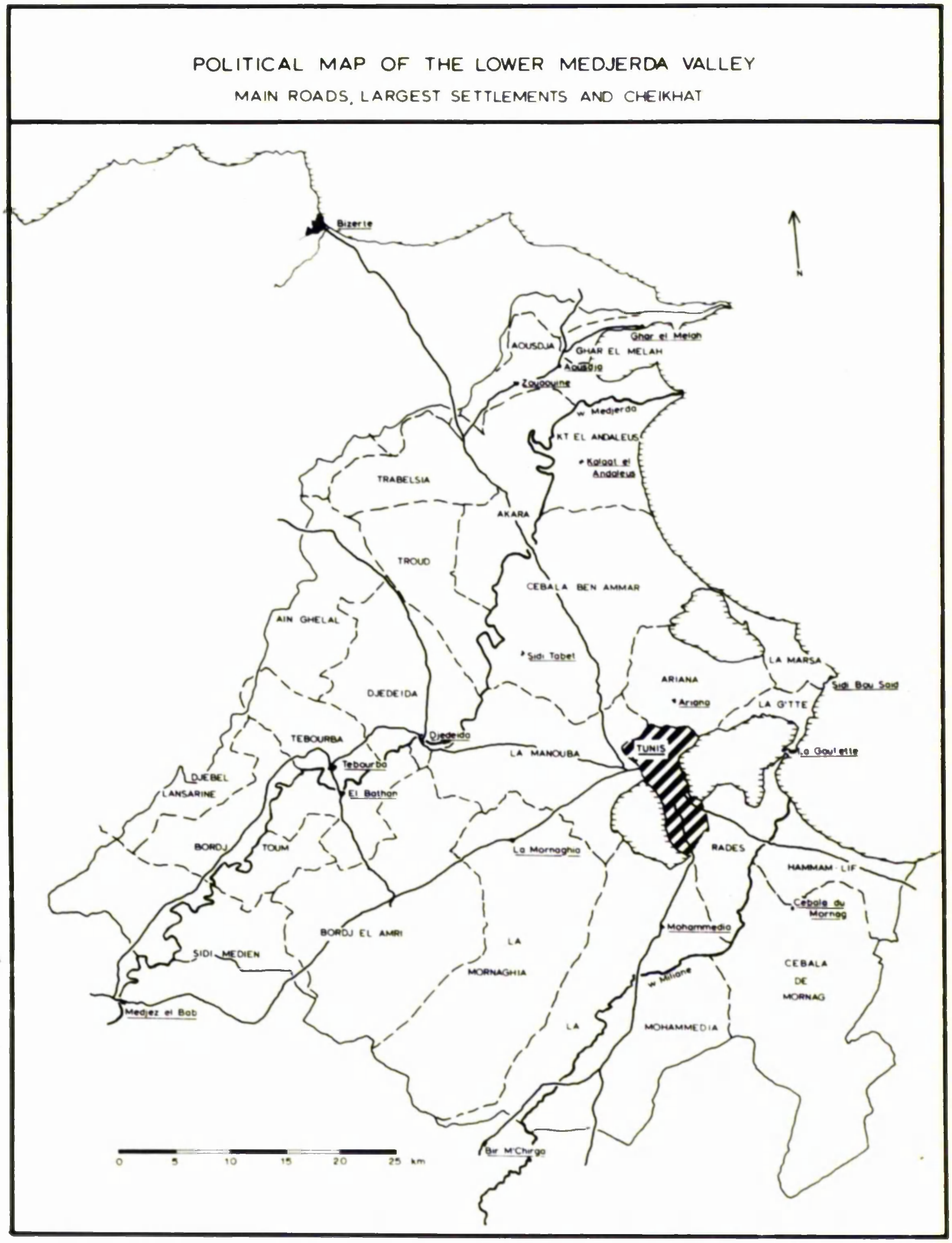
Erosion and gullying caused by the wadi Miliane is increased in this cereal growing region because most of the land has no protective cover of vegetation for 17 months out of 24.

3.6 The Importance of Tunis to the LMV. When Carthage was the major town in Tunisia the Phoenicians controlled the Mediterranean and took their livelihood from sea trade. The Carthaginians took little interest in the hinterland of their town and in fact sited Carthage so that it was isolated from the land by an extension of the sebkhet Ariana (Monchicourt, 1904) to protect it from Berber attack.

By contrast Tunis, an Islamic town, grew to prominence when the land was relatively secure and the main danger was from the sea. It is sheltered in the gulf (Fig. 17, p. 93) which extends between Sidi Bou Said and Rass el Fortass (itself an extension of the Gulf of Tunis) on the westward (landward) shore of the Lake of Tunis. It is thus well defended from the sea yet has direct access to it at La Goulette across the Lake of Tunis. Ships leaving La Goulette have only a short sea crossing to France, Italy and other Mediterranean countries making Tunis a natural avenue for international trade. Because of this Tunis grew rapidly. By 1904, 23 years after Tunisia had become a French protectorate, Tunis had a population of 175,000, including 68,000 Europeans in Tunis and its environs. This made it the third largest town in Africa after Cairo and Alexandria - but bigger than Algiers.

Inevitably the Europeans, particularly the French and Italians, were interested in developing the economic, agricultural potential of the hinterland of Tunis. This hinterland consists of the Plain of Mornag and the LMV. Both were potentially fertile areas though, for the most part, extremely under-exploited by the Tunisians; provided with only a minimal infrastructure and often beyond the effective control of the law.

Fig. 17


POLITICAL MAP OF THE LOWER MEDJERDA VALLEY
MAIN ROADS, LARGEST SETTLEMENTS AND CHEIKHAT
Bizerte
N
AOUSDJA
Ghar el Melah
GHAR EL MELAH
Aousdja
Zouaouine
w. Medjerda
KT EL ANDALEUS
Kalaat el Andaleus
TRABELSIA
AKARA
TROUD
CEBALA BEN AMMAR
AIN GHELAL
Sidi Tabet
LA MARSA
ARIANA
Sidi Bou Said
Ariana
LA G'TTE
DJEDEIDA
TEBOURBA
Djedeida
LA MANOUBA
TUNIS
La Goulette
Tebourba
DJEBEL LANSARINE
El Bathan
BORDJ
TOUM
La Mornaghia
RADES
HAMMAM - LIF
Cebala du Mornag
Mohammedia
BORDJ EL AMRI
LA MORNAGHIA
SIDI MEDIEN
CEBALA DE MORNAG
w. Miliane
Medjez el Bab
LA MOHAMMEDIA
0 5 10 15 20 25 km
Bir M'Chergo

Once the French had started land purchase (see ch. 5.1, p. 119ff.) the area was rapidly brought under the law and, by 1904, a network of roads and railways had already quartered the entire area. Agricultural produce could be transported quickly and cheaply to Tunis. Here was a large and expanding home market and also the port, Tunisia's major outlet for agricultural commodities.

The presence of Tunis was beneficial to the LMV in other ways as well. Firstly as the major port for importing agricultural equipment and fertilisers and, secondly, as the principal research and agricultural training centre. The results of research work done at Ariana were naturally of most relevance to the area of the country surrounding Tunis.

PART II

HISTORY AND DEVELOPMENT OF CEREAL AGRICULTURE IN THE LMV.

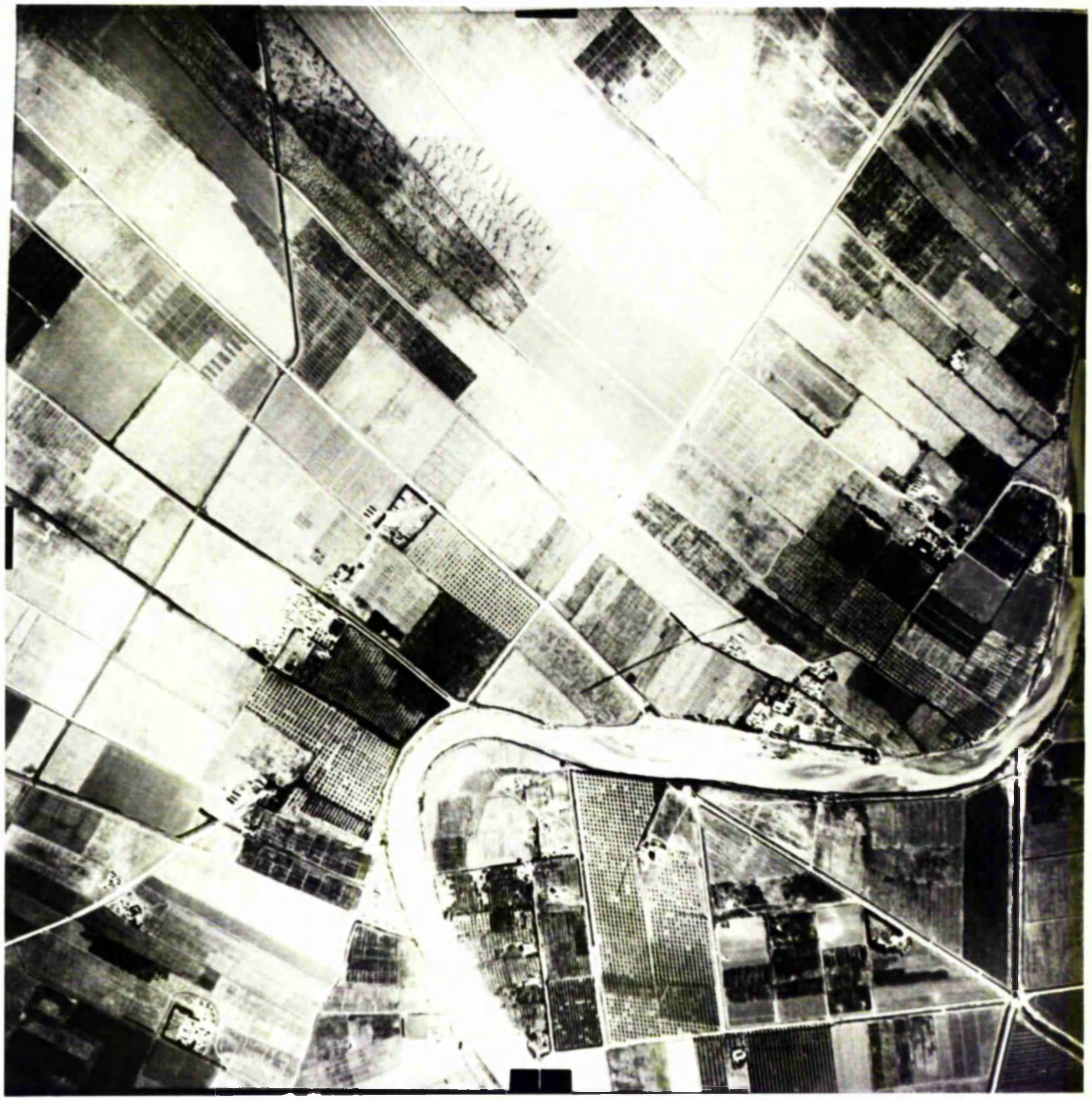
This second section of the thesis is concerned with the dry-farmed part of the LMV or, more correctly, the part which lies beyond the reach of irrigation water. Up to 1948 this included the whole of the LMV with the exception of narrow strips of land either side of the major wadi (Pte. 7, p. 97) - the Medjerda, the Chafrou and the Miliane - which were insecure sources of irrigation water because they were liable to flood. Other irrigable areas lay above accessible, salt-free aquifers. These, mostly in Mornag and the region immediately to the west of Tunis, were being tapped to irrigate vines and market garden crops.

Throughout most of the rest of the LMV the aquifers were either too far below the soil surface or too saline (Dutton, 1968, pp. 37/38) to be useable. In this area, necessarily dry-farmed, winter cereals played the dominant role in crop rotation.

In 1948 a start was made to the development of the LMV (Dutton, 1968) which, up to 1970, had brought an additional 12,000 ha. within reach of irrigation. This is only 4% of the total area of the LMV and 7% of the cereal growing area. Even if the planned total of 33,000ha. is finally brought under irrigation it will still leave most of the agricultural land under some sort of dry-farming regime.

For this reason, although the conclusions of this section are drawn from a study of the colonial period up to 1964 (when European land was nationalised) the lessons are still relevant today and will remain relevant in the future. For most farmers the principal question will be one of coming to terms with the climate in order to fully exploit the land; overcoming as far as possible the limitations imposed by the irregular Mediterran-

Pte. 7. Intensive and Extensive Farming near Djedeida



source: Air survey of Tunisia 1962/63

The narrow strip of land bordering the Medjerda is irrigated, growing annual crops and fruit trees. Further from the river, north-west towards Chaouat, cereals predominate.

ean rainfall (see ch. 3.1, p. 48ff.) and the high summer temperatures, without endangering the fertility of the soil.

This was the question which the French colonists set themselves to answer during the period 1881 to 1964.

The aim of this section is therefore to examine the answers which the French gave; to see whether they came close to the border between fully extending and everextending their land and to see whether, and to what extent, they were able to overcome the problems imposed by the local climate in order to use it to their own advantage. It will be pertinent to see whether in the course of their work the French hindered the development of cereal agriculture overall, as has been suggested by Poncet, by putting the Tunisian farmer's land in jeopardy.

CHAPTER 4

AGRICULTURE BEFORE FRENCH COLONISATION

4.1 Introduction. A brief account of the history of agriculture in Tunisia, and particularly the LMV, from Roman times serves to illustrate the agricultural potential of the region. This potential together with French experience in Algeria were factors which encouraged both land purchase and European farming in the LMV and in Tunisia as a whole.

A more detailed look at the agricultural situation immediately before the arrival of the colonists explains why the colonists were able so easily to acquire land and penetrate deeply into the country. In the LMV French land purchase was not evenly distributed throughout the area. It will be argued that this inbalance cannot be adequately explained on the assumption that the colonists bought only the best land. The distribution of European farms within the LMV is partially explained by the study of indigenous agriculture at the time of colonisation.

4.2 From Rome to the 19th. Century. The French were not the first to see or attempt to realise the agricultural potential of the LMV. The quality of the land had been proved and a rudimentary infrastructure of villages, roadways and bridges established by a succession of colonising powers from the time of the Roman empire onwards.

Numerous ruins, including Utique, testify to the use of the Medjerda valley in Roman times. But the security of the valley was constantly threatened by the Berber inhabitants of the hills and against them the Byzantines built many forst e.g. Béja, Teboursouk and Ain Tonga.

After a period of insecurity at the start of the Arab invasion (650-700 AD) first the Aghlabids then the Fatimids gave priority to agricultural development. El Bekri, an Andalusian geographer, wrote; 'Béja is named the granary of Africa. Its territory is fertile, its cereals are so good and the harvests so large that all the foodstuffs are at a very low price'. (quoted in Pellegrin, 1955).

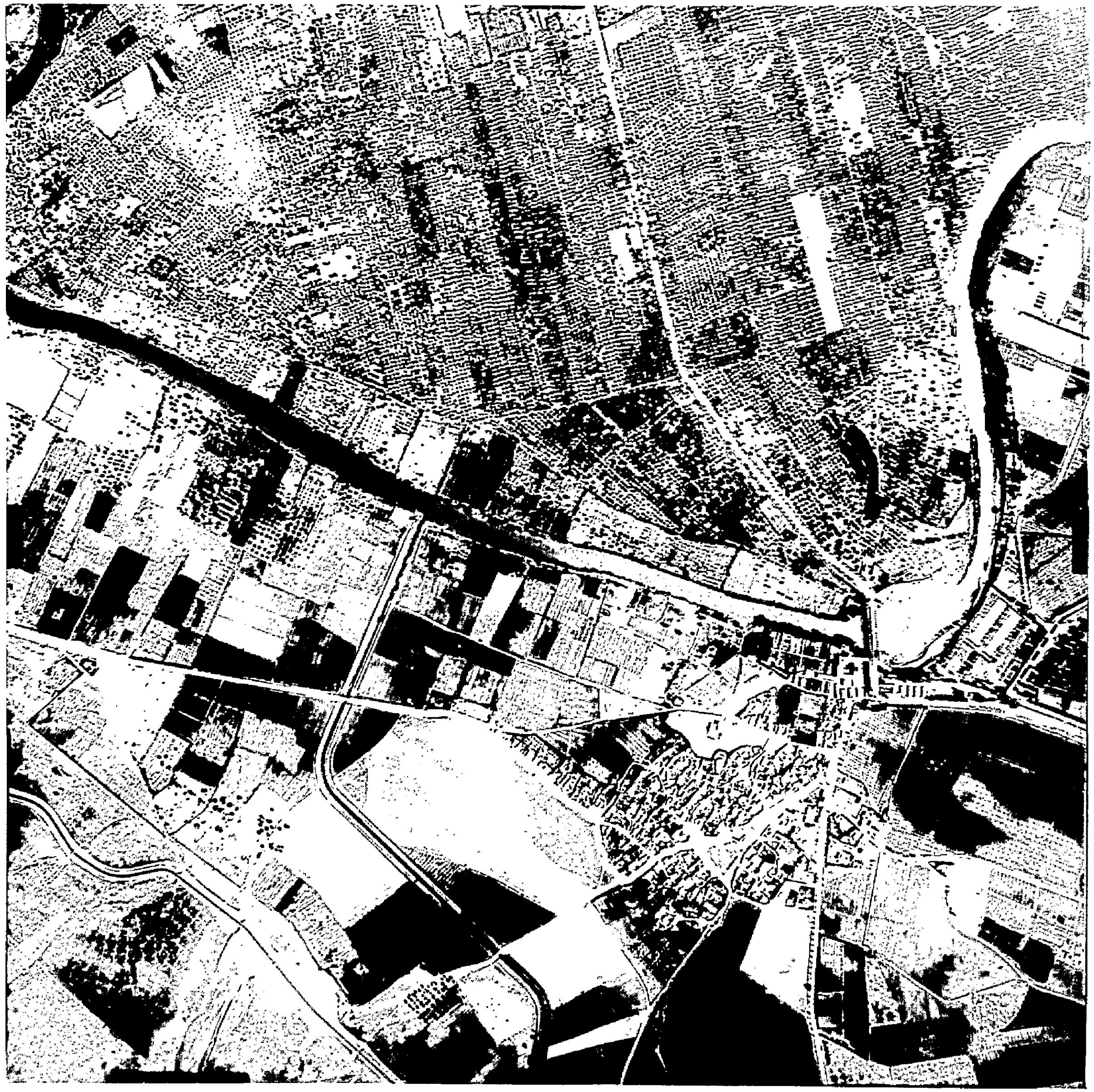
But in the 11th. Century the Beni Hilal from Egypt destroyed the prosperity though Béja maintained a shadow of its wealth. Under the Hafeides no town was mentioned by Arab chroniclers; urban life had retured before nomadism and the all conquering scrub.

The Turks (1574-) reintroduced some order and improved the valley because they assigned land to Andalusian Moors chased from Spain at the beginning of the 17th. Century. Many of these Moors were farmers and they restored life to the Medjerda growing fruit and market garden produce and rebuilding the towns of Testour, Slouguia, Medjez el Bab, Tebourba, Djedeida and Kalaat el Andaleus amongst others. Communications across the LMV were improved by building three bridges at el Bathan (1616-1622 AD), Medjez el Bab (1677 AD) and at Djedeida (1699-1700 AD). See Plate 8, p. 102.

But much of the valley was left uncultivated and the economy was closed. In consequence by the 19th. Century, according to Pellegrin (1955); 'most of the inhabitants of the valley lived in tents or gourbi. The Andalusian villages were decaying and even Béja offered an appearance at once both hideous and desolated'.

Agriculture was not only in decline but the valley, outside the villages, lay beyond the law. To add to these problems the river was virtually uncontrolled (see ch. 3.2 p. 69ff.) so that flooding was a cpnstant winter hazard bringing malaria and other diseases in its wake.

Yet, in spite of the depressing overall picture, a closer examination of the indigenous agriculture at the time of colonisation shows that conditions were far from uniform from region to region.



Pte. 8. Olive Forest at el Bathan

source: Air survey of Tunisia 1962/63

Ancient olive trees irrigated by water dammed behind the Andalusian barrage, right, at el Bathan. The olives, now unproductive, are being uprooted by the OMVVM.

4.3 Indigenous Agriculture at the Time of Colonisation in 1881.

A regional study of indigenous agriculture in the LMV, before the arrival of the colonists, illustrates the geographical conditions needed to allow agriculture to thrive at a time when the central authority was weak and the level of agricultural technology low. These conditions were present in some parts of the valley and conspicuously absent in others.

Where agriculture was being successfully practised the French were virtually unable to buy land but in other areas colonisation was both rapid and dense. The colonists were only able to buy land where the owners thought it more profitable to sell than to exploit.

Where there is a strong sense of attachment to the soil, where the traditional structure of a settled society has not been disrupted for several generations, and where the individual or the village lives primarily from crops grown, then it is normal that productivity is relatively high and dependable from year to year.

A dependable yield, under the extremely unpredictable Mediterranean climate, normally calls for some control over the supply of water to the soil. In a highly mehanised farming community the soil can be made to act as its own reservoir by the rigorous application of dry-farming techniques but elsewhere the exploitation of a source of running water is required. This might be a spring, a river or a well. Rivers have particular advantages and disadvantages. They contain more water so that they can irrigate more land but, in the Mediterranean region, rivers are either low or stop flowing altogether in the driest months of the year (see ch. 3.2 p. 72ff.) and are liable to flood, thereby endangering both crops and people, in winter. Where such rivers have been successfully used for irrigation by people with a low level of technology they have made use of peculiar topographical structures and relief to make them more secure against flooding.

Successful agriculture also depends on security against loss of land to creditors or invaders. Protection must either be given by a strong central authority or by the topography of the country. It is no accident that one of the regions more renowned for good traditional agriculture, which lived on into the 20th. Century, was in the mountainous region of the Kroumerie (Poncet, 1961B) where neither the 19th. Century brigand nor the 20th. Century colonist tractor could penetrate. Here one still finds the practice of intensive farming dependent on long used skills of damming water, conservation of the soil, construction of terraces and canals and the growth of plantations and market gardens.

Successful Indigenous Agriculture in the LMV. The fact that some successful indigenous agriculture could be found in the LMV was established, in 1906, when the government decided on a general survey of the protectorate. The survey was not done with a view to collecting precise statistics of the agricultural situation so that the reports on each contrôle are a summary of the impressions of those in charge of the work. In the report on the contrôle of Tunis Violard (1906) praises the use of irrigation by the indigenous population; an example often ignored by the colonists. Violard wrote (p. 197) that; 'in all parts of the contrôle which can be irrigated the natives have created beautiful orchards planted with fruit trees; olive groves are found in large number'; Ptes. 9 & 10, pp. 106-107.

All the springs of the _djebel_ Lansarine were being used for irrigation.

Near to Tunis, and in other areas rich in underground water, there were many small, flourishing properties (_melk_) which produced vegetables, fruit, olives, wheat and animal products; mixed farming dependent on available water. The farmers near to Tunis (Pte . 5 , p. 85) or, more specifically, in the Manouba syncline, enjoyed the advantages not only of the largest resources of salt-free water in the LMV, which could readily be drawn from shallow wells, but of the protection and the market facilities afforded by Tunis.

Other examples of successful indigenous agriculture in the LMV were only to be found in the mountainous extremity of the valley at _djebel_ Lansarine and near the mouth of the Medjerda river. In both areas good supplies of irrigation water had long been used for intensive agriculture and market gardening.

Other factors had made these areas unattractive to migrant populations. The factors are, in the case of the _djebel_ Lansarine, the mountainous terrain and, in the case of the Medjerda mouth, the twin dangers of flooding and malaria. The latter explain why very little land was purchased by the French in the _cheikhat_ of Ghar el Melah, Aousdja and Kalaat el Andaleus. The main villages in these _cheikhat_ (from which the _cheikhat_ takes their names) had, and retain, a strongly independent spirit, and they are also renowed for their agricultural produce - particularly potatoes (Ghar el Melah), tomatoes, peppers and melons. In Kalaat el Andaleus these crops are watered from the Medjerda. In the other two _cheikhat_ water

Pte. 9. Private Irrigation from the Medjerda: Tractor Pump

source: Dutton, summer 1969

The tractor has replaced traditional means of raising water from the bed of the Medjerda.

Pte. 10. Private Irrigation from the Medjerda: Earthen Aqueduct

source: Dutton, summer 1969

Water, pumped from the Medjerda, is carried in a hand-made earthen aqueduct to irrigate vegetables and fruit trees.

was taken from shallow wells dug at the foot of the hills bordering the north and north-western flanks of the LMV.

A detailed study of one of these _cheikhat_, Kalaat el Andaleus, amply illustrates the cohesive strength of the society based on long-established ties between families and the land they cultivate, when irrigation resources are readily available.

Kalaat el Andaleus is one of the most densely populated _cheikhat_ of the LMV (80 people/sq.km. in 1956). Only one European farmed land in the _cheikhat_ - a farm which formed most of the Farm Group of Kalaat el Andaleus in this study - and even he did not fully own the land he cultivated.

Geographically important features which account both for the density of the population and the relative intensity of agriculture include the steep-sided hill on which the village was built, making it secure against even the worst floods and allowing it to benefit from the cool maritime breezes in summer. The proximity of a large market in Tunis is an important factor. Finally the proximity of the river, which is raised on _levées_, allows for cheap gravity irrigation (Pte. 11, p. 109) once the water has been lifted from the river bed.

The agricultural land was also protected from flooding because at this point of the river's course the land level was considerably higher on the right bank than on the left bank so that flood water drained away from Kalaat el Andaleus into the plains of Mabtouha and Utique which were the lowest-lying parts of the whole river valley.

The clay-sand soils are good for market garden produce, particularly tomatoes and melons which are popular in this region. Unfortunately the lowest-lying areas (some 1,200 ha. of

Pte. 11. The Medjerda River South of Kalaat el Andaleus

source: Air survey of Tunisia 1962/63

A new mouth of the river (lower right-hand corner) was opened by the OMVVM to reduce the risk of flooding from the main river. Land near to the river's left bank is irrigated but the traditional irrigation network only extends the length of the levées. There is no irrigation on the right bank which is raised above the general level of the plain.

the 7,000 ha.) are saline and good only for rough collective pastures.

Actual ownership of the land (Aouani, 1965) has undergone considerable change during the past 100 years. Before them most of the village and the land belonged to members of the Beylical family. After colonisation this land was sold to speculators living in Tunis but later resold, at a greatly inflated price, to the peasant farmers in small units of 10-20 ha.

Where private habou (some 800 ha.) was owned by absentee landlords the land became the property of the mokaddem; they later had the full melk ownership granted to them in 1926, instead of the uncertain 'right of occupation'. Where the private habou was owned by peasants the land tenure was in practice melk and the farms extremely sub-divided (Pte. 12, p. 111); a common feature of Middle Eastern agriculture where land has been continuously cultivated for generations.

The land is divided extremely unequally between the owners,

Table 18. Pattern of Land Tenure at Kalaat el Andaleus.
source: Aouani, 1965

Area(ha)	Nos. of Owners	%	Total Area	%
-1	127	27	64	1
1-2.5	126	27	221	3
2.5-10	131	28	724	11
10-100	71	16	2312	34
100-	10	2	3594	51
Total	465	100	6915	100

Table 18; only 2% of the farmers own 51% of the land.

The 1962/63 agricultural census showed that 1/5 of the land is irrigated; the percentage rising to 26-35% on farms of less than 10 ha. About 60% of the land was under cereals, legumes or

Pte. 12. The Village of Kalaat el Andaleus

source: Air survey of Tunisia 1962/63

The village is on a hill crest overlooking the plain. The land near the village and adjacent to an old river bed of the Medjerda is extremely subdivided, irrigated and intensively cultivated. It is mostly melk land.

fodder crops.

Poor Indigenous Agriculture in the LMV. The regions of the LMV where irrigation water could not be obtained presented a very different picture from the above. Here none of the conditions necessary for good traditional agriculture were present.

There was no sense of social cohesion in the areas south and south-west of Tunis, in the Chafrou valley and the LMV proper. In 1904 Monchicourt described the population as very mixed: 'A veritable dust of tribes deposited bit by bit during the centuries', with no coherence and, often, little attachment to the soil.

This mixture of ethnic elements is related to the fact that the region is low lying and easily accessible. The major routes (Fig. 17,p. 93) from Tunis to Zaghouan and the South, and Tunis to Medjez el Bab and the West lie across it. Tunis itself, is a natural pole for migrant populations and colonisers from the north to settle near. And the LMV which has the added attraction of being a potentially rich agricultural region, is thus fully exposed to any movement of population. It has only been effectively farmed when the government has been strong and stable.

The rapid colonisation of this region by the French and the success of their agriculture may be seen in these terms. Some 5/7 of the land here was sold to the French, and French and Sicilian villages sprang up amongst the newly cultivated lands. By 1901 Europeans had bought 133,000 ha. of land (Monchicourt, 1904) of which 111,500 ha. were owned by the French. Much of this land, divided into henchirs, had been owned by the

Beylical family and the bourgeoisie though it was normally farmed by the khammes.

The main factor making this part of the LMV difficult to cultivate was the lack of water. Firstly it received less rainfall (Fig. 7, p. 51) than the northern cheikhat at the mouth of the Medjerda or the djebel Lansarine in the west. Secondly it had very little access to additional water; there were no rivers or springs and very little subterranean water that was not too saline to use. As a result success or failure in any year was entirely dependent on the climate; a low rainfall could mean no yield, landing the farmer in debt from which, all too often, he never emerged.

The general picture of agriculture in this region is clearly summarised in the report by the Northern Sub-Committee of the, 'Commission de l'Amelioration de l'Agriculture Indigène', (Decker-David, 1911) published in 1911.

The only hopeful comments were made about the few larger farmers who farmed their own land - 'Those who farm themselves are sufficiently advanced in mind to do some cultivation in the European manner' (p. 539) - and about the agir, or labourer, who usually prefered to work for a fixed salary than risk the dangers of the khammes. The agir were normally found on the colonists' farms.

The landowners are described as indolent and often in the hands of money-lenders: 'These owners generally have only a very moderate taste for the life on the fields; that of the town pleases them more and retains them there. They go from time to time to visit their lands which they leave under the care and direction of a ouakaf, or which they let to a principal tenant who sublets what he does not cultivate himself to agriculturalists living on the estate, or he gets a khammes to work the land' (p. 539).

In practice the khammes worked about 4/5 of all land. He could lease land for only one year at a time and the owner gave him the necessary advances to cultivate it. But the khammes only received 1/5 of the harvest and unfortunately: 'this gain only very rarely permitted the khammes to pay the debt which he had contracted from the owner; it was impossible for him to free himself, he remained a slave; serf attached to the glebe' (p. 541).

The peasant who rented land was in the same position and it was thus impossible for him: 'to make improvements, to cut the scrub, to clear the land... through lack of resources and, above all, because of the short duration of the lease' (p. 541).

In summary the report concluded that: 'There emerges an unequivocal feeling of discontent and decadence... in the region of the North of Tunisia. Local agriculture is far from being prosperous; the price of land, the lack of fertiliser, incompetence and lack of knowledge of scientific agriculture and above all the lack of capital are the primary causes of this atrophy... IThe farmerI continually cultivating his land without rotation, renewing each year the same crop on the same field, always ploughing the same small thickness of soil with his primitive plough, never applying fertiliser, has thereby achieved a constant reduction of the yields of his harvests' (p. 545).

A very revealing account of the impact of colonisation on the indigenous agricultural system was written by Mottes (1925), the contrôleur civil at Medjez el Bab during the critical period 1900-1925. Only part of the contrôle of Medjez el Bab lies within the area of the OMVVM. But although most of the area occupied by the OMVVM was, at this time, the contrôle of Tunis other contemporary accounts (Monchicourt, 1904) suggest that the situation in Tunis was identical to that described by Mottes.

In 1900 the Beylical family, ministers and wealthy bourgeois from Tunis owned vast estates in Mejez el Bab which they did not cultivate but rented out to tenants or khammes. It is not surprising that Mottes (1925, pp. 7/8) reported that; 'these estates yielded little to their owners. Those who cultivated them lived frugally. They had neither the will nor the means to clear the scrub which covered the countryside'. The farm tools could not cultivate the heavy rich land so the farmers crudely cultivated the lightest and the poorest, sandy, alluvial soils.

The landowners generally sold to the colonists land which appeared to them most difficult to cultivate either because of the nature of the soil or the problem of clearing the scrub, or because the land lay beyond the protection of the law.

The habou land, 42,000 ha. in Medjez el Bab, was farmed worse even than the private estates. The people with rights in the habou could sell them annually to the highest bidder in auction. Usually the buyer was a man not interested in farming who sublet to the peasant on the land at a very high price. If the latter was not prepared to pay the price he was moved off the land. The peasant, usually a khammes, could not leave the land if he wished because he was normally tied by perpetual debt.

Under these conditions it is not surprising that almost no attempt was made to improve the land or the crops grown in it. Yields were low and irregular; aften falling to zero in an unfavourable year. Thus owners of the large <u>henchir</u> willingly sold to the French buyer.

When discussing the cereal growing regions of the LMV at the time of colonisation Poncet rightly criticises the absentee landlord but paints a falsely optimistic picture of peasant cultivation (1961B, p. 130) saying that: 'the poverty itself of the means employed by the people as well as the low density of rural exploitation, the character at the same time extensive and itinerant of the cereal cultivation considerably attenuated the destructive effects of the ploughing and the denudation'.

He added that the people did not feel constrained to clear and plough the soils whose poor quality they knew.

In fact the attenuating circumstances which Poncet attributes to the poverty of the people should be attributed more to the small population; there was no need for intensive or non-itinerant cereal agriculture. On the other hand Mottes has made it clear that the constraints on cultivation were distance of land from the village and the ability of the primitive plough to turn the soil. Doubtless the sandiest soils were not used, there was no pressure to do so, but neither were the rich heavy soils which were to yield so highly in the subsequent years.

4.4 Conclusions. The only bright spots in the picture of indigenous agriculture at the beginning of the colonial period were where relatively small areas of land were 'privately' owned (melk) and farmed by the owner and his family. Springs and underground sources of water, where they existed, were tapped to create flourishing mixed-farm economies.

In these parts of the LMV the colonists found it very difficult to buy land and farm. Their density of penetration in, for instance, the mountainous djebel Lansarine or in the cheikhat lying beneath the northern hills and round the mouth of the river Medjerda, was very low although the indigenous farming communities had proved the soil to be stable and fertile.

Further from the towns, and beyond the range of springs and wells, agriculture lay in ruins. Both economic and social conditions militated against any improvement taking place. Yields of cereal crops were extremely irregular and very low for many reasons. All operations were done late and inefficiently using the least fertile and the most drought prone soil.

The principles of crop rotation, use of fertiliser and dry-farming were either unknown or ignored. The varieties of cereals used were of the most 'rustic', suited to local conditions only in so far as they were able to withstand the crudities of local agricultural practice and produce any yield at all.

The situation was so bad that it could never be self righting..Land owners felt it more profitable to sell than to keep running their land at a loss. They sold what to them appeared to be the most unpromising land to cultivate; the land covered by dense scrub which they could not clear, the land which was too heavy for their simple ploughs to till, and the land which lay so far from the villages that it was beyond the protection of the law. To cope with these problems a new dynamic agricultural force was needed (protected and encouraged by an effective central authority) to effect the fundamental changes required. This force was to be provided, complete with its inherent faults, by the French colonisation of the country.

CHAPTER 5

THE EXTENT AND IMPACT OF COLONISATION

5.1 The General Effect in Tunisia. French commercial interests in Tunisia (McKay, 1945) date back to the 12th. and 13th. Centuries. By 1800 there was a French community in Tunis of about 100 people. Their interest was concerned with trade and other commercial ventures but not with land.

After the middle of the nineteenth century France and other European powers were pressing for commercial 'concessions'. This paved the way to raising loans for Tunisia and so to Tunisian bankruptcy and the establishment, in 1868, of an International Control Commission, under France, Italy and Britain, to watch over Tunisian affairs.

The French, and the Italians, were becoming more interested in the purchase of land and so in 1871 the Bey signed a treaty allowing French citizens to purchase property in Tunisia. Subsequently similar concessions were granted to Britain, Austria, Prussia and Italy. However it was the French, individuals and companies, who were responsible for nearly all land purchase although easily the highest percentage of immigrants was Italian.

The need to protect the largest of these land purchases, notably the 100,000 ha. Domaine of Enfida, was an important immediate reason leading to the declaration of the protectorate in 1881.

Up to 1892 (Poncet, 1961A) land purchase continued at the rate of 20,000 ha. to 30,000 ha. a year. The development of this land was usually not done by the French, who were buying for speculative resale, but by the Italian immigrants who already outnumbered the French.

The French government was taking an increasing interest in expanding and directing colonisation of the soil. One of its main aims was to enforce French development of French-owned land. A succession of laws was passed to overcome the restrictions on the sale and cultivation of private and public habou.

By 1946 not only did the French and other colonists own 1/5 of the cultivated land but this land lay in the most fertile regions of the country. Of the 270,000 ha. of arable land 225,000 ha. were in the north whilst 190,000 ha. of the 210,000 ha. of European owned plantation land lay in the Steppe; mostly around Sfax.

With the expansion of foreign commercial and agricultural interests so the non-Tunisian population of Tunisia grew. The

Table 19. Evolution of the Population of Tunisia 1881-1956. ('000).

source: Chevalier, 1957

Year	French	Other European	Tunisian and other Muslim	Total
1881	2	19	1500	1520
1921	55	101	1938	2094
1936	108	105	2395	2608
1946	144	96	2991	3231
1956(Feb.)	180	75	3528	3783

French only became the majority colonists in 1936; Table 19.

Most of the other Europeans were Italians. Their rapid decline relative to the French after 1921 was primarily due to laws giving them French nationality.

At independence the first French to leave were mostly from the administration and the liberal professions. Those with commercial interests, including farmers, tended to stay but, Chevalier (1957), without much feeling of security.

5.2 The Colonisation of the LMV.

General. By 1906, according to Violard, there were some 13,000 French already in the contrôle of Tunis (double the number recorded in 1891) and Europeans owned 134,000 ha. of land of which 109,000 ha. were in French hands.

Significantly the general pattern of exploitation of the soil, true in 1956, had already been established. Violard noted that the European colonists were planting some vines but otherwise neglecting fruit trees which needed long term advances. They prefered to grow cereals which had an immediate return.

Mornaghia was completely in colonial hands. Here the colonists grew mainly secondary cereals from which they obtained reasonable yields. Violard says that barley yielded 15-18 ql/ha. and oats up to 30 ql/ha. However wheat gave markedly lower yields, up to 8 ql/ha., and was of secondary importance. The wheat then grown would have been local varieties of hard (durum) wheat, to provide cous-cous and pasta products for the Tunisian market. The poor varieties and the Tunisian market explain, to some extent, the low yield and limited interest the colonists took in growing wheat.

The fact that oat and barley yields of the turn of the century were never substantially improved in the later years, whereas wheat yields had doubled or trebled by the end of the colonial period, shows the direction and degree of success of research and development of cereals during this time. The problems of cereal cultivation south of the Dorsale, in a region primarily suited to growing oats and barley, were never adequately studied. It is a region in which very few colonial farmers settled.

Apart from cereals, vines were being successfully established by the Italians and market gardening was attracting some farmers. Pastures, though good, were small.

In Tebourba, a caidat which then extended from Medjez el Bab to the sea, 120 Frenchmen owned 34,000 ha. and some 200 Italians either owned or rented land. This region included easily irrigable land on either side of the Medjerda river. Here the colonists successfully experimented with market gardening so that it became an important source of revenue for many of them. Violard estimates that in addition some 1,000 ha. of vines and 2,000 ha. of olives were also grown (Pte. 8 , p.102) where they could be irrigated. Further from the river 6,000 ha. were under cereals. The rest of the land was, presumably, uncultivated or used for rough pasture.

The reasons for the French farmer turning to cereal farming in Tunisia (Pte. 13, p. 123) are manifold. Firstly these annual crops offered the considerable advantage of almost immediate returns and could give acceptable results in favourable years with a fairly summary preparation of the soil. The cultivation of cereals was mechanically easy, suceeded with a small labour force and, because of specialisation, the capital per hectare invested in mechanical equipment was relatively low. Moreover the grain is easy to preserve so that marketing was therefore easier than for commodities that perished easily, In subsequent years the research done to improve methods of cultivation resulted in a solidly based technique which assured a very acceptable regularity of yields north of the Dorsale. Finally the cereal market became a protected market.

Few crops benefit from so many technical and economic advantages.

Pte. 13. A Typical Colonial Farm

source: Dutton, spring 1970

This farm, now incorporated into a cooperative, has several features typical of French farms in northern Tunisia. The farm buildings and olive trees occupy the hillside. The flat land is sown with a bearded, hard wheat.

The final expansion of agricultural colonisation by the French in the LMV came in the early 1950's as a direct result of measures taken to control the flooding of the Medjerda river. The drainage of the plain of Mabtouha (Dutton, 1968) completely secured part of the area against flooding. Some 600 ha. were registered and bought by six colonists in 1951 (source: the Land Registry in Tunis) although the land was still too saline to bring under production. No records of sowing or harvesting were to be found in the STONIC indicating that the land was never effectively farmed.

So much for the general extent and type of colonisation in the LMV. To understand more of the impact that the European farmer made on the agricultural situation he found we must turn to specific examples.

Medjez el Bab/Montarnaud. The most detailed contemporary study of colonisation was made by Mottes (1925) who was the contrôleur civil at Medjez el Bab throughout the crucial period, 1900-1925. At the beginning of the period no land had been bought by the Europeans but by 1924 they owned, Table 20,

Table 20. Land Tenure at Medjez el Bab. 1924. (ha.)

source: Mottes, 1925

Nationality	Type of Tenure	Area
French		67,981
Other European		3,133
Tunisian:	melk	55,840
	habou	42,730
	lotissement	15,316
State:	Agricultural	3,000
	Forest	46,500
		235,000

some 70,000 ha. The land purchases were, initially, often speculative and the land resold in smaller units usually with no work having been done on it.

Of the 68,000 ha. owned by the French some 37,000 ha. had been private purchases, that is without state intervention, and a further 46,000 ha. had been bought by the government. Of the 46,000 ha. 30,000 ha. were sold to French settlers and the rest sold to Tunisian farmers.

Mottes examined the effect of colonisation on ten of the largest estates bought privately. Between 1900 and 1924 the

Table 21. Colonisation at Medjez el Bab: Cultivation and Labour.

source: Mottes, 1925

	1900	1924
Area of Private Colonisation	-	37,218 ha.
Total Area Cultivated	1,260 ha.	27,600 ha.
Tunisians on the Land	1,388	3,937

area of land under cultivation on these estates had increased twenty fold, Table 21, and the number of Tunisians gaining their livelihood from the land had trebled. There was a shortage of labour so the colonists even paid off the debts of khammes to obtain labourers for their developing estates. Labour shortage also helped to establish the pattern of extensive cereal farming in the region. In addition the heavy machinery used by the colonists to clear the scrub from their land was well suited to extensive cereal agriculture where it replaced manual labour. It is for these reasons that the area under cultivation was able to rise seven times faster than the number of people on the land.

The ten estates studied in detail by Mottes include Montarnaud (4,500 ha. by 1925) which is one of the farms (Fig. 2 , p. 12) in the individual farm study. In 1900 (Mottes, 1925, p. 12) on this land: '25 families, totalling 160 people, cultivated 180 ha. A few thin herds of goats browsed on the scrub'. The land had a bad reputation.

By 1925 3,950 ha. had been cleared of which 2,000 ha. were sown each year. Twenty families of local tenants and _métayers_ and 120 families of workers, about 600 Tunisians in all, and about 30 European families were attached to the property. In addition 100 to 150 Tunisians were found temporary employment during the summer.

Upwards of 10 km. of irrigation canals had been constructed from the Medjerda river.

Colonisation here also had a marked effect on land which remained under Tunisian ownership. The area of land under cultivation rose, between 1900 and 1924, from 13,310 ha. to 35,324 ha. but, as Mottes pointed out, there still remained enough scrubland on the _melk_ and especially on the _habou_ properties to absorb the efforts of: 'several generations of _fellah_' (p. 23). Much of the increase in area under cultivation was on the 16,000 ha. of land ceded by the government to 650 families against annuities for 20 years. The standard of farming was rising: 'On land uncultivated three years ago, and covered with scrub, one sees today a well conducted development where the rhythmn of agricultural life is tending to approach little by little that of the neighbouring French farms' (p. 25). The practice of cereal/fallow monoculture introduced by the French was naturally the model adopted by the Tunisian farmers who were in a position to modernise their farming.

Sidi Tabet. An example of the impact of colonisation in a region of the LMV with somewhat different physical advantages to those of Montarnaud is given by the Domaine of Sidi Tabet. The present day village of Sidi Tabet has grown around the original farmyard.

Sidi Tabet (Pte. 14, p. 128) lies between the Medjerda river and the lower slopes of the djebel Ammar. The Domaine is particularly rich in water including both the higher rainfall with its run-off from the djebel Ammar and the irrigation potential of the Medjerda river. On the other hand the neighbouring circle of hills helps to push up the summer temperature maxima to around the 40°C. mark.

In 1866 the Domaine of Sidi Tabet (Loth, 1910) was bought by a Frenchman, M. de Saney, for speculative resale. The property included some 5,000 ha. of which 1,000 ha. were in the hills. The Domaine was resold in 1880 to the Société Marseillaise de Crédit but it was left to a company called the Société Franco-Africaine to develop the land. They found that; 'Invaded by brushwood the plain only offered a few rare clearings for cultivation... Laid waste by fires and exposed to the depredations brought about by the practice of ineffectual pasturing, the mountainous area was completely denuded and presented the sad aspect of so many regions of Tunisia today stripped of their covering vegetation' (Loth, 1910, p. 181).

At this time the only buildings were the haras and a house. By 1910 some 174 ha. of vines had been planted and a pasture area of 70 ha. had been established by the river where lucerne and other fodder crops were grown for sheep and cattle bred on the farm. About 6,000 trees had been planted.

Pte. 14. The Domaine and Village of Sidi Tabet

source: Air survey of Tunisia 1962/63

Part of the old domaine of Sidi Tabet, now divided up. The lower slopes of the dj. Ammar are mostly terraced, contour-planted with vines or planted with olives. The plain of Cherfech is ploughed for cereal and fodder crops.

All types of cereal were grown though Loth (p. 184) notes that wheat suffered from: 'the effect of rust and early shedding of the grain caused by the proximity of the Medjerda'.

Djebel Lansarine. A third type of region which felt the impact of colonisation was the high hill country of the djebel Lansarine. A comparative study, 1890-1956, of the cheikhat of Djebel Lansarine (Documents, 1965) shows the limited effect that the colonists were able to make on the agriculture of a closely bonded indigenous population.

In 1890 the livestock and other produce were mostly for home consumption. Cultivation was in 'family gardens' rather than farms, although some large areas were owned by absentee landlords.

The figures in Table 22 show the very limited European

Table 22. Development of Agriculture in Djebel Lansarine.
source: Documents, 1965

	1890	1956:-	European	Tunisian
Inhabitants	1,170	4,984	322	4,761
Cattle	1,191	1,600	550	1,050
Sheep	1,580	2,800	90	2,710
Goats	2,650	1,500		
Olives(ha)		6,000		
Vines(ha)		131		
Cultivated Land(ha)	1,137	4,300	2,000	2,300

penetration of the cheikhat; and most of that was on the sloping plain between the djebel and the Medjerda river. A more important fact emerging from the study was that the Europeans created a modern sector almost as large as the traditional sector but the peasant milieu changed remarkably little. The changes that did occur were due to the increase in population which had led to more marginal land being brought under cultivation, such as that shown in Pte. 15 (p. 131). But the land cultivated and the livestock per Tunisian inhabitant had dropped by a half to a fifth of the 1890 level.

As a result of the growing population the people were in a worse position economically and the land, particularly the newly cultivated marginal hill slopes, was in greater danger from erosion.

Pte. 15. Marginal Wheat Cultivation in Djebel Lansarine

source: Dutton, summer 1969

Tilling these poor quality hill soils gives only a low yield of wheat and encourages erosion.

<u>5.3 Colonisation and Population Movement</u>. It is impossible to trace the evolution of the population of the LMV from the beginning of the colonial period. The population censuses were not sufficiently detailed to show the distribution of population within the LMV. Only in 1936 were figures first given for the Tunisian population by <u>cheikhat</u>. The details of the 1946 census are not to be found in Tunisia but the 1956 census gives the Tunisian population of each <u>cheikhat</u> and the population, Tunisian and foreign, of each settlement with a population of 100 or more. The 1966 census gives similar details taking the picture both beyond independence and the nationalisation of French land in May 1964.

<u>Pre-1936</u>. For the pre-1936 period there are only the indications given by contemporary writers or by studies of particular localities. Writing, for instance, in 1904, Monchicourt said that the area round Tunis and other areas rich in underground water had a lot of <u>melk</u> land which was being successfully cultivated. Small villages were strategically placed out of reach of the floods. For the rest of the valley Monchicourt gives the impression that the cultivators, usually <u>khammes</u>, were normally very poor, living in tents or simple huts; a depressed region with a low population density.

The picture given by Mottes (1925) fully substantiates this. But Mottes (see ch. 5.2, p. 124ff.) also shows the effect of French farming on the local agricultural population. This was stabilised, became more settled, and grew, though more slowly than the new areas brought under production. As the population rose and the level of economic activity with it so, inevitably, other jobs were created in the service sector.

Two detailed farm studies, Montarnaud and Sidi Tabet, further illustrate this point. In fact many villages grew up around the nucleus of the colonists farmyards. In Table 23 are listed some typical examples. The larger villages had a

Table 23. Population of Typical Colonial Farm Villages. 1956
source: Census 1956

Name of Village	Tunisians	Foreigners
Montarnaud 1	149	46
Montarnaud 2	684	44
Sidi Tabet	1,071	227
Creteville	853	326
Chaouat	274	149
Fedjet Kemakhem	173	64

school and a mosque as well as houses and farm buildings and a small church.

1936 Onwards. When considering the data from the censuses of 1936, 1956 and 1966 the region of Tunis and environs must be set aside because its population changes were strongly influenced by urban factors. For the purposes of this work the cheikhat of the truly agricultural areas are, in the discussion below, distinguished by the name of rural cheikhat.

In 1936, of the rural cheikhat, the large southern and south-western cheikhat (Fig. 17, p. 93) were then the more populous but it was still true that the cheikhat with the highest density of population were those clustered round the mouth of the Medjerda; Aousdja, Ghar el Melah and Kalaat el Andaleus. In 1956 and 1966 the percentage increase in population was higher in the south than the north, Table 24, and rather higher than the national mean. Easily the greatest increase was in

Table 24. Population Growth in the Rural Cheikhat of the LMV. 1936-1966.

source: censuses, 1936 & 1966

Cheikhat	Population 1936	Population 1966	Percentage Increase
*Ariana	8,284	31,734	283.1
C. du Mornag	6,443	13,988	117.1
Mohammedia	5,668	12,066	112.9
Bordj el Amri	3,445	10,039	191.4
C. Ben Ammar	5,333	13,215	147.8
Kt. el Andaleus	3,893	6,336	62.7
*La Manouba	5,577	83,553	1,398.2
La Mornaghia	4,415	9,920	124.7
Ain Ghelal	3,019	5,016	66.2
Bordj Toum	3,004	4,417	47.0
Djedeida	4,282	10,181	137.8
Dj. Lansarine	3,721	5,716	53.6
Tebourba	6,249	17,497	180.0
Akara	1,597	3,271	104.8
Trabelsia	2,061	4,373	112.2
Troud	858	1,557	81.5
Aousdja	3,093	4,872	57.5
Ghar el Melah	2,643	4,857	83.8
		Mean:	105.1

* Cheikhat part of whose area lies within the urban growth of greater Tunis. Their precentage inc rease is therefore not included in the mean of 105.1.

Troud cheikhat whose population growth was less than the mean.

the central cheikhat, Table 25, of La Manouba. The rural part of this cheikhat incorporates most of the land first supplied

Table 25. Evolution of the Population of La Manouba.

source: censuses, 1936, 1956 & 1966

Year	Rural	Urban	Total
1936			5,577
1956	9,443	23,170	32,613
1966	24,107	59,446	83,553

with irrigation water by the OMVVM - including Saida and el Habibia (Pte. 16, p. 136). This further illustrates that water is the key factor governing the intensity of agricultural activity and, therefore, the density of population in the LMV.

Still, in 1956, of the seven rural settlements with a population over 2,000 in the LMV, Table 26, six lay on the

Table 26. Population of Settlements over 2,000 in the LMV in 1956.

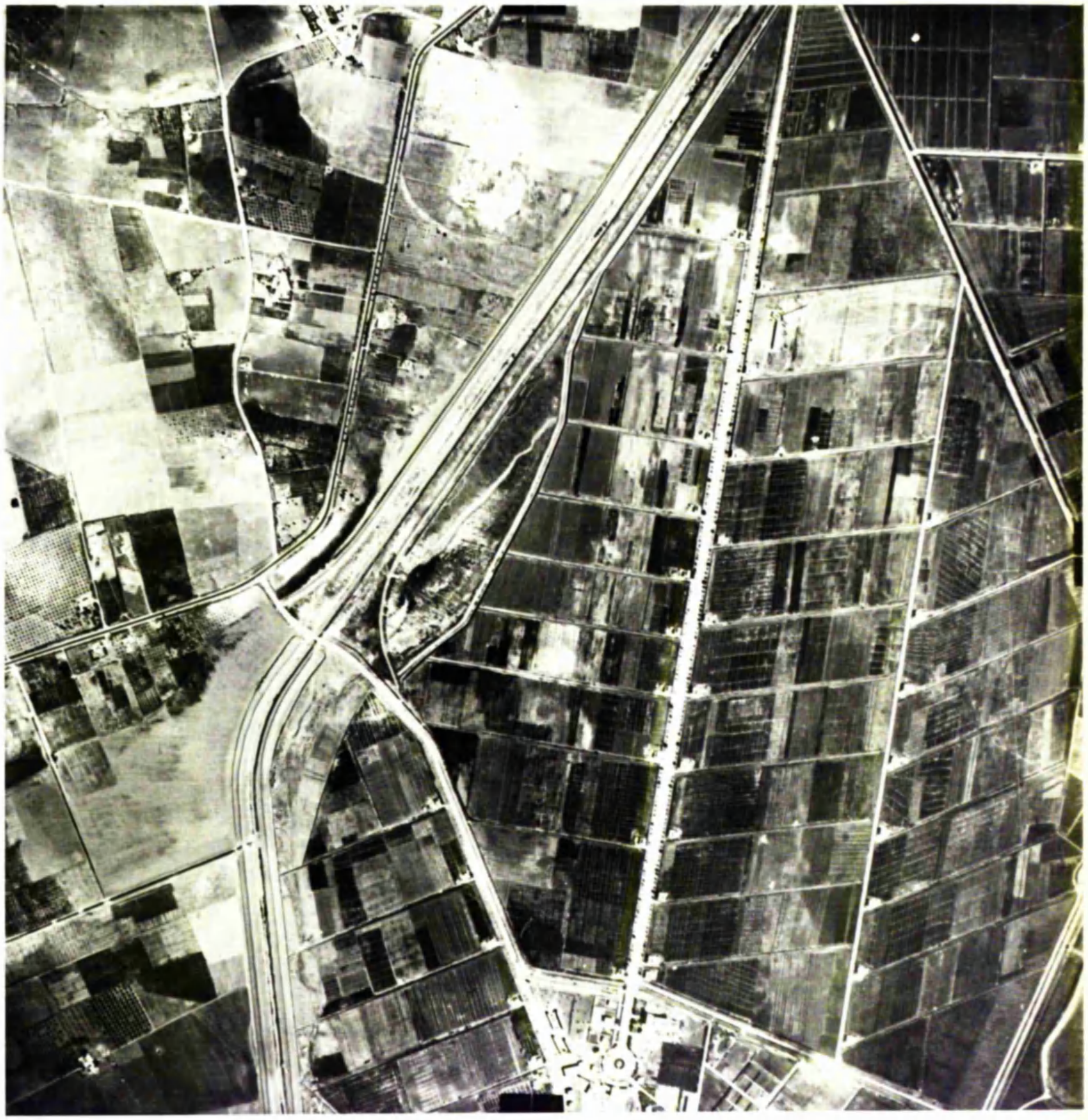
source: census, 1956

Settlement	Foreigners	Total
Tebourba	649	6,103
Kt. el Andaleus	20	4,709
Ghar el Melah	334	3,194
El Bathan	177	2,936
Aousdja	58	2,695
La Mornaghia	699	2,448
Djedeida	806	2,153

Medjerda or in the north. The exception was Mornaghia; in one of the rich and heavily colonised rural cheikhat of the southern LMV.

The number of foreigners in these settlements reflects

Pte. 16. El Habibia and the Main Right Bank Irrigation Canal



source: Air survey of Tunisia 1962/63

The cooperative of el Habibia, on the site of a disused airstrip, was the first to benefit from the combined use of land reform and irrigation water by the OMVVM. The land is intensively cultivated to produce a wide variety of irrigated market garden crops and green fodder for milk cattle.

what has been said about the failure of the colonists to penetrate the north. The southern and western settlements had a much higher percentage of foreigners than the settlements near the river mouth. The apparent exception to this rule is Ghar el Melah but the large number of foreigners in Ghar el Melah is not an indication of agricultural colonisation. They were mostly connected with the local fishing industry.

The view that the development of cereal agriculture by the Europeans in the regions denied access to irrigation water led to an increase in population is contested by Poncet. He believed that the Europeans' cereal cultivation (Poncet, 1959) was responsible for forcing the Tunisian peasant to farm on the poorer soils and the hill slopes where they achieved little except an increase in soil erosion.

In the gouvernorat of Tunis, he says (p.252); 'the increase in population may be identified with that of the capital and its suburbs. The Tunisian population diminished in nearly all the neighbouring rural sectors including Djedeida, Ain Ghelal, Cebala Ben Ammar, La Mohammedia and Mornag'. However, as has been shown above, this assertion is not borne out by the census of 1956 or 1966. The rural population of the LMV was increasing most rapidly where the land was newly irrigated or the soils of good quality.

The relatively minor role played by the colonists in causing the peasants' plight emerges from the general Tunisian picture of the percentage evolution of land useage between the two agricultural censuses of 1949/50 and 1961/62 (Attia, 1966) for a total area of some 9,000,000 ha. The percentage of land under

Table 27. Evolution of Land Useage in Tunisia 1949/50 to 1961/62.

source: Attia, 1966

Crop	Percentage Agricultural Land Under Each Crop	
	1949/50	1961/62
Annuals (mostly cereals)	32	36
Annuals and Fruit Trees	1	4
Fruit and Vines	9	11
Woodland and Forest	10	13
Pasture and Grassland	47	36
	100	100

cereal crops increased, Table 27, from 32% to 36% representing an expansion onto marginal land; all too often hill slopes which were thereby exposed to more rapid erosion.

The growth in the area of cereal crops occurred at a time when colonial agriculture was drawing to its close in Tunisia. A high percentage of the French farmers had left by the end of 1960/61, before the agricultural census took place. This does not suggest that it was the presence ot the colonists but rather the growth in the Tunisian population which was responsible for peasants being pushed back into the hills to cultivate the more unstable and poorer quality soils.

Poncet also regrets what he calls the 'proleterianisation' of large numbers of peasants in Tunisia by which he means the increase in number of agricultural wage earners at the expense of the khammes. He believed (1961B, p. 131) that: 'This proleterianisation itself signifies the impoverishment of the workers and the destruction of the line uniting man and the land he cultivates'. In saying this Poncet was blaming the colonists who were responsible for this change by paying off the debts of the khammes (see ch. 5.2 p. 125ff.); accusing them of breaking the natural bond between man and the soil to the detriment of both.

But both Mottes and Violard have shown the bond he refers to was not a natural bond but a slave bond preventing investment of either money or work into agriculture. Moreover if the khammes was more content to work as a labourer this can only have improved his low standard of cereal farming and not, as Poncet's arguement implies, endangered it.

The two major crops which the Europeans grew in the LMV - cereals and vines - both employed a very small labour force for most of the year but were labour intensive during harvest. For vines this situation has remained unchanged up to the present day but harvesting of cereals has been much easier to mechanise.

The temporary labour force required for the harvests, especially grain, was supplied by migrant, transhumant, labour from central Tunisia. The labourers received a share of the harvest which varied from one-half to one-thirtieth (Clarke, 1955), the freedom to graze their stock on the stubble and the right of gleanage. In a good year these 'Summer Nomads' (Clarke, 1955) might return home with their main provision of grain for the rest of the year.

The situation was not satisfactory, from the point of view of the cereal farmer, because the labour force was uncertain. If there was a good harvest in the south the summer migration never occur. In addition the stock grazing on the stubble prevented early ploughing and compacted the soil.

It was therefore inevitable that the 'modern' farmers should reduce their dependence on migrant labour with each improvement of harvesting machinery. But it was the advent of the combine harvester (Pte. 17,p. 161) in the late 1930's and, particularly, after the war which has reduced the harvest work (along with the fallen grain to be gleaned) to a job for a few, skilled, full time employees and the machinery they control.

This action has had enormous social consequences. It must be associated with the increase in permanent internal migration; people leaving central Tunisia in a hopeless bid to find work in the north or the coastal towns. The post-war period saw a growth of slums and <u>bidonvilles</u> around Tunisia's major urben centres.

But it would be anachronistic and, indeed, quite unrealistic to blame the colonists for their part in causing these migrations. The answer is not to ban the use of the combine harvester, which is even more commonly used today than when the French left. The government must, as Clarke (1955, pp. 166-167) suggested, stabilise and augment the agricultural potential of central Tunisia by improving pastures and planting trees.

5.4 Administration, Research and Training. The training of farmers was first put onto a serious footing in 1898 (Violard, 1906) with the foundation of the Ecole Coloniale d'Agriculture. This school had two aims: firstly to teach the new farming community the skills needed to cope with North African conditions, and secondly, a more purely colonial ambition; 'To attract to Tunisia the youth of France tempted by the agricultural colonial life'. The ex-pupils had the right to first choice of farmland which the government periodically put on sale. Total entrants in the school up to 1904 were 232, of whom 193 were French and only 14 Tunisian.

The first experimental station was opened in 1891 (Violard, 1906) for trials on annual crops, vines and fruit trees. It was here that work on the selection of varieties of cereals began and research was undertaken to improve and design techniques of cultivation.

The research centre, the SBAT, was granted laboratories and an experimental farm at Ariana and other experimental stations scattered throughout the country. Many of the country's best varieties of hard wheat and soft wheat (including the internationally renowed F/A) were selected and tested here. The effects on production of ploughing, fertiliser and crop rotations were also examined; notably by Yankovitch and Poletaef. Many Directors of the SBAT were primarily involved in research into cereals, particularly Boeuf, Valdeyron and Séguéla.

There was considerable interchange of information between the SBAT and the colonists. Of the latter Trouillet (see ch. 6.4, p. 163 ff.), Cailloux (see ch. 6.2, p. 156 ff.) and Martinier (see ch. 6.5, p. 176 ff.) made the greatest contributions. For the SBAT successive Directors rigorously countered any tendency towards an 'ivory tower' atmosphere. Long farm visits were considered an integral part of their duties and they sought opinion and production data from the better farmers.

Research was not only published in the SBAT journal, Annales du Service Botanique et Agronomique, but, less academically, in the monthly journal of the farming society, La Tunisie Agricole, and in the weekly farming newspaper. Each year the opening meeting of the farming society was addressed by the Director of the SBAT who summarised and analysed the achievements, or failures, of the previous cereal year.

But it must be said that the improvements effected as a result of this work concerned primarily the colonists and the small modern sector of Tunisian agriculture. New methods penetrated very slowly through to the mass of small and traditional Tunisian farmers. Where such methods depended on mechanisation or were only economic if practised on a large scale they could not be adopted by the Tunisian peasants.

Little attempt was made to change this through education. The Agricultural College trained agricultural engineers to work in the modern sector. Up to independence the country was producing more of these engineers (Zghal, 1966) each year than extension agents.

But some major changes were effected in the peasant sector through other agencies. From 1936/37 the production and marketing of the major cereals came under the control of the STONIC. A guaranteed price was offered for hard and soft wheat from 1936/37 and for barley from 1939/40. This gave an extra measure of security to all farmers and began to erode the power that the 'middlemen' had over the peasants. Their influence was further reduced as more small farmers were able to obtain short term loans from the <u>Sociétés Tunisiennes de Prévoyance</u> (STP).

After the war a cereal grain multiplying organisation (the COSEM) greatly increased the quantity of the better varieties of hard wheat for wider distribution. By 1948/49 the peasants were growing the better wheats (Valdeyron, 1953).

At the same time the <u>Co-operative de Motoculture</u> was making machinery available to small farmers who could not afford to purchase their own.

These were all solid benefits which affected those small farmers who commercialised their harvests. But the others, who did not take part in the cash economy, living in remote hill villages, remained rooted in their traditional means of cultivation.

<u>5.5 Conclusions</u>. The colonists were able to buy land in areas of the LMV which were extremely under-exploited. In other areas where the indigenous population had been able to tap sources of water for irrigation for generations and where they had some immunity from flooding and brigands the colonists were unable to settle.

Colonisation meant a rapid increase in the area of land under permanent cultivation. Away from the Medjerda river most of the land was dry-farmed to grow cereals. The local population grew, though not as rapidly as the area of land brought into production, and new villages were created round the nucleus of colonial farm-yards. The whole region became much more secure and local land-owners were stimulated by the presence of the colonists to increase their farming activities. With the growth of the population their work went too far. They reclaimed hill land whose natural vocation was for pasture and ploughed it for cereal crops. The land was thereby exposed to the danger of wind and water erosion.

The labourer replaced the impoverished <u>khammes</u> whose debts were paid off by the colonists. The labourer lost the theoretical freedom which the <u>khammes</u> had but gained security and a regular wage. The increase in area of cereal farming also provided temporary harvest work, and a supply of grain, for the Summer Nomads from central Tunisia. This source of employment was short lived; with the increased use of combine harvesters after the Second World War the employment of Summer Nomads by the modern farms has been reduced almost to nothing.

During the colonial period the central government was strong and effective. It took control of the marketing of all cereal crops, to the benefit of all the farmers. Other organisations bred, multiplied and distributed new varieties of wheats. In addition the SBAT tested and developed methods of cereal farming but neither the improved seed nor the improved methods penetrated right through the agricultural community. A peasant sector remained, employing outmoded techniques on unstable soils.

CHAPTER 6

ADAPTING CEREAL CULTIVATION TO THE SOILS AND CLIMATE OF THE LMV.

6.1 Introduction. This chapter will examine the time distribution of wheat yields in Tunisia from when the agricultural colonisation had been firmly established at the beginning of the century. Special reference will be made to the LMV where it differs from the other wheat growing regions. Otherwise the conclusions drawn from the chapter are of general validity for all colonial cereal farming in the north of Tunisia.

The study will attempt to assess qualitatively the effect on productivity of new varieties and of changing techniques of cultivation. Their effects both on the soil's fertility and, in the section on erosion, on the soil's very existance, will be emphasised. It is important to stress that both new varieties and new methods of cultivation can have short and long term effects which may be both different in degree and opposite in direction.

Although the chapter will follow the changes in varieties and techniques up to the end of the colonial period a closer examination of the final phase of colonisation, preceded by an outline of the peculiar effects of the Second World War on cereal productivity, will be left to chapter 7. A separate study of the final phase of colonisation is required to isolate the likely effects on yield of changing farming practice during this period before continuing to construct a statistical and deterministic model to explain as far as possible the space/time relationship between climate and wheat productivity in the LMV.

Changes in yield through time were influenced by the climate independently of soil quality or cultivation techniques. The farmers could not, of course, change the climate, as they did the fertility of the soil, but attempted to overcome the problems that it posed and, where possible, turn them to advantage. They did not always achieve this end, and indeed, it has been argued by Poncet and others that in some respects the techniques had the opposite effect; they leached the soil of its fertility and encouraged rain erosion.

When the French started cereal farming in the north of Tunisia there was very little that they could learn, as has been shown above, from the traditional practices they found. Nor could they rely on a useful body of skills from France whose cereals were grown in a different climate. They therefore had to evolve their own methods of cultivation from their own experience and from the research work done at the SBAT. But can it be said that the practices they evolved were best suited to the climate and the soils in order to maximise yields ? And did they get most from the land and climate without, at the same time, permanently lowering the fertility of their soils ?

To answer these questions it is necessary to set the trend in yields against the different techniques of cultivation as they evolved in order to see how far the inherent soil and climatic problems were overcome, or accentuated.

The achievement of the colonists will be examined under the following headings:

New Varieties
Mechanisation
Ploughing and Tillage
Fallow and Crop Rotation
Use of Fertiliser
Weed Control
Cultivation Techniques and Soil Erosion.

6.2 New Varieties.

Hard Wheats. When the French arrived in Tunisia they at first cultivated the local varieties of hard wheat (having no experience of such wheat in France) which were hardy but low yielding.

Biskri AC/2 was the best of the old varieties and amply exemplifies their strengths and weaknesses. These were, according to Séguéla and Jacquard (1955), a very good resistance to drought, slight sensitivity to mitadinage, but very sensitive to black rust and flattening and of only average productivity. The variety matured late and was considered as a wheat passe-partout although its sensitivity to black rust meant that its yield was more regular in the drier central part of the country.

This then was a wheat which, in a country where water shortage is chronic, could not make use of the higher and more certain rainfalls of the north because the extra moisture made it suffer badly from rust. As soon as rust resistant varieties had been selected it was condemned to the poor soils and low rainfalls of the south of the country.

By 1910 the colonist farmers were growing some 25,000 ha. of the old varieties. The area rose to 45,000 ha. in 1915 but fluctuated below this total until 1927. Thereafter the area under hard wheat rose steadily to a maximum of 105,000 ha. in 1931 but, during the 1930's (Fig. 3b, p. 20), gave ground to F/A and the other soft wheats.

Up to 1925 the mean yield of hard wheat had only twice surpassed 10.0 ql/ha.; in 1923 and 1925. But from 1923 to 1938 the mean yield only twice dropped below 10.0 ql/ha.; in 1924 and 1936.

This impressive improvement stemmed from several causes. Firstly it coincided with the first period of massive import of heavy agricultural machinery (see ch. 6.3 and Fig. 20, p. 234) which improved ploughing, tillage and the preparation of the seed bed (see ch. 6.4, p. 164ff.). Secondly better crop rotations (see ch. 6.5, p. 173ff.) pioneered by Trouillet, Cailloux and Martinier were being widely adopted.

But the development of improved varieties of hard wheat was of major importance. The criteria for selection were complex and it is fair to say that none of the new varieties was well adapted to all aspects of the Tunisian climate. If a variety was resistant to drought and shrivelling (see ch. 8.3, pp. 275-279) it might be sensitive to excess moisture, mitadinage and fungal diseases. If it was high yielding and nitrogen demanding it might be sensitive to the leaching effects of winter storms and competition from weeds.

With these problems to overcome it is perhaps not surprising that the SBAT did not select wheats specifically for different regions of the country. A variety was judged by its mean yield on the experimental stations spaced throughout the north of the country.

The region south of the Dorsale was not considered primarily suited to wheat. The varieties grown there were simply the more drought resistant ones selected for the north.

For the northern part of the country, including the LMV, each farmer was, eventually, able to select from half a dozen varieties the ones more suited to his particular type of soil and rainfall.

To start with these varieties were introduced from countries (Séguéla and Jacquard, 1953) with similar climates. The best of these were M'Rari 549 (sensitive to yellow rust in years of high rainfall) and Mahmoudi 552, both from Tel Aviv. The latter was considered the best general hard wheat in Tunisia.

Following the First World War the SBAT started to produce its own hybrids. The first of note was Sindyouk x Mahmoudi 870 which had a much improved yield and good resistance to black rust making it more adaptable to the higher northern rainfalls. It also matured 15 days earlier than the older varieties which gave it an automatic resistance to late spring drought. It was also more demanding than the older varieties and could only yield to its full potential if the seed bed was carefully prepared and the soil maintained free of weeds.

In 1930 came Mahmoudi x Kokina 77 which was very resistant to rust and drought, very sensitive to flattening, tillered fairly well and was very productive. In addition it matured early, could thrive on medium quality soils and withstood competition from weeds but was very sensitive to <u>mitadinage</u>.

During the 1930's other varieties were added to the list including:

Mahmoudi 981 (Kasserine),
Roussia 975,
D117 Mahmoudi 552 x M'Rari,

and Chili 931 was introduced from Marseilles.

These were the varieties that produced the improved yields of the late-1920's and the 1930's. Because they all had good and bad points no one of them dominated the others. In the right conditions and on the right soil, Table 29 (p. 158) all of them could yield reasonably highly.

Unfortunately interest in the selection of hard wheat was not maintained. This was partly due to the success already achieved but more because the potential of the new varieties was never fully exploited. From 1933/34 the Europeans grew a smaller area of hard wheat than soft wheat, which was the primary export crop and gave higher yields, so the hard wheats were given the poorest land and the least attention.

Valdeyron (1948, p. 164), questioning why hard wheat yields had been lower than soft wheat yields, concluded that quite apart from differences of potential between them, the hard wheats yielded poorly because they were regarded as second class cereals. He found that in the great majority of cases hard wheat was treated as a pis aller used because through lack of equipment the farmer did not have (or risked not having) the time to carry out the necessary work. Ploughing done too late or a field badly weeded were the most commonly given motives. They also used hard wheat because it gave an earlier start to sowing or extended the harvest through a longer period. Many reasons but all of them negative.

This explains why in 1955 when Séguéla and Jacquard listed the varieties of hard wheat cultivated in Tunisia there was not one new name. Indeed in 1964 the old varieties were still being recommended with the addition of only two new 'lines' -

D52 XXIV(1952) from Sindyouk x Mahmoudi and
D117 60 1(1960) from Mahmoudi 552 x M'Rari -

isolated from the old varieties, and one new variety -

Biskri x Bouteille -

which had the same mixture of good and bad qualities as the old varieties.

But the record of the 1940's (Fig. 3b, p. 20) shows that although the yields of hard wheat did fall during the years of low rainfall in the 1940's they fell noticeably less than those of F/A and the other soft wheats. They had proved themselves to be overall more resistant to drought. Probably their longer growing season allowed greater flexibility, making them able to survive the dry periods and make use of any rainfall when it came.

As a result of this, combined with the loss of the export market for F/A (see ch. 2.4, p. 32ff.), more intensive research was resumed to test the potential of the hard wheats.

Field trials of the late 1940's and the early 1950's - including both drier and wetter years - showed that the hard wheats could yield as highly as F/A. They also showed that there was little to chose between the major varieties of hard wheat; as shown in Table 28.

Table 28. Yields of Major Hard Wheat Varieties. Field Trials 1946-1954. (ql/ha.).

source: Valdeyron, 1953, p. 129 and 1954, p. 98.

Year	F/A	Mah.552	Chili	Kasserine	Sind.x Mah.	D111
1946	21	22				
1948	12	11	11	11		
1949	18				18	
1952	23.7	23.1	22.4	23		25.1
1953	21		23		22	
1954	19.6					21.4

The post-war resurgence of wheat cultivation, starting in 1948/49, showed a distinct move towards the hard wheats which were able now to compete on equal terms with the soft wheats. They were given better land than previously and every attempt was made to get the yields as high as possible.

The four major varieties were:

Chili
Mahmoudi 552
Sindyouk x Mahmoudi
Mahmoudi x Kokina.

The two faster maturing varieties, the latter two, were confined almost exclusively to the region south of the Medjerda river (Valdeyron, 1955), and as far south as Siliana; that is to say in the drier part of the major wheat growing zone. Here early maturing was clearly seen to give an advantage over the more 'rustic' wheats. The fast maturing, 'force', varieties would have suffered from shortage of nitrogen if grown north of the Medjerda where there is always more likelihood of heavy, leaching winter storms. But although the 'rustic' varieties were not grown as far south as Le Kef or Siliana they were grown both north and south of the Medjerda river. This is a further indication of the adaptability of the slower maturing wheats.

This is not to say that farmers stopped growing F/A or the other soft wheats. In the wetter years of the early 1950's the yields of F/A went up. But in the LMV 1955/56 and 1956/57 were the last years that F/A was grown, according to the individual farm data, on most farms. Its higher yield was not enough to offset the price differential in favour of hard wheat which rose from 518 francs to 872 francs per quintal (see Table 7, p. 39) in 1958. Some farmers even now remained unconvinced by hard wheats. They switched from F/A to the more rustic soft wheats (see p. 157) - EAP(Guelma) and Etoile de Choisy - which were yielding well.

Thus by the time they departed the French had selected a number of good varieties of hard wheat each with slightly differing qualities which enabled the farmers to make their own choice of variety according to their judgement of local conditions.

However none of the varieties was without faults and the yields on the farms were not as high as the soft wheats led by F/A. They appeared most promising under the adverse conditions of the 1940's which showed that slower maturing varieties - more flexible in adapting to the unpredictable rainfall - were better at withstanding long dry periods.

<u>Soft Wheat</u>. The total area of soft wheat grown by the Europeans grew from 12,000 ha. in 1911 to 63,000 ha. in 1925. It remained at this level until 1930/31 (Fig. 3a, p. 20) when it began to climb steadily to a maximum of 138,000 ha. in 1939/40. The increase during this decade was entirely due to F/A which also accounted for most of the 50,000 ha. of soft wheat being grown by the Tunisians. The rapid expansion of area under this wheat was due to its excellent yields (far surpassing the yields of the other soft wheats), its renowned industrial properties, and because it had an ensured export market to France. At home the local demand for bread was increasing and, in addition, F/A could be used, unlike other soft wheats, for making cous-cous.

But before the advent of F/A the dominant soft wheat in Tunisia was Baroota 52, introduced from Australia in 1913. Its qualities were similar to the early varieties of hard wheat; hardy but low yielding. Séguéla and Jacquard (1955, p. 218) described it as: 'sensitive to black rust, good resistance to drought... productivity low. For hill slopes Iwith soilsI light, shallow, leachable and weedy'. It withstood competition from weeds very well, gave reliable, average yields and was a very good bread wheat.

Baroota was used on the poorer soils which the hard wheats could not tolerate. Its hardiness was important at a time when the mechanical power did not exist to provide well tilled, weed free soils.

But Baroota could not make use of the greater soil fertility created by deep ploughing (see ch. 6.4 p. 164ff.) and crop rotation. During the 1930's the high yielding F/A so completely filled this role that work on developing other soft wheats was very slow. This fault was only realised when F/A proved too demanding on the less fertile soils and in the drier years of the 1940's.

During the 1940's therefore trials of a new soft wheat, EAP 63A(Guelma), were advanced with greater urgency and passed from field trials to the farms in 1947. This new variety differed in three important respects from Baroota. It was high yielding and early enough to escape from the danger of late spring droughts. And it was also resistant to black rust (though not to yellow rust) which made it much less susceptible to the higher northern rainfalls. As Valdeyron said(1950, p. 96): 'it has the enormous merit of giving, in very bad conditions of fertility, harvests comparable in an average year to those given by F/A in good soil'.

At first it was badly received because of the reddish colour of the grain but by the mid-1950's it had almost entirely replaced Baroota and was fast usurping the role of F/A as the principal soft wheat.

One further soft wheat, Etoile de Choisy, promised well in field trials conducted from 1950/51 to 1956/57; its productivity surpassed F/A. The care in cultivation that it required was relatively little compared with F/A. Equally important, it matured slowly, so complimenting the qualities of the fast maturing Guelma and making it more flexible in adapting to an uncertain climate. Séguéla (1958) forecast that it would become popular but it was not in the 1964 list of recommended varieties (INRAT, 1964) probably because it was not a very good bread wheat!

Florence x Aurore. The variety of wheat which played the leading role in the development of cereal agriculture in Tunisia is F/A. The variety was bred at Versailles and introduced to Tunisia in 1922. It was grown first as a field crop by Maurice Cailloux at Koudiat, near Jendouba, in 1925. Two new lines of the variety were isolated, Ariana 8 and Koudiat 17 (known as Blé Cailloux), which were more resistant to rust but still sensitive to smut. It was the highest yielding of all Tunisian wheats and capable of doing well in a wide variety of soils and rainfall. But it was very demanding, preferring deep and heavy soils and needing them to be well tilled and carefully cleaned of weeds. It had also to have a plentiful supply of nitrogen at the critical phases of tillering and grain maturation; any shortage seriously limited the final yield. It is for these reasons that the period of greatest popularity of this wheat, the 1930's, coincided with the generalisation of both mechanical farming (see ch. 6.3, p.159 ff.) and deep ploughing. The deep ploughing of the newly cultivated soils together with the use of fallow stimulated a very high degree of activity by nitrogen fixing bacteria. This made F/A yield well on even light and marginal soils for a number of years. But by the end of the 1930's it was seen that these soils were fundamentally unsuited to this demanding wheat so they were left for hard wheats or secondary cereals.

When the yields of F/A declined on even the better soils during the 1940's it was generally assumed that F/A had permanently limited the fertility of the Tunisian soils because it was taking too much from them. A decrease of soil nitrogen or soil humus was blamed. However this assumption was based on the premise that F/A was very resistant to drought because it matured considerably earlier than the other wheats so that a succession of drought years was a likely explanation.

But early maturing only protects a wheat against end of season drought while making it more susceptible to mid season dry periods because its phase of vegetative growth is too rapid to be adequately flexible for the irregularities of a Mediterranean climate.

Indeed when the climate became wetter in from 1948/49 the yields of F/A once again rose above those of the hard wheats proving that the soil had not lost its fertility. It was grown in the LMV until 1956 or 1957 when a combination of the loss of export markets (see ch. 2.4, p. 32ff.), the increasing price differential in favour of the hard wheats, and the excellent qualities of two new varieties of soft wheat (pp. 155-156) saw the end of its reign.

Table 29. Varieties of Cereal Suited to Different Combinations of Soil Types and Rainfall in Tunisia.

source: Séguéla and Jacquard, 1955

Soil	Rainfall(mm) 600plus	600-500	500-300	300-200	200minus
Sand					Chili Mah/Kok F/A O. d'A
Light Soil: White			Guelma Baroota O, 14J O. d'A	Mah/Kok Guelma O. 14J O. d'A	
Light Soil: Red or Grey	Roussia	Chili Mah 981 Baroota Guelma O.Martin Forrage	Chili Mah 981 Baroota Guelma O.Martin	Chili Mah 981 S/Mah F/A Guelma O. 14J O. d'A	
Medium Soil	Roussia	Chili Mah 981 F/A O. d'A Forrage	Chili Mah 981 F/A O. d'A Forrage	Chili Mah 981 S/Mah Mah/Kok F/A O. d'A O. 14J	
Heavy Soil: Grey, Brown & Black	Roussia Mah 981 F/A	Chili Mah 981 F/A O.Martin O. d'A	Chili Mah 981 F/A O.Martin O. d'A	Chili Mah 981 S/Mah F/A O.Martin O. d'A	
Very Heavy Soils	Roussia	Chili Mah 981	S/Mah F/A Guelma	S/Mah Mah/Kok F/A Guelma	

6.3 Mechanisation. Although traction engines were used to help clear and prepare the land for cultivation from the start of the colonial period it was not until after the First World War that the 'modern' agricultural sector became more generally mechanised.

Impetus was given to mechanisation by the experiments of Maurice Cailloux, near Jendouba, on the importance of deep ploughing (see ch. 6.4, p. 164ff.) for obtaining high wheat yields. Such ploughing needed the most modern ploughs and powerful tractors so that from 1920 imports of tractors and other heavy agricultural machinery greatly increased.

Deep ploughing was particularly beneficial for the new wheat, F/A, whose high yields and secure export market both encouraged, and provided the capital for, further mechanisation. As a result expansion of the area under the plough was rendered both desirable and easy; 1925-1933 was for this reason marked by a great increase in imports of both tractors (Fig. 20, p.234) and other farm machinery (Bigourdan, 1947).

The farmers' desire for expansion was supported by expert advice. In 1932, Boeuf, the Director of the SBAT, wrote that 1,000,000 ha. could be opened up for cereals. He thought that; 'in the region of the High Plateau, mainly, excellent land under a favourable climate is used for pasturing animals with insignificant yield and without profit for the country' (quoted in Bigourdan, 1947, p.11).

Under the influence of the tractor and the plough cereal cultivation spread from the plains to include the foothills and the light marginal soils normally considered to be more suitable for rough pasture.

It was not until the end of the decade (1930-1939) when the climate turned against dry-farming and the virgin marginal soils had lost their initial fertility and begun to show dangerous signs of erosion, that the danger of over-use of mechanical power became apparent.

Crop rotation was also markedly affected by the great increase in the number of tractors. Mechanical cultivation meant decreasing the livestock used for traction and, in consequence, the demand for fodder crops - particularly beans/oats. As beans/oats was usually alternated with barley or oats, the area under these secondary cereals decreased proportionally. It was the new and more profitable varieties of wheat which took their place. Boeuf (1932) noted that where the tractor had replaced the horse and the rainfall under 500 mm. the Wheat-Fallow rotation had become the rule.

A very optimistic view of the effects of machinery on cereal production was given by Dumont in 1947. As a result of the use of machinery: 'Tunisia at first in deficit concerning food production, covered its needs thanks to mechanisation, then surpassed them; the use of tractors on nearly 240,000 ha. had led at the same time, to an increase of the area cultivated and a mean increase of yields which reached 12 ql/ha. under mechanisation while the land cultivated by the ancestral method remained at about 3.0 to 3.5 ql/ha.' (p. 130).

Apart from the fact that 12 ql/ha. is an optimistic assessment of yields for the modern sector it is likely (see ch. 2.2, p. 22 ff.) that Dumont was underestimating the yields of the traditional sector by half. The yields of the modern sector were not so far in advance of the traditional sector as has been

Pte. 17. A Combine Harvester Working near Medjez el Bab

source: Dutton, summer 1970

The modern sector of agriculture is fully mechanised. The wheat crop on all large farms is gathered by combine harvesters. These machines have replaced the large, temporary labour force of Summer Nomads for whom harvesting was a principal source of income.

imagined. Moreover the credit for the real increases in yield that were made must be shared between mechanisation (and the deep ploughing and other improvements in cultivation which this allowed), improved crop rotation, new varieties, the fertility of virgin land, the excellent climate of the 1930's and the increasing use of fertiliser.

It would be equally true to say that mechanisation led to the over-extension of fertile soils, the misuse of marginal hilly land for cereals, reduction in the quantity of soil humus and soil erosion. Mechanisation also cut down the manpower per hectare. In this latter respect the combine harvester played a critical role (Pte. 17, p. 161), as discussed in chapter 5.3 (p.139ff.), by minimising harvest labour.

These evils had become manifest by the outbreak of the Second World War and measures to counteract them were initiated in the late 1940's. Unfortunately, however, no solution was found to the growing problem of rural under-employment although the increasing use of irrigation created some additional work.

The great advantage of heavy machinery was that it made the modern farmer relatively independent of the climate as far as preparation of the land was concerned. Work could continue during the summer months when the ground would otherwise have been too hard to allow machines to penetrate the soil and the final stages of seed bed preparation did not have to await the autumn rains. The area sown varied relatively little from year to year though, even in the LMV, the record shows that too much or too little rainfall reduced the area sown. The mechanised farmer still hoped for early autumn rainfall (August/September) to allow early preparation of the seed beds; for example the August rainfall of 1953 and 1959.

<u>6.4 Ploughing and Tillage</u>. From the beginning of the colonial period French experiments with techniques of cultivation fully recognised the climatic problems with which they had to cope and, where possible, tried to turn them to advantage. The local farmers were totally dependent on autumn rainfall to soften the land before the preparation of a seed bed could begin. As Boeuf (1932) pointed out, the iron-pointed wooden plough could only turn soils hardened by the summer drought when the soil was very light and sandy. The peasants awaited the autumn rains to make their first ploughing and a second rain before they were able to sow and cover the grain by a second ploughing.

Mechanical ploughing, even with the clumsy power of traction engines which the French first used, allowed the farmers to begin preparing the land much earlier. It also allowed larger areas to be cultivated and opened up virgin land; breaking up long-compacted soil, allowing deep penetration of rain and stimulating the activity of nitrifying bacteria.

But the method and timing of ploughing was to come under considerable discussion. Ploughing was originally done in summer. Even when the biannual rotation became common the fallow was ploughed in summer after the plants - amongst which were a high proportion of nitrogen fixing legumes - had matured and seeded.

The alternative was to plough in spring but this meant that the fallow or the secondary cereal (barley or oats) had to be cut early and used for fodder. But the advantages of spring ploughing over summer ploughing, first studied in detail by Albert Trouillet in 1894 (quoted in Boeuf, 1932, p. 309) were manifold. Firstly the cost was minimised. Secondly the soil was cut and broken up more effectively and the weeds were destroyed before they could produce their seeds instead of the seeds being buried, as was the case with summer ploughing. Thirdly there was a chemical effect of the greatest importance for the fertility of the soil. When the earth is turned in the spring, at a time when it is moist, it provokes an intense nitrification which continues into the summer for as long as the moisture persists under the mattress that tne surface, loosened by the plough, has created as an insulating layer against the sun's heat. Summer ploughing, on the other hand, by breaking the ground at the time of the greatest summer heat, speeds the dessication of the soil, and the nitrifying bacteria, deprived of this essential element, lose all activity.

A more recent opinion, based on experiments in Arizona, Harle (1958), supports the argument developed by Trouillet. After summer ploughing the upper soil temperature can exceed air temperature, so that the living organisms in the soil die and the soil becomes; 'calcined, dry, sterile' (p. 112).

Spring ploughing, when it was most effective, incorporated the principle of dry-farming; the conservation of soil moisture by maintaining a very non-compact surface layer of 10-15 cm. to act as an insulating layer. The top layer dried rapidly but preserved the water in the lower soil. After any hot season rain the surface mulch had to be kept lose by using harrows and cultivators, which meant that dry-farming was not an easy option to follow. The land demanded attention throughout the summer months.

The science of ploughing was further advanced by Cailloux at Koudiat, in the Great Plains. He found that deep ploughing to a depth of 40-45 cm. made the soil more fertile, greatly increasing the activity of nitrogen fixing bacteria. This advance coincided with the development of wheat varieties which required high concentrations of soil nitrogen for them to give their highest potential yields. The rapid adoption of deep ploughing by the colonists in the major cereal regions of Tunisia was assured.

By 1928 Cailloux had perfected a method, which incorporated deep ploughing, of preparing a good seed bed (Boeuf, 1932) for use with the commonly practised Wheat-Fallow rotation. Using

Table 30. The Cailloux Method of Soil Preparation for Wheat after Fallow.

source: Boeuf, 1932, p.335/336.

Step	Month	Activity
1	June/July	Harvest
2	July/Aug/Sept	Ploughing to 45 cm: must be finished before the autumn rains.
3	Aug/Sept	Surface cultivation a fortnight after the first rains, to kill weeds.
4	Jan/Feb/March	First deeper cultivation (12-15 cm.) and harrowing.
5	April/May	Second deeper cultivation: delay as long as possible to kill the summer weeds.
6	May	Hand weeding (after two weeks) to kill tufts of wild oats and other weeds.
7	June/July	Second ploughing (polydisc) to kill bindweed.
8	Aug/Sept	Cultivation to kill weeds: fortnight after first rains.
9	Oct/Nov/Dec	Sowing

this technique, outlined in Table 30, as well as keeping strictly to the Wheat-Fallow rotation and applying superphosphate, Cailloux obtained good yields even in poor years. In 1921/22, for example, with only 260 mm. of useful rainfall he obtained 14 ql/ha. in spite of a complete drought after 23 February and a sirocco at the end of April.

Boeuf (1932) went on to recommend this method for the 350 mm. to 500 mm. rainfall zone (which includes all the LMV). He suggested that: 'during the summer months which follow the harvest, break the ground to a depth as great as possible to facilitate the penatration of rain, often torrential, which tends to run off if the ground is sloping... or accumulates in the depressions' (p. 336).

'During the winter, spring and summer which follows keep the land soft and free from weeds by appropriate surface cultivation' ; cultivation to a depth of 12-15 cm., then harrowing the weeds before sowing.

This meant that two experts, Boeuf and Cailloux, were advocating summer ploughing; a method which had been severely criticised as early as 1894. They were advocating a policy which could help to sterilise the soil reduce the level of nitrification and plough in weed seed rather than kill the weeds. However Cailloux had foreseen the latter problem; a glance at Table 30 will show the importance he placed on keeping the soil completely weed free.

Within a few years the Cailloux system, or modifications of it, became standard practice. The biannual rotation, as practised in Tunisia with the regular use of superphosphate, included a deep ploughing, sometimes down to 40-45 cm.

Poletaef confirmed that this was true for the whole of the LMV when he reported that in the regions of Tunisia which received 300-500 mm. of rain a year, and where the modern system was based on the Wheat-Fallow rotation, the land was ploughed after the harvest (the so-called 16 month ploughing). 'This ploughing is considered more and more advantageous as it is made deeper and earlier'(Poletaef, 1954, p. 1).

It may be accepted that ploughing, particularly deep ploughing, has many values. It controls weeds and prevents ground becoming compacted, allowing it to be prepared for sowing even in the absense of autumn rain. The deep ploughing of land previously uncultivated or not turned deeply for several years is important to help create and maintain a uniform, deep soil, to spread organic matter and fertiliser and to destroy bindweed and other weeds. However the usefulness of regular deep ploughing - every two or four years - may be questioned. It can be beneficial but its effects depend both on the time of ploughing and on the rainfall between ploughing and the subsequent harvest. Deep ploughing affects yields indirectly; acting through the concentration of water and nitrogen in the soil.

Because there were doubts about the effects of deep ploughing experiments were begun in 1935 to further understand the relationship between soil fertility, ploughing and wheat yields.

The first of these, run from 1935 to 1939 (Poletaef, 1946) conclusively proved that the sooner ploughing was done after the harvest - leaving 16 months between ploughing and sowing - the greater was the concentration of soil nitrogen in September of the following year. Similarly early ploughing allowed time for the preparation of a good seed bed which gave a better start to germination. Nevertheless the highest yields were on the plots where the ploughing was done in the summer immediately preceding sowing, where the soil was still in 'large, hard clods' and the concentration of soil nitrogen at sowing lowest.

The reason for this is probably that in a finely prepared seed bed the rain water penetrates slowly and washes each soil particle free of nitrogen salts but in the cloddy soil the water would penetrate rapidly so that the interior of each clod would be wet but not washed.

In addition the better aerated, cloddy soils allow nitrogen fixation to take place during the growing season. In the experiment at least half of the nitrogen absorbed by the plants on these soils was fixed during the growing season.

To examine in more detail the effects of deep ploughing on soil nitrogen and soil water, compared with a control worked to only 14-18 cm. deep, a longer experiment (Poletaef, 1954) was conducted from 1946/47 to 1952/53; a period which fortunately included dry and wet years.

Deep ploughing 16 to 17 months before sowing, by drying the land, reduced nitrification in the summer but, compared with the control, increased it in the winter and greatly increased it the following summer; up to a gain of 35% (or 30 kg. of nitrogen per hectare) mostly in the 20-40 cm. level.

In the wheat year, when the rainfall was heavy, the upper 20 cm. of the soil tended to be more susceptible to leaching than the control - 13 mg. of nitrogen per kilogram of dry soil instead of 9 mg/kg. This may be more significant than it seems, affecting the early stages of plant growth.

Deep ploughing in autumn or late second spring firstly depressed nitrification then greatly speeded it. At the end of the fallow the land had up to 34% more nitrate than the control, but leaching during the crop year was faster.

Lastly deep ploughing three months before sowing had much less effect but it confirmed that leaching of the cloddy soil was slower than in the control.

The effect of deep ploughing on the soil water is not nearly as great. At the most, with good rains and deep ploughing 16 months before sowing, the land may have gained 12 mm. of rain; sufficient for only a very slight increase in yield. It may be more important in the long run that the soil is exposed to the dessicating summer sun immediately after ploughing. The soil became as much as 20% drier than the control; which brings to mind the dangers of summer ploughing expressed by Trouillet and Harle.

However because it is difficult to generalise about anything so unpredictable as the Tunisian climate it is worth analysing the results of the deep ploughing experiment year by year before drawing any conclusions.

During the years of the experiment the rainfall was of three basic patterns: A, B and C.

A. Rainfall:

Year	Autumn	Winter	March/April
1946/47	65 slight	233	16 low
1947/48	39 to	135 average	62
1949/50	93 average	180	134 high

Although a high rainfall is normally important in obtaining a good harvest its role was negligible compared with the effects of the date of deep ploughing. The ploughing at the start of the fallow increased yield while the ploughing of the second year decreased yield. In the first case the quantity of nitrogen in the soil at sowing was very high and there was no heavy rain to leach it. In the second case the ploughing in the second summer encouraged dessication of the soil and the low autumn rainfall prevented this being made good. In both cases water was the limiting factor on yield.

B. Rainfall:

Year	Autumn		Winter		March/April	
1950/51	139	good	96	dry	36	dry
1951/52	233		156	average	48	

In both years (above) at the time of sowing, the quantity of nitrogen in the soil was high due to good spring and/or early autumn rainfall (high in September 1951). But in 1951 the high level of soil nitrogen did not produce a high yield; soil water was the limiting factor in 1951 - an unusually dry year. In 1952 the good harvest was further improved on the land ploughed three months before sowing, which allowed the soil to absorb the heavy rains of September (reduced run-ff) and limited leaching.

C. Rainfall:

Year	Autumn		Winter		March/April	
1948/49	144	good	326	average to high	43	dry
1952/53	143		208		108	wet

In both the above years the yield decreased as the time between deep ploughing and sowing increased. There was no possibility of a shortage of water so the effect must have been due to the increased leaching of nitrogen in the more homogeneous soils.

In conclusion it can be seen that the standard practice of regular deep ploughing 16 months before sowing, used by the modern farmers of the LMV had mixed advantages and disadvantages.

It was certainly useful in maintaining a deep homogeneous soil which encouraged the deep penetration of plant roots and it was perhaps essential for breaking up long-compacted virgin soils and so allowing air and water to penetrate deep into the soil where they stimulated nitrogen-fixing bacteria to intense activity; nitrogen concentration up to 25% above the control three years after execution.

Deep ploughing can change the water balance in a soil in two ways. It can leave the soil much drier at the end of a Tunisian summer which itself can have good and bad effects; destroying humus and killing both bindweed and other, beneficial, soil organisms. Also a dry soil prevents nitrogen fixation. But deep ploughing can increase the quantity of soil water - though by only a small amount. It also allows heavy rain to penetrate the soil rather than run off. In this way erosion is, to a small extent, reduced.

Summer ploughing, as Trouillet knew, comes after weeds have matured and dropped their seed so that the plough turns in the seed instead of killing the plants. This danger can be overcome if the farmer carefully follows a system like Cailloux's but this demands vigilance and continual work throughout the fallow year.

The system of 16-month deep ploughing exposes the soil to the twin dangers of dessication following ploughing and rapid leaching in the autumn and winter of the crop year. In other words in areas where the Tunisian climate begins to approach extremes of dryness or wetness so the regular use of deep ploughing 16 months before sowing becomes more dangerous then beneficial.

Poletaef judged from the results of his experiment that 16-month deep ploughing would have tended to increase yields in seven years from 1930/1 to 1949/50 (six of them falling in the drier decade 1940/41 to 1949/50) but to have reduced yields in nine years (compared with ploughing three months before sowing) because of increased leaching of nitrogen salts.

But the village of Ariana, where the experiments were conducted, has a mean rainfall of just over 502 mm. a year compared with 420-450 mm. for the main agricultural region of the LMV. Probably in the drier LMV the system practised was the best from the point of view of nitrogen concentration and was complemented by the use of fallow which prevented the land becoming critically short of water.

Probably, therefore, the main danger of summer deep ploughing in the LMV lay in exposing the soil to temporary dessication; killing soil organisms important to the cycle of soil fertility and destroying humus.

6.5 Fallow and Crop Rotation. Before the French arrived in Tunisia only a small percentage of the land was farmed each year. Using traditional methods a patch of land was cleared, prepared, sown, harvested and then in the following years, except in the case of melk land near towns and villages, left alone. A fresh patch of land was cultivated. This system could not be dignified by the name rotation. The full potential of the land had hardly been touched, in spite of which yields were low and extremely irregular being entirely dependent on the climate.

Valdeyron (1953) termed the period up to 1900, for the majority of farmers as, 'prehistoric'; a period of minimum investment and maximum dependence on providence.

The efforts of the colonists were directed towards increasing total production and yields while trying to eliminate the null year. One null year was capable of completely wiping out the hard earned profits of a series of average to good years.

From 1900 the use of fallow as fundamental to the rotation became more and more widespread - beginning at Bordj Toum in the LMV. For the first time the farmers agreed to work the soil with no hope of a return for that year in order to build up a reserve of soil moisture to ensure a good harvest from the second year.

An early crop rotation used with fallow (Boeuf, 1932) was, Fallow-Wheat-Barley/Oats. The fallow was not cultivated but grew a wide variety of wild plants, including many nitrogen fixing plants, which were cut in April and the ground prepared for wheat. The barley and oats were used for forrage.

Ploughing was done between harvest and sowing - in summer

- which had many disadvantages (see ch. 6.4, p. 163ff.). Albert Trouillet altered the rotation to allow the major ploughing to be done in the spring of the fallow and forrage years. This considerably increased soil fertility allowing a four year rotation - Cultivated Fallow-Wheat-Forrage-Barley/Oats - in regions of rainfall like Bordj Toum.

This four year rotation became popular because it increased yields. However the wild forrage plants which ripen late (e.g. Sulla) were disappearing, leaving only the early flowering crucifers (Ptg. 18, p. 175) which have no value as forrage. The result was that cultivated forrage plants had to be sown; Fenugreek and beans/oats were tried. The latter was successful (and is still a major dry land forrage crop in Tunisia) but the former had to be abandonned because its seed were being mixed with the cereals causing an unpleasant smell in the bread.

The expense of growing cultivated forrage crops made the rotation less economic. It also demanded a careful preparation of the soil after wheat - in summer - which was both onerous and detrimental to the soil.

The forrage had two further disadvantages. Firstly it was a dirty crop; many weeds appear in it which disperse their seed before the crop is cut. Secondly it was seen that in zones of under 500 mm. rainfall the yield of the cereal after the forrage year was lower than after fallow.

For these reasons the farmers began dividing their land into two and adopted two, two-year rotations:

1. Cultivated Fallow-Wheat
2. Forrage-Barley/Oats.

As the tractor replaced the horse during the 1920's the

Pte. 18. Uncultivated Fallow near Medjez el Bab

source: Dutton, spring 1970

The fallow field has been left wild. A large variety of wild plants - weeds - are flowering and setting seed which will be turned in but not killed by the plough.

part under Forrage-Barley/Oats became small or non-existant.

In regions like the LMV (under 500 mm. of rain and highly mechanised) the Fallow-Wheat rotation became the rule (Fig. 19, p. 177). Boeuf (1932, p. 312) believed that; 'it has allowed the attainment, after 15 to 20 years of application, of such an increase of fertility that yields of 20-25 ql/ha. which previously no-one would have dared claim, have become common and yields passing 30 ql/ha. on fields of more than 100 ha. have stopped being rare exceptions'.

However the Fallow-Wheat rotation meant two years expenditure for only one crop. It also left the land with no vegetation cover through 17 months of sun and rain. Autumn storms, particularly where the land was not absolutely flat, led to erosion. Therefore, for all these reasons, better systems of rotation were still being looked for.

Martinier (of Montarnaud) farming in a region of under 400 mm. rainfall obtained a higher money return from a three year rotation:

Broad Beans: with deep ploughing and heavy superphosphate after the harvest.

Hard Wheat: with fertiliser.

Soft Wheat: with fertiliser.

But although Martinier extended the use of this rotation over 1,000 ha. he himself believed that a similar method was only to be recommended on land already improved by the Fallow-Wheat rotation strictly applied for many years and on condition that these lands should be sufficiently light to allow ploughing to be done in summer without leaving large clods of earth. It was only possible where there was agricultural machinery of sufficient power to ensure in summer a rapid and perfect pre-

Pte. 19. Land Farmed with the Fallow-Wheat Rotation in the LMV

source: Dutton, summer 1969

Stubble in summer after the harvest. Ploughing has begun at the base of the hill.

paration of the soil.

Boeuf considered that this rotation could be used on the light hill slopes where the summer preparation of the seed bed would not be too difficult and the soil needed continuous cropping to protect it against erosion.

The disadvantages of the rotation were considerable. Firstly wheat is itself a dirty crop; it encourages weeds which would have to be turned in with their seed in summer and the ground cleared of germinating weed seed in the autumn. Inevitably this would delay sowing the second wheat. Secondly the Martinier rotation is very demanding on soil reserves. Also the soil would not be wet enough in summer to allow much nitrogen to be fixed; a limitation which could only be overcome by liberal application of nitrogen fertilisers. But, more important still, a succession of dry years would be disasterous. Instead of yielding a low harvest the second wheat would yield nothing at all.

It is probably a good thing that very few farmers took to this more exacting rotation. In the LMV it remained normal to devote most of the land to the Fallow-Wheat rotation. Small amounts of secondary cereals and leguminous crops were grown as well, up to the end of the colonial period in 1964.

Perhaps the principal benefit of fallow is held to be the increase of reserves of water and nitrogen that take place during the fallow year, so that a good crop is assured in the following year. But this poses several questions. Could a higher mean yield be attained by another rotation ? Would nitrogen fertilisers in practice prove an equal or better alternative to the soil nitrifying bacteria ? What is the level of rainfall above which a two year reserve for one crop becomes unnecessary ?

The questions concerning the reserves of water and nitrogen are discussed below.

Water. There is no doubt that a fallow field under a carefully prepared mulch does build up its reserves of useable water. This was known in Tunisia by the 1920's. Table 31, drawn from an experiment at Ariana in 1929, indicates how great an

Table 31. Soil Moisture After Wheat and After Fallow: Water as a Percentage of Soil. (SBAT 1929).

source: Boeuf, 1932, p.316

	Soil Level	24 July	23 Sep.	25 Sep.
After Wheat	0-30 cm	5.6	5.1	
	30-60 cm	9.1	7.5	
	60-90 cm	9.5	10.1	
After Fallow	0-30 cm	8.3		10.0
	30-60 cm	13.2		12.8
	60-90 cm	14.0		14.4

effect a fallow can have on soil water reserves. Assuming that the soil water capacity was 16% a further 200 mm. of water, entirely absorbed, was needed to saturate the land after wheat, but only 80 mm. after the fallow.

Table 32. Rainfall Required to Saturate the Soil and Start Infiltration Following Wheat or Fallow. (mm).

source: Yankovitch, 1956, pp. 29-33.

In:-	Following:-	Mean	Minimum	Maximum
Fallow	Fallow	190	91	283
Wheat	Fallow	199	91	321
Fallow	Wheat	340	162	538

Yankovitch (1956) showed conclusively that the reserve of soil moisture after wheat was much less than after fallow. A far smaller mean total rainfall was needed, Table 32, to start infiltration in the plots following fallow than following wheat. But in both cases the difference between minimum and maximum was large; the reasons for this including differences in temperature, the nature of the rainfall and its distribution through the year, the yield of wheat, the varying coefficient of transpiration of different varieties of wheat and also the rainfall of the previous spring. It must also be noted that a fallow is by no means a perfect water trap. The mean quantity evaporated from a cultivated fallow, saturated with water was 366 mm; varying between 283 mm. and 446 mm.

Fallow does then increase the reserve of water in the soil; much of two years' rainfall was made available for one year's crop. Fallow farming overcame the natural geographical barrier to permanent agriculture posed by low rainfall and lack of irrigation water. But defining the point at which this becomes necessary is more difficult especially in a region where the reservoir of water trapped in a fallow can lead to leaching of mineral salts the following year if the autumn or winter rains happen to be heavy.

The water requirements for wheat vary considerably between varieties (they are small for early-maturing small-leaved plants) and regions. But in general terms, for the northern part of Tunisia (Boeuf, 1932) about 300 mm. of rain should theoretically be sufficient to give a harvest of 20 ql/ha. of grain. This quantity can easily be held in the top 1.5 m. of soil, but it must be remembered that the distribution of the rains can have a greater importance than their total amount.

The distribution of rainfall in Tunisia, a country with a Mediterranean climate, can vary tremendously from year to year (see Fig. 11, p. 56). A region with a mean of 300 mm. a year would often receive much less than that quantity of useful rainfall. Therefore the boundary below which fallow becomes essential must lie well above that figure.

Before the war it was generally accepted that the level lay between 500 mm. and 600 mm. (Boeuf, 1932). In practice the level accepted by the farmers was probably somewhat higher.

But the importance of fallow farming in increasing yields by building up the reserves of soil moisture has been overemphasised by some writers. For example, Knight (1928/29) convinced of the value of fallow dry-farming as developed and used by the French in Tunisia, stated that; 'the effects of Europeanisation of methods in parrying the effect of dry years are very apparent in the statistics'(p. 90).

The statistics he refers to are the yields for wheat grown by the modern sector and by the non-Europeanised traditional farmer; the yields on the modern farms were higher in the statistics. However Knight's conclusions cannot be accepted because in his comparison he takes into consideration neither differences in rainfall nor differences in the quality of the land farmed by the two sectors. Perhaps even more important, he does not allow for underestimation of yields on the traditional farms. This may be by as much as 100% (see ch. 2.2, p. 22ff.).

On the other hand one unexpected result of Yankovitch's 22 year experiment at Ariana, Table 33, was that in the years when low rainfall failed to saturate the fallow the harvest of the following year was particularly high. Yankovitch makes no attempt to explain this anomaly but it is certain that one result of the non-saturation of the fallow was that no nitrates were leached to a depth greater than 2 m. and leaching

Table 33. Fallow-Wheat Rotation; Yield Following non-Saturated Fallow. (ql/ha.).

source: Yankovitch, 1956, p. 39

Year of Fallow	Yield in Subsequent Year
1942/43	34.6
1945/46	28.0
1947/48	28.9
1950/51	37.0

was delayed and reduced in the first part of the following year. It also shows that a fallow need not be saturated in order to obtain sufficient nitrogen for high yields. But it must be noted that Ariana has a higher rainfall than the major cereal zone of the LMV and the plots in which the experiments were done tended to augment this rainfall by 15-20%. For these two reasons the danger of low rainfall at Ariana would have been masked.

Too much rain - or too great a penetration of this through the soil - is recognised as a danger to cereal yields. Boeuf (1932) defined this point as 600 mm. of rainfall. Above this point and it is, he thought, sometimes necessary to 'sponge' the soil with a crop of beans or chickpeas. Chickpeas were grown in 1957/58 on a farm mentioned by Séguéla (1959B) to be followed in the very wet year of 1958/59 by wheat. Yields in that year were generally low but this farm produced 27 ql/ha. of hard wheat. The chickpeas would have affected this yield by adding to the reserves of soil nitrogen and by leaving the soil relatively dry at the start of the 1958/59 season.

A major danger of leaving land under fallow when it was not strictly needed in order to conserve water was erosion. The farming community was becoming aware of the destructive force of erosion (see ch. 6.8, p. 217ff.) by the end of the 1930's which led the experts to lower their estimation of the rainfall limits above which fallow was not necessary. Their opinion was not based on true experimental evidence but it did stem from familiarity with the practices of fallow under the Tunisian climate.

In 1942, Chabrolin, head of the SBAT, summarised the conditions under which fallow should be retained, or abandonned. He believed that on alluvial soil of medium to heavy consistency the biannual rotation remained obligatory in the regions where the total rainfall lay between 350 mm. and 500/550 mm. But in the case of the light hill soils, particularly where they were hamri soils overlying a tuff subsoil, and the rainfall above 450 mm., he recommended that the biannual rotation be abandonned because it encouraged the leaching of nitrogen salts and favoured erosion. However, when, in the case of this soil type, the rainfall was 300 mm. to 400/450 mm. he believed that the biannual Fallow-Wheat rotation should be retained.

Nitrogen. As far as nitrogen is concerned Yankovitch showed that in November after fallow if a field contains 100 kg/ha. of nitrogen then after wheat it will have only 20-30 kg/ha. But although a fallow produces much more nitrogen, the Fallow-Wheat rotation has a very high ratio of nitrogen leached to nitrogen used. It was the most inefficient, Table 34, of the rotations tested.

However the most important single test of the effectiveness of any rotation must be yield. The best experimental evidence is again provided by Yankovitch. An analysis of the yields

Table 34. Nitrogen Leached to Nitrogen Used by Different Wheat Rotations With and Without Fertiliser.
source: Yankovitch, 1956, p. 169

	Without Fertiliser			Full Fert.
	Fallow-Wheat	Fallow-Wheat-Legume-Wheat	Continuous Wheat.	Cont. Wheat
Nitrogen leached	1257.6	853.4	1035.3	850.6
Nitrogen used	793.3	1286.3	961.5	1417.3
Total	2050.9	2139.7	1996.8	2267.9

of 1948/49 to 1954/55, a mixture of wet and dry years coming after the rhythm of the rotations had been established for more than a decade, gives the most significant picture.

When not using fertiliser (and with medium depth ploughing) the change from continuous wheat to wheat and fallow increased yield from 11.3 ql/ha. to 27.6 ql/ha. cropped; the latter being equivalent to 13.8 ql/ha. arable. But continuous wheat with complete restitution of fertiliser (see Table 36, p. 196) yielded 24.1 ql/ha. cropped. The effect of deep ploughing on these rotations was to decrease yields over this period, thereby supporting the result of the deep ploughing experiment.

The final rotation tested, Fallow-Wheat-Forrage-Wheat, did not significantly improve yields; its value depended on the demand for forrage crops.

As a result of his initial experiments Yankovitch (1947) was able to review the question of the value of the Fallow-Wheat rotation. He believed that in spite of its faults it was a viable rotation particularly suitable for bringing virgin land into cultivation and, 'inevitable', on heavy land receiving less than 500 mm. of rain. He also believed that it was not possible in agricultural practice to adopt the continuous wheat rotation because of the multiplication of weeds, diseases and parasites of wheat and, in addition, because of the dry years. But he thought that there was no serious obstacle against cultivating wheat for several years without interruption. This was dependent upon the farmers obtaining and using adequate supplies of fertiliser, regularly and efficiently.

But before accepting Yankovitch's conclusions for the LMV there are two important factors to consider. Firstly it was easy for Yankovitch, on his small experimental plots, to maintain the land absolutely free from weeds. On the farm the weeds - particularly bindweed and wild oats - are much more difficult to eradicate (see ch. 6.7, p. 203ff.) especially where continuous cultivation is the rule. Secondly the plots at Ariana, as mentioned above, received at least 30% more rain (Yankovitch, 1956, pp. 15-21) than the majority of the modern farms in the LMV. Therefore in the LMV the greater likelihood of dry years combined with the difficulty of preparing a weed free seed bed between harvest and sowing and the danger of disease and parasites becoming endemic, would forbid continuous cultivation of wheat.

A final criticism of the use of fallow which should be considered here is that it lessened the soil fertility by reducing the amount of soil humus. Humus can improve the structure of the soil and act as a source of nitrogen for the wheat plants. Yankovitch showed that the level of humus did drop after using the biannual rotation.

Essafi (1964) believed that it was this drop in humus that explained the low yields of the 1940's. But he produced no evidence to support this opinion, nor to explain the improvement in yields during the 1950's. He also ignored the principal reasons for the lower yields, advanced above, so his opinion can carry little weight.

The reserves of nitrogen in the soil can be built up by adding fertilisers containing nitrogen (see ch. 6.6, p. 196ff.) or by increasing the concentration of organic matter. Yankovitch did the latter, by introducing a leguminous crop into every second fallow, but this actually tended to lower the yield of the subsequent wheat crop because it dried the soil. On the other hand fertiliser improved yields regularly in spite of a drop in humus.

As for the structure of the soil, Valdeyron (1957), concluded that the problems of soil structure posed by dry-farming and a semi-arid climate in Tunisia did not seem to seriously interfere with the conduct of rationally established cereal farming.

He believed that the appropriate application of fertiliser would overcome problems of soil fertility.

Conclusions. It is clear from the 126 farm data that the colonist farmers of the LMV kept to the Fallow-Wheat rotation up to their departure in 1964. Roughly half of their arable land was kept under fallow each year though the proportion of fallow did drop in the final years (see ch. 7.4, p. 244 and Table 42). The area under secondary cereals, leguminous crops and other dry-farmed annuals was small; 15% to 25% of the cropped area.

Most of the colonial farms were situated south and east of the Medjerda river (Fig. 2 , p. 12) in the drier part of the LMV. The mean rainfall in this region lies between 375 mm.

and 450 mm. per year. None of the expert advice suggested that with the aid of this rainfall, on the heavy alluvial soils of the plains, the use of fallow should be stopped. Even the conclusions of Yankovitch that the wheats could be grown for several years in succession did not apply to this region.

However not all the colonial land was flat and alluvial. Much of it fell into the category of hamri or light hill soils overlying tuff. Here the preparation of the soil was easier, between harvest and sowing, and the twin dangers of poor soil structure and soil erosion much more acute. On these soils the use of cultivated fallow, which leaves the soil without vegetation for 16 to 17 months out of the 24, should be avoided wherever possible.

This is not to say that the Europeans were guilty of always using the Fallow-Wheat rotation under these conditions. In the hilly parts of the LMV where the Europeans farmed and where the rainfall was sufficiently high, the percentage of land under vines and fruit trees was highest (see ch. 6.8, p. 210ff.). In the drier regions the better farmers terraced their land where necessary. An example is shown in Plate 26 (p. 230).

Pissaloux (1955), who in general defended the record of the European cereal farmers, was critical of the extension of the Fallow-Wheat rotation from the plain to the hill flanks. He blamed the Europeans and the Tunisians but saw that; 'the only difference is that the Europeans very quickly realised their technical error and are now beginning to fight correctly against erosion while the Tunisians are slower to understand this need' (p. 555); see Pte. 20, p. 188.

But there is no doubt that the Fallow-Wheat rotation was

Pte. 20. A Peasant Hill Farm in the LMV

source: Dutton, summer 1969

An example is shown above of marginal peasant hill farming; growing wheat and barley on unstable soils.

The mountain in the background is the djebel Ressas (795 m.) which is the highest point in the LMV.

being used by the colonist farmers on some light hill soils up to 1964, when they left. It is difficult to blame the farmer entirely because if he had cropped these soils each year and taken due measures to preserve their quality he would have worked at a loss. At any rate he could quote the advice of the experts at the SBAT who said that up to 400/450 mm. rainfall the Fallow-Wheat rotation was obligatory.

The burden of responsibility must lie with the experts and the advisory service. The danger of erosion and misuse of the land was only appreciated by them at the end of the 1930's. Action was taken after the war (Pte. 21, p. 190) but too little and too late.

The farmers working in the wetter parts of the LMV - the northern region and the hill areas to east and west - could almost certainly have obtained overall increases in yield by reducing the number of fallow years and augmenting the supply of nitrogen by the use of fertilisers. A small amount of fallow would have remained necessary to cater for the dry years and to control weeds effectively.

Pte. 21. Boundary Between Dry-Farming and Irrigation on the Djedeida/el Bathan Road

source: Air survey of Tunisia 1962/63

The low land to the south of the road (crossing the picture) is intensively farmed using water brought by the OMVVM. North of the road the low hills are beyond the reach of irrigation. They only support secondary cereals but they have been terraced by the OMVVM.

<u>6.6 Use of Fertilisers</u>. In 1908, Minangoin published a paper on the growth of cereals in Tunisia. Among other things he discussed the use of fertiliser (p. 92) saying; 'today the soil is, if not exhausted, at least strongly impoverished', principally of phosphoric acid. As a result of the growth of cereals phosphates were being continually removed from the soil. Minangoin thought that the soil would become completely exhausted unless phosphitic fertilisers were used. He recommended the application of 300 kg/ha. of superphosphate which was giving excellent yields to those colonists already using it in the north.

This article tells us that the experts at least were already in 1908 fully aware of the importance of fertiliser for maintaining both high yields and the quality of the soil. Some colonists in the north of the country were already using the same quantity of superphosphate that they were to use in the 1950's. The concern for the fertility of the soil is surprising for its date; fears of soil exhaustion was a theme common in the years after the Second World War but both between the wars and in recent years - with Mexican wheats - the land has shown itself capable of overcoming the feared loss of fertility and yielding heavily. Stories of soil exhaustion cannot be taken at their face value.

The last point of interest is that the article refers only to phosphates, to the entire neglect of the role played by nitrates in promoting high yields. Experimental work in nitrate fertilisers, though not increase in the quantity used, grew roughly parallel with the introduction and spread of the force wheat F/A. In 1933/34 Yankovitch began his 22 year trials which underlined the dominant importance of nitrates on yield of F/A.

However as late as 1943, Pocthier, when giving an extremely optimistic address about the future of cereals in Tunisia, explained the increase in productivity by: 'The widespread useage of fertilisers and, in particular, of superphosphate resulting from the nearly constant shortage of the element P_2O_5 in all our soils. The farmers who spread 4 ql/ha. of super. are today very numerous' (p. 5). Pocthier makes no mention of nitrate fertilisers or nitrates in the soil. He believed that the problems of wheat cultivation in the north of Tunisia had been overcome. But the low yields of the mid-1940's were to undermine this optimistic spirit (although they could be partly explained by the poor climate and the war) and make the farmer, the government and the research worker intensify their efforts to maintain and improve yields. In the post-war years the use of nitrogen and other fertilisers was to greatly increase.

One reason for the neglect of nitrogen fertilisers before the war lies in the system of cultivation elaborated and adopted by the colonists. Certainly as early as 1894 the importance of nitrogen and of nitrogen fixing bacteria in the soil was fully appreciated and taken into consideration when methods of improving rotation were being tested. In 1894, Trouillet (quoted by Boeuf, 1932, p. 309) advocated ploughing fallow land in spring rather than summer because, amongst other reasons, it; 'aerates the soil at the time when it is wet and provokes an intense nitrification which continues into the summer for as long as the moisture persists'. When the soil was dry Trouillet knew that the nitrifying 'ferments' lost all their activity because they were deprived of water.

In 1932, Boeuf, commenting on the three year rotation - Beans-Hard Wheat-Soft Wheat - introduced by Martinier, thought that it was exhausting because it left the soil no opportunity when it was sufficiently wet to be the seat of microbe activity. He realised that the legume (beans) helped restore some nitrogen to the soil but said that the necessary corrective was to add phosphoric acid and sometimes potash. So Boeuf, the authority on wheat in Tunisia, although worried by possible shortage of nitrogen, was not able to advocate the useage of nitrogen fertiliser to reconstitute the mineral reserves of the soil when the land was under permanent cultivation. The fallow, for Boeuf, remained the most effective source of nitrogen although a leguminous crop could also be 'of some value' to this end.

Thus for the experiment in which Yankovitch wished to imitate the typical system under which the French grew wheat in Tunisia he noted that (1956, p. 54); 'the biannual rotation is practised in Tunisia with the regular use of 300-400 kg. of super IphosphateI to the hectare'. No mention of nitrates. Yankovitch used 300 kg. of phosphate applied a month before sowing.

But although by 1900 the importance of nitrogen to the plant and the importance of the soil as a nitrogen 'factory' were fully appreciated - and in subsequent years all changes in techniques and crop rotations took this fully into consideration - what was not fully understood was the mobility of nitrogen in the soil.

One major difference between nitrogen salts and other minerals is that when the nitrogen is in a form in which it can be assimilated by the plant from the soil it is very soluble in water and hence easily leached. For this reason any factor which tends to increase the drainage of water through the soil will tend to increase leaching of nitrogen and consequently inhibit vegetative growth and decrease yields.

Failure to appreciate this meant that methods standard to the technique of cereal farming in Tunisia, such as deep ploughing 16 months before sowing and the Fallow-Wheat rotation, not only fixed large quantities of nitrogen but made this reserve extremely vulnerable to the leaching force of winter storms.

The early experiments of Poletaef (1946), 1935 to 1939, showed how much leaching could affect yields, yet shortage of water was still considered the primary factor limiting yields well into the post-war period. As Valdeyron (1949) said, the modern farmers were aiming essentially at sheltering the cereals from drought the : 'primordial factor limiting yields in Tunisia' (p. 115).

He blamed the mediocre yields often obtained in 1949 in the north of Tunisia on the dry spring which, he said, had dried the top decimetres of the soil so that the plant could not draw from them; 'nitrogen liberated by the bacteria avid for oxygen and above all for phosphates that the farmer has placed here' (p. 114). He thought that to obtain a normal grain the plant had to draw its nutrients from the upper soil even if it drew from the subsoil a complement of moisture.

Table 35. Rainfall at Montarnaud in 1948/49. (mm).
source: data from BIRH

	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.
1948/49	4.7	49.4	72.2	147.2	61.6	42.4
Mean:1917/63	33.3	44.9	43.8	48.2	51.5	37.7

	Mar.	Apr.	May	June	July
1948/49	52.6	18.5	28.6	1.8	0.0
Mean:1917/63	42.8	34.9	21.9	12.5	2.7

However there are several criticisms of this argument. To begin with the spring of 1948/49 was not dry, Table 35; April was the only month to fall below the mean. In fact the outstanding feature of the year's rainfall was the very high precipitation in November, December and January. The upper soil could not have dried out but neither would it have contained much soluble nitrogen which would have been strongly leached by the winter rains to a depth greater than 1.5 m. - beyond the reach of the plants' roots. The mediocre yields of 1948/49 were not caused by the dryish April but by the extremely wet December. This analysis gets confirmation in the results of Poletaef's experiment for the same year; see ch. 6.4, p. 170.

If Valdeyron, head of the SBAT, as late as 1949, did not emphasise the danger of an excess of rain reducing yields by leaching the nitrogen it is not surprising that the farmers were not prepared for it either.

It was not until the work of Yankovitch and Poletaef had been completed in the mid-1950's that it became more generally known that heavy rain could leach the all important nitrogen out of finely divided soils; soils, for example, that had been deep ploughed 16 months before sowing.

By 1955, Valdeyron himself was able to make the point that when the ground is perfectly prepared as a seed bed, so that nitrification is rapid, if early rains arrive the results of this work are carried deep without any hope of compensation: 'The harvest which follows rainy winters, above all on light land, are as low in grain as in organic residue'(p. 149).

Probably the worst single month to have heavy rain, from this point of view, is September. The effects are multiple.

Firstly it brings an early and abrupt end to the activities of the nitrifying bacteria by cooling the soil and limiting the supply of oxygen. Secondly, with the ground at its least compact, leaching is maximised.

The agricultural press began to advise the application of nitrogen fertilisers when the autumn or winter rainfall had been particularly heavy. The response was immediate. In the spring of 1958, following an extremely wet winter, the country's reserves of nitrogen fertiliser; 'had been suddenly exhausted by a strong demand' (Séguéla, 1959A, p. 16). Nitrogen fertilisers resulted in a marked increase in yield of both soft and hard wheats on the experimental stations. The European farms apparently reflected this improvement. Yields in 1958 were reasonable and many farmers noted a very clear reduction of mitadinage in their harvest of hard wheat.

Table 36. The Yankovitch Trials. Mean Yields 1948/49-1954/55.
source: Yankovitch, 1956, p. 89.

Rotation	Fertiliser	Ploughing (cm)	Yield (ql/ha.) Wheat	Forrage (dry wt)	Beans
1. Wheat-Fallow	None	17	13.8		
	Superphos.	17	13.1		
	Superphos.	40	11.2		
2. Continuous Wheat	None	17	11.3		
	Partial + Fertiliser	17	21.6		
	Complete * Fertiliser	17	24.1		
3. Wheat-Fallow-Forrage-Fallow	None	17	12.8	12.8	
	Fertiliser	17	15.5	14.0	
	Fertiliser	40	13.6	15.5	
		17	14.2		6.0

+Fixed amount of nitrate, phosphate and potash at sowing.
*Complete replacement of salts used by plant or leached.

The marked effect of nitrogen fertiliser on yield is well illustrated by the final result of Yankovitch's work. The highest yields were obtained, Table 36, from continuous wheat with complete restitution of fertiliser. But these yields were not sufficiently superior to those from partial restitution of the soil to make them economic. This is because the fertiliser, applied just before sowing, could not depend on sufficient rain after sowing to carry the fertiliser into the soil. In dry years the wheat germinated in the plots with complete fertiliser in a layer too rich in soluble salts and its growth was thus hindered rather than helped.

Superphosphate when used as the only fertiliser with the Fallow-Wheat rotation actually depressed yields because in the wetter years, when nitrogen was strongly leached, the balance between nitrates and phosphates was destroyed.

Yankovitch found that only rarely did a wheat, germinating in good time, become short of water in winter or even spring, though this sometimes caused the yields of wheat after forrage to drop. On the other hand a shortage of water can mean a better aerated soil with, consequently, a greater activity of nitrogen fixing bacteria, and no leaching; the yields in the middle years of the experiment were not less than those of the later years which were usually wetter. Yankovitch was thus drawn to the conclusion that 'the fertility of the soil is more important than the water of the soil' (1956, p. 209). In the case of continuous wheat without fertiliser rain water drained through the 2 m. deep plots in each year except 11, 13, and 15, but the yields became lower and more irregular. On the other hand the wheat with complete restitution of the soil gave high yields during the drier 1940's and the wetter later years.

But it must be emphasised, once again, that the design of the plots augmented the natural rainfall by 20%. This meant a mean of 586 mm. from 1933/4 to 1954/55 instead of 488 mm. And Ariana has, at any rate, a considerably higher rainfall than the main cereal regions of the LMV.

In the LMV the problem of leaching would be less important and the problem of water shortage more acute. But there is

Table 37. Wastage of Mineral Reserves at Ariana (kg/ha.): Without the Addition of Fertiliser.

source: Yankovitch, 1956, p. 191

	Nitrogen	Phosphate (P_2O_5)	Potash (K_2O)	Calcium (CaO)	Manganese (MaO)
Quantity at Start	14,760	17,640	69,300	5,410,000	43,200
Mean Loss p.a. '41/42-'52/53:-					
1,All Fallow	98.1	0.29	18.0	95.9	38.9
(Years to exhaustion	150	60,830	3,850		1,111)
2.Wht-Fallow	73.3	12.8	39.0	61.4	28.5
(Years to exhaustion	205	1,400	1,777		1,516)
3.Wht/Fa/Leg/Fa	78.3	20.4	79.0	57.6	27.9
(Years to exhaustion	192*	865	877		1,548)

*Does not include amount fixed by leguminous crop.

little doubt that in the long term shortage of nitrogen would be the critical factor limiting yield. Without the addition of fertiliser the reserves of the major soil minerals drop each year, Table 37, but the soil loses a much greater proportion of its slight reserves of nitrogen each year than of other minerals. Theoretically, without the use of fertilisers, the Fallow-Wheat rotation would completely exhaust the nitrogen reserves in

200 years. Unfortunately this was not known by the colonist farming community until the mid-1950's. However the mid-1950's marked the beginning of a period of political change, from independence in 1956 to land nationalisation and the expulsion of the French in 1964, that created a climate of uncertainty making farmers less likely to respond to new ideas. Nevertheless the imports of nitrogen fertiliser did rise (Fig. 22, p. 240) quite rapidly at this time.

Supposing that the application of 100 kg/ha. of nitrogen is needed to maintain the soil reserves this leaves the question of when to apply it to make maximum effect on yield.

The practice of applying nitrogen two to five days before sowing and then harrowing it in, can encourage shallow rooting, if the winter rains are light, making the wheat more susceptible to spring drought. Indeed if there is not a substantial fall of rain shortly after sowing the upper centimetres of the soil can be left so rich in nitrogen that germination is inhibited. On the other hand if the winter rain is very heavy much of the nitrogen will be leached before the plant first requires a large amount of nitrogen, Table 38, during tillering.

Application of nitrogen towards the start of tillering would seem ideal both because the plant needs a large amount and because sufficient rain can be guaranteed to dissolve the fertiliser and carry it down to the roots. But even this is not without danger; in 1958/59, an extremely wet year, many farmers reported that the application of nitrogen at tillering appeared to have spurred vegetative growth (Séguéla, 1959B) without making much impact on yield. This may have been because of the uniquely wet April, May and June of 1959 both causing leaching during the final phase of nitrogen absorption and mak-

Table 38. Nitrogen Absorbed by Phase for a Harvest of 8,000 kg/ha. Dry Weight.

source: Séguéla, 1959A

Variety	Nitrogen Absorbed Date	Total	By Phase	Growth Phase
Early Variety (Florence x Aurore)	9 Jan	3.97	47.10	Tillering
	3 Mar	51.07	18.49	Shooting,Heading
	4 Apr	69.56	18.90	Flowering,Grain growth
	4 May	88.46	2.72	Maturation
	Maturity	91.20		
Late Variety (Mahon)	22 Dec	3.14		
	14 Jan	7.78	22.52	Tillering
	4 Mar	25.66	17.19	Shooting,Heading
	12 Apr	43.35	12.88	Grain Growth,Maturation
	25 May	56.23		

ing the general conditions for grain growth very poor.

Again the late application of nitrogen, in March or April, can increase yield provided that sufficient rain falls to carry the soluble salt down to the roots. Unfortunately such rain cannot be guaranteed and if it does not come the fertiliser at the surface is not only wasted but can 'burn' the plant. Furthermore the late application of nitrogen after a very wet winter has weakened the plants, can reduce yield even if March and April are wet and, as was reported after the wet winter of 1957/58 (Séguéla, 1959A), encourage invasion of the crop by weeds at a time when it is very difficult to control them.

Yet many farmers spread nitrogen fertilisers in autumn partly because it was easier to do so on the drier land (before the winter rain) at the same time as the operation concerned with sowing.

In 1962, Essafi, recommended sowing with 100-120 kg/ha. of nitrate (20-25 kg/ha. of nitrogen) and adding 15-25 kg/ha. at the end of January. If the spring was very wet he recommended a further dosage at the beginning of March.

Conclusions. It was known from the beginning of the colonial period in Tunisia that increasing the concentration of soil nitrogen could greatly improve yields. Because of this, methods of deep ploughing and the use of fallow were continually improved and adapted to suit different rains and soils in the northern part of Tunisia.

But these same techniques of cultivation also increased the ease with which heavy rain leached the soil and this fact was not fully realised until after the Second World War. The Fallow-Wheat rotation reduced the danger of water shortage in the LMV only to increase the danger of an excess of water. The cultivation of wheat, a nitrogen demanding plant, in rotation with fallow was steadily reducing the reserves of nitrogen in the soils.

Because the problem was only fully understood by the mid-1950's, at the beginning of the period of political uncertainty the only major corrective measure was an increased useage of nitrogen fertiliser; the first period of growth of their importation (Fig. 22, p. 240) was from 1956 to 1958. But the European farmers of the LMV continued to leave nearly half their arable land under fallow and to plough or subsoil it to a depth of 40-45 cm.

Nitrogen fertilisers were not used very efficiently. They were normally applied in November, at a time when the land was rich in nitrogen after the fallow, although the plant did not require them until January, February and March. This was after the winter rains had had the opportunity to wash them beyond the reach of the roots.

However knowing when to apply nitrogen in a climate of such uncertain rainfall is problematic; to be judged to some extent according to the year. The experts did not speak with one voice and were of limited assistance.

The effect of nitrogen on disease could not be ignored. A shortage of nitrogen for the maturing grain caused mitadinage (see ch. 8.3, p. 274ff.) in varieties sensitive to this disease while an excess of nitrogen in the soil sometimes caused roots to 'burn' and could inhibit proper plant development.

6.7 Weed Control. Very important to obtaining high yields - and not wasting the soil's fertility - is the control of weeds. There are a large number of broad-leaved weeds which can cause trouble but by far the most damaging and difficult weeds to eradicate are wild oats (Ptc. 22, p. 204) and bindweed.

The former has a growing season similar to that of the cultivated cereals. Its seed can survive several years in the ground before germination under favourable conditions. Crop sprays which can be used to destroy the broad-leaved plants leave wild oats unaffected. In Tunisia they had to be cut by hand or turned in green when a fallow was tilled.

Bindweed is similarly very resistant to destruction. No amount of cutting kills the underground stem. The only way to kill it is by complete removal from the soil or by allowing the soil to dessicate in the hot summer.

When trying to improve crop rotations the problems of weed control must always be a major consideration. Weed infested land can reduce yields by more than a half.

When in 1894 Trouillet outlined the major advantages of spring ploughing one was; 'better cultivation by the destruction of weeds before they have been able to produce their seed while the summer ploughing only deeply buries the latter' (quoted in Boeuf, 1932, p. 309).

Again an important reason for entirely separating the Forrage-Oats/Barley from the Fallow-Wheat rotation was because the cultivation of forrage plants encouraged many weeds whose seeds fell before cutting.

One of the principal reasons given by Boeuf (1932) against employing the Martinier rotation was that wheat itself is a

Pte. 22. Hard Wheat Infested with Wild Oats

source: Dutton, summer 1970

Once wild oats have become established they are one of the most difficult weeds to eradicate. One advantage of fallow farming was that it controlled wild oats, bindweed and other weeds.

dirty crop necessitating very careful clearance of weeds in autumn before sowing the seond wheat. This, if done properly, would have delayed sowing.

The great advantage of the Fallow-Wheat rotation was that the land, tilled throughout the fallow year, was rendered virtually weed free and easily and quickly prepared for sowing the following autumn. The weeds thus cleared included wild oats. If the land became infested with bindweed harrowing drew some of it from the land but its growth was better checked by deep ploughing and leaving the clods exposed to the summer heat for a time before tilling. This was an effective technique although, as it broke a cardinal principle of dry-farming, it had to be used rarely and with caution.

Yankovitch obtained the highest yield per area arable in his experiment with continuous wheat and full fertiliser but noted (1956, p. 89) that; 'it is not possible in agricultural practice to adopt this formula because of the multiplication of weeds, diseases and parasites of wheat', so that some fallow had to be maintained.

The point was finally underlined by Valdeyron who defined good cereal farming by saying (1949, p. 115); 'what we call good cultivation has as its essential aim, while suppressing the competition of weeds, to shelter wheat from drought'. Once weeds have established themselves the use of fertilisers can favour them at the expense of the wheat.

In recent years the government has encouraged the growth of beans/oats to reduce the fallow area. This trend coincided with a major disruption to agriculture cause by the expulsion of the colonists in the early 1960's (see ch. 7.3, p. 235ff.)

and has undoubtedly led to inefficiency and neglect of the land. The position was unequivocally summed up in a report prepared for the FAO in 1969 which, while condemning current agricultural practice, noted that; 'the fields are usually full of weeds - Wild Oats, Mustards and many broad-leaved weeds'. (Hafiz, 1969, p. 4). Far from condemning fallow the report advocated an intensive campaign to begin tillage of the fallow (Pte. 23, p. 207) after the end of the rains; to use the fallow, by continual tillage, as an opportunity to free the land from weed competition.

This report, in 1969, was restating the principles governing the use of fallow farming that the Europeans had adopted by the end of the 1920's; it was re-emphasising the primordial importance of weed control and good tillage that had governed the evolution of the methods of cereal farming adopted by the colonists since 1894.

Pte. 23. Cultivated Fallow with Broad-Leaved Weeds

source: Dutton, summer 1970

The fallow has been ploughed but not tilled so that thistles and other broad-leaved weeds have been allowed to mature and set seed.

6.8 Cultivation Techniques and Soil Erosion. As pointed out in chapter 3.2 (p. 74) the entire length of the Medjerda river valley lies in a zone of rapid erosion resulting from flash flooding of precipitation after autumn and winter storms. The area is made especially vulnerable to erosion because the high rainfall is concentrated in cyclonic storms during only five to seven months of the year.

The strength of the erosion can be seen in the silt content of the Medjerda river itself. Each year the river carries about 20 million cubic metres of silt roughly 90% of which is lost to agriculture (see ch. 3.2, p. 75) because the river carries it into the sea.

Before the colonists started to extend the area under permanent cultivation erosion was controlled by the natural scrub vegetation (see ch. 3.5 p. 90). Except for the small area of intensely farmed melk land near the villages (see ch. 4.3, p. 103ff.) only a small percentage of the land was cleared, sporadically, for cultivation. Even where this occurred the land was never entirely cleared of scrub trees and brush because the peasants had not got the necessary traction power. The soil was not broken to any great depth. There were neither deep furrows for rain-water to flood down nor was there a finely prepared surface mulch which could readily be eroded.

The European farmers completely changed this situation. The land was farmed in large units of 100 ha. to 1,000 ha. or more. Both the heavy alluvial land and the light hill soils were brought into continual cultivation and completely cleared of their natural vegetation. Heavy machinery loosened the soil to a depth of up to 45 cm. and, as has been shown above, prepared a fine, loose mulch on the surface to keep the land from drying in summer.

The agricultural census of 1949/50 showed that of the 3.4 million hectares of arable land under cultivation nearly 1.2 million hectares were under fallow (Plan, 1962) resulting from the spread of the Fallow-Wheat rotation. Because this land was left without a cover for 16 months out of 24 Poncet believed the colonists to be primarily speculators (Sethom, 1963, in a commentary on Poncet's thesis) who evinced little interest in preserving the soil; they prefered the Fallow-Wheat rotation because it was an easy option. However this is an unrealistic assessment of the situation. The rotations adopted by the colonists (see ch. 6.5, p. 173ff.) were painstakingly evolved over many years. Far from being an easy option, the Fallow-Wheat rotation involved two years of continual work for one year's harvest; see Table, 30, p. 165. Moreover not only the colonists but the experts at Ariana and the Ministry of Agriculture favoured the rotation, up to and after the end of the colonial period, where the mean rainfall was below 500 mm.

It was only when the European farmer took the rotation from the plain to the hillside that he caused an undue amount of erosion. Unfortunately but naturally, the Tunisian farmers followed the colonists' lead (Fig. 15, p.131) and the clearing of the hills was actively pursued by them. The important difference was, according to Pissaloux (1955, p.555) that the; 'Europeans very quickly realised their technical error and are now beginning to fight correctly against erosion while the Tunisians are slower to understand this need'.

Pissaloux and Poncet give quite different pictures of the colonists attitude to their land. So the question remains: Were the colonists primarily speculators (disregarding the agricultural potential of their soil) who ploughed land wherever they could in order to obtain short term gains from cereal cultivation ? This question has never been put to quantitative examination, but some light has been thrown on it by analysis of the colonial farm data from the LMV.

It has been possible to correlate the area of ploughed land in each Farm Group (as a percentage of total area of the Farm Group) against the mean gradient of the Farm Group. Secondly the ploughed land as a percentage of the cultivable area was correlated with the available amount of ground water. The ground water figures were derived from the volume of water in the soil (classed as; important or 10+ cu.m./hr., medium, small, localised and absent) and its concentration of soluble salts (below 1.5 gm/li., 1.5 to 3.0 gm/li., over 3.0 gm/li.) as recorded by Drogue (1966, A,B, & C).

The relationship between the ploughed land and the gradient is best expressed by a second degree curve (Fig. 18, p.211) which accounts for 21.5% of the total variation. The curve suggests that the area of ploughed land diminished slightly on the flattest land but was at its lowest on the land of highest gradient indicating that the colonists recognised the danger of ploughing the steepest parts of their land. The degree of significance, however, only just attains the 10% level but it must be noted that most of the unexplained variation, Table 39, occurs where the land is flattest; where it may be best suited to fruit trees, pasture or plough depending on the quantity and quality of the ground water. It is for this reason that the correlation

Fig. 18

RELATIONSHIP BETWEEN AREA OF PLOUGHED (CEREAL) LAND AND MEAN LAND GRADIENT OF FARM GROUPS

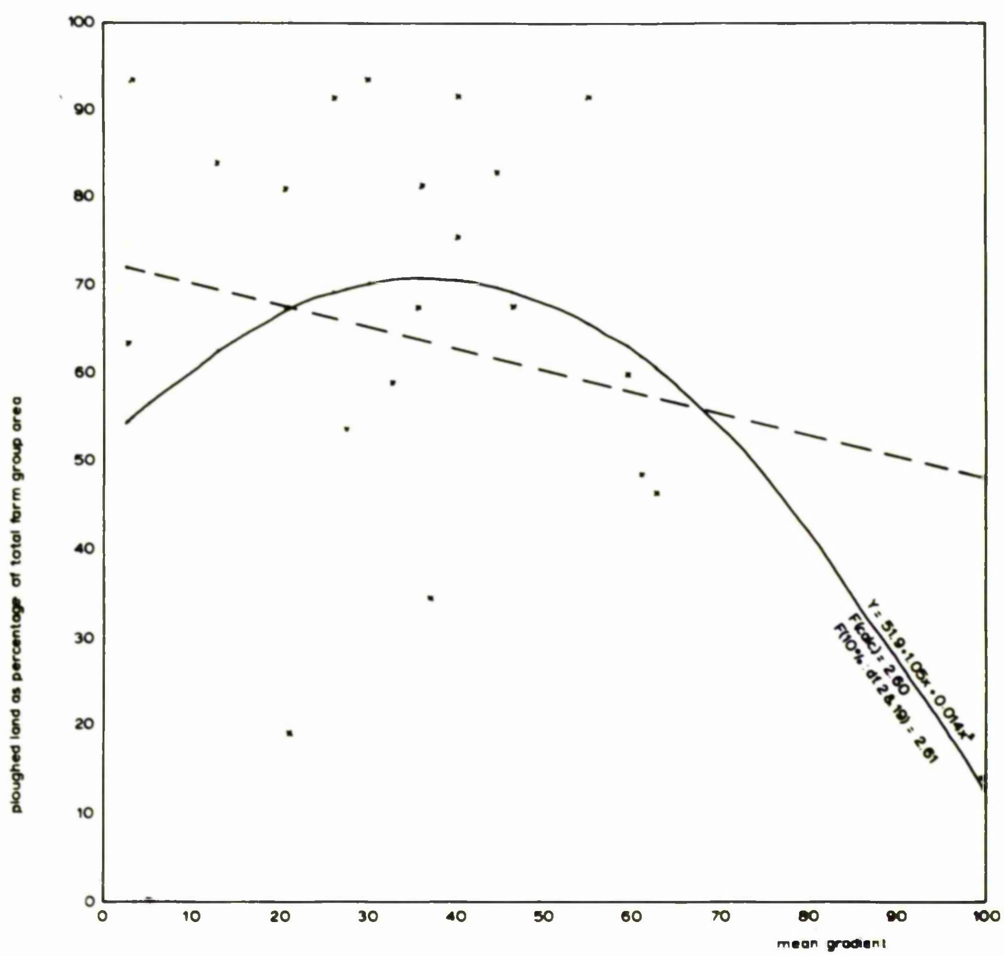


Table 39. Residual Values from the Second Degree Polynomial Regression of Plough Land Against Gradient.

Farm Group	Gradient	Plough%	Plough% (est.)	Residual	Total	Mean
1	2.6	63.6	54.5	+9.1		
4	3.1	93.4	55.0	+38.4		
22	5.1	0.3	56.8	-56.5		
17	12.8	84.0	62.9	+21.1		
8	20.5	81.1	67.3	+13.8		
21	20.9	19.1	67.5	-48.4		
18	26.1	91.4	69.4	+22.0		
9	27.3	53.8	69.7	-15.9		
12	29.9	93.5	70.3	+23.2	248.1	27.6
16	32.6	59.0	70.7	-11.7		
11	35.5	67.5	70.9	-3.4		
10	35.9	81.5	70.9	+10.6		
5	36.9	34.7	70.9	-36.2		
3	40.1	75.7	70.7	+5.2		
7	40.1	91.6	70.7	+20.9		
14	44.6	83.0	70.0	+13.1		
2	46.3	67.8	69.4	-1.6		
13	55.1	91.5	65.8	+25.7		
6	59.4	60.2	63.1	-2.9		
20	61.1	48.7	62.0	-13.3		
15	62.6	46.2	60.9	-14.7		
19	99.8	14.1	12.5	+1.6	160.3	13.1
				Grand Total & Mean:	408.4	18.5

of fruit trees/plough land distribution against available water was attempted. Fruit trees and vines are much less tolerant of saline soils than are cereals.

The second degree curve (Fig. 19, p. 214) accounted for 57.0% of the total variation giving an F-value(2 & 19 df) of 12.6 which is clearly significant at the 0.1% level. That is to say the farmers believed that the quantity and quality of the ground water were of great importance in determining whether or not to plant fruit trees and vines (Pte. 24, p. 215). The drier and more saline soils had to be left for rough pasture or the plough.

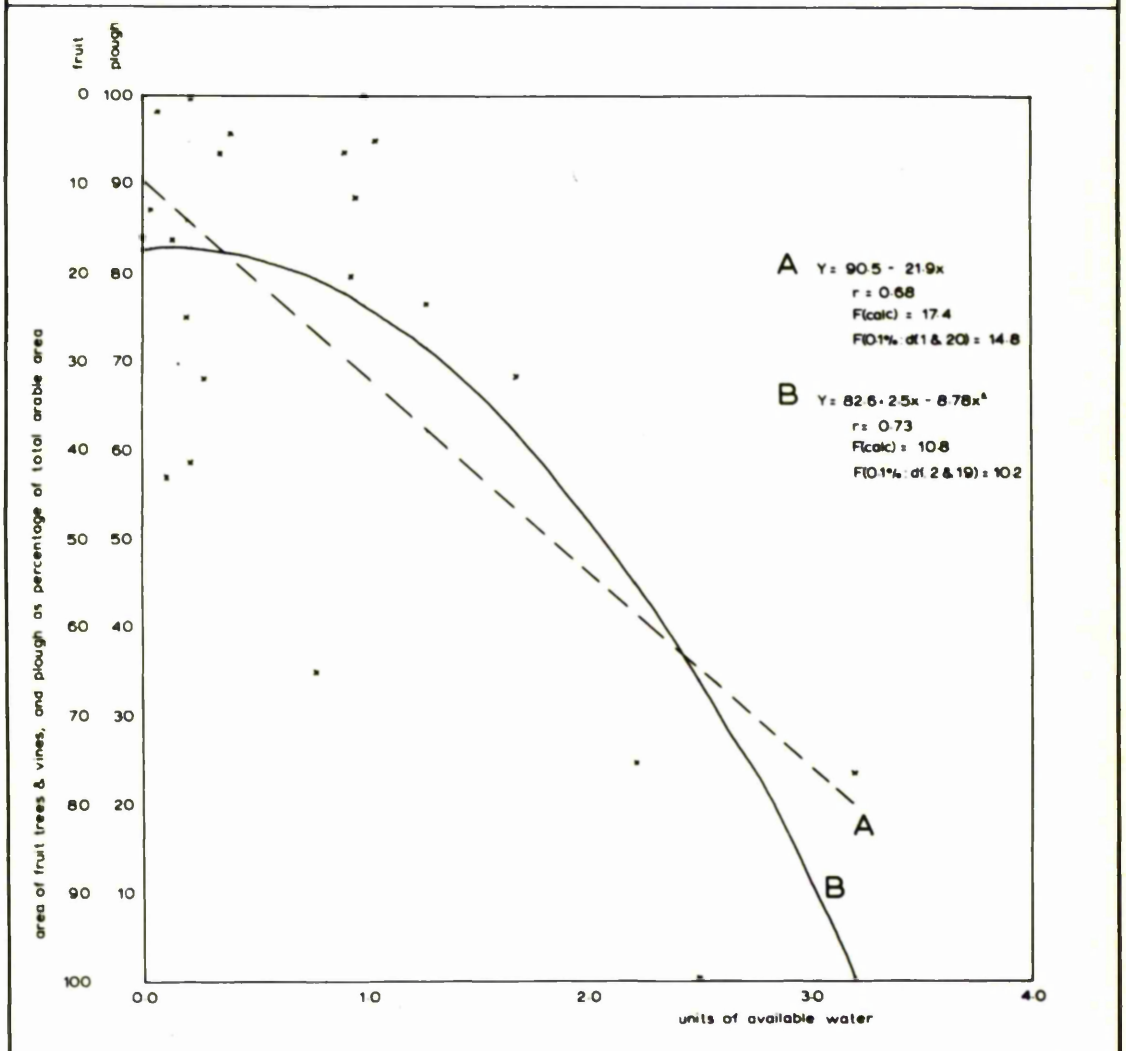
In spite of the erosion that it causes, the Fallow-Wheat rotation was a necessary step in the development of European agriculture. To condemn it, as Poncet does, because of the harm it does to the soil is a harsh judgement which is plausible because it contains a part of the truth but is not supported by the historical and technical examination of the development of cereal farming by the colonists undertaken in this thesis.

Poncet also criticised ploughing as a cause of soil erosion by saying (1961B, p. 93) that; 'in a semi-arid soil all types of ploughing have the result of reducing the compacity of the upper soil layers, dividing them and more or less crumbling them... while separating them from the lower soil horizons'.

This is true but then all agriculture will cause some erosion and land has to be ploughed. In fact deep ploughing a soil facilitates the penetration of rain water (so long as the standard precaution of contour ploughing is followed) and reduces run-off (see ch. 6.4, p. 167 ff.). It is the creation of

Fig. 19

RELATIONSHIP OF DIVISION OF ARABLE LAND BETWEEN FRUIT & VINES AND PLOUGH, AND AVAILABLE WATER



Pte. 24. Modern and Traditional Farming in the Plain of Mornag

source: Air survey of Tunisia 1962/63

The regularity, size and order of the French vineyards and cereal land contrast with the irregularity of peasant smallholdings in the plain of Mornag. The region, rich in good quality ground water, is famed for its vines.

a surface mulch or finely prepared seed bed which facilitates erosion (Pte. 6 , p. 91). As this also increases leaching and decreases the amount of nitrogen fixed during the growing year ploughing could be done late leaving the ground rougher at sowing.

Elsewhere Poncet attempts to find a parallel in Tunisia between soil erosion and the system of land tenure. He refers to the fact that the colonists farmed large estates (100 ha. or more) which meant that the growing Tunisian population had to find land in the hills. But he appears to contradict his belief that the colonists were primarily speculators interested only in short term gain (Poncet, 1961B, p. 116) by saying that; 'the large scale landlords, owners of machinery and important financial means have, for several years, undertaken the most remarkable measures against erosion in Tunisia'. This statement is more realistic and can be supported by examples of terracing (Pte. 26, p. 230), canal irrigation and contour planting, taken from the farm data from the LMV.

However Poncet believed that the colonists were, at least, the indirect cause of hill erosion. This was due, he wrote (Poncet, 1959), to the extensive European monoculture pushing back the increased Tunisian population to farm in the poor hill soils (Pte. 20, p. 188) where they achieved little except an increase in soil erosion.

But during the colonial period the Tunisian population of the <u>cheikhat</u> in which the colonists settled, and the <u>cheikhat</u> in which new sources of water expanded the area under irrigation, grew much more rapidly (see ch. 5.3, p. 132ff.) than the population of the hill <u>cheikhat</u>. Any increase which did take place in the latter was due not to the colonists but to the rapidly increasing population of the country. Dividing the colonial farms into smaller allotments would have made little appreciable impact on this problem outside the small irrigable areas.

There is therefore no evidence that either the presence of the colonists bringing large estates under permanent cultivation or their use of the plough and the Fallow-Wheat rotation were the cause of undue erosion; 'undue', because some erosion is inevitable when semi-arid land is cleared of its natural vegetation to bring it into permanent cultivation.

However the cultivation of annual crops on steeply sloping land and the creation of a fine surface mulch were causes of undue erosion.

The danger of erosion was only appreciated when the yields of hard wheat started dropping in the late 1930's to be followed by those of F/A during the 1940's. But although erosion clearly had occurred - even cutting deep gullies in the northern hills (Fig. 25, p. 218) - it was only one of several causes of low yields and, as the improving harvests of the 1950's showed, a relatively minor one.

Nevertheless the colonists began taking corrective measures on their own land and pressured the government into action. By October 1949 (Person, 1955) a Comité Supérieur de Défense et de Restauration des Sols (CSDRS) had been created. It laid down the general policy of soil conservation to be adopted in different parts of the country and supervised the working of Associations Syndicales constituted in 1951 to carry out the work. The associations received a 40% grant and interest free

Pte. 25. An Eroded Wadi Bed in the LMV

source: Dutton, summer 1969

Tilling hill soils has facilitated wadi erosion.

loans (payable over 25 years) to finance their activities. The Plan of 1953-56 (Kool, 1963) provided for the treatment of 76,000 ha. Research into the problems of erosion was begun at Sidi Tabet and special extension agents were trained. In theory the peasants could get financial aid for measures to combat erosion from the Soiétés Tunisiennes de Prévoyance but the area thus treated is unknown.

The LMV received particular attention because measures for the conservation and restoration of the soil were a major part of the LMV development scheme (Dutton, 1968) begun in 1948. The OMVVM designated 117,000 ha. as an area needing measures against erosion (Pte. 4 , p. 80). This included an area of primary urgency of 80,000 ha. on the hill flanks. Essentially the work involved terracing the hill slopes and canalising the wadi.

6.9 Conclusions. Before preceding to an examination of this chapter section by section in the light of the questions posed in the introduction it is necessary to emphasise the complexity and the very close interrelationship of the effects of changing varieties and techniques on productivity. This is accentuated by the fact that long term and short term effects may act in opposite directions. But in order to simplify and make comprehensible the overall picture the different effects will be examined, in isolation, under their separate section headings.

Varieties. Before the French began improving the varieties in Tunisia the best feature of the local varieties - all of which were hard wheats - was hardiness; the ability to withstand some of the worst aspects of the climate and produce an acceptable yield on a poor and unimproved soil. What one might call the geographical potential of the soil/climate ecosystem was extremely underexploited. And even at this low level the hard wheats had a fundamental weakness which was their sensitivity to black rust, a disease which flourished in moist, warm conditions. This meant that in the north of Tunisia where the rainfall is higher and more dependable and the soils of good quality neither climate nor land could be exploited by the wheat. The best variety, Biskri AC/2, gave most regular yields in the drier centre of the country which is today considered a wheat growing area of secondary importance.

The climatic problems that the wheat breeder had to overcome (see ch. 3.1, pp. 48-65) were formidable. Although normally distributed the standard deviation of the rainfall is very large which means that the extremes are widely separated and that there is no marked cluster about the mean. The wheat breeder cannot make do with a variety that does well in the years of near mean rainfall and ignore the extremes. Each variety has to be resistant to drought and to excess rainfall; it has to be resistant to wilting and shrivelling of the grain on the one hand and mitadinage, leaching and fungal disease on the other.

A variety has to be all of this and produce a reasonable to good yield under these conditions, being able to capitalise on good growing conditions and soils when they occur.

The SBAT introduced and improved several varieties of hard wheat before the Second World War. The great strength of these wheats lay in the very fact that there were several of them, all capable of giving reasonable to good yields, each with different weak and strong points making them as a group better able to adapt to the variations in climate from year to year and to the different soil types. The weakness in the system was that because, before the war, the European farmers concentrated their attention on soft wheat the hard wheats were never extensively tested and no further varieties developed to meet the post-war demand. An added problem which, perhaps, one cannot blame the plant breeders for not anticipating was the extreme periodicity of the rainfall which manifested itself in the very dry 1940's and the very wet 1950's. Under the wet conditions the hard wheats, in general, showed that they were not resistant to extremes of moisture. They suffered badly from mitadinage and even, in the wettest years, from black rust, which was thought to have been controlled in Tunisia.

Because hard wheats had been regarded by the colonists as a second class cereal before the war their strengths had not been tested either. They had been reserved for the worst soils, tilled last and least carefully. None of the hard wheat varieties had been given the opportunity to exploit either the soil's or their own full potential. On the other hand they never risked the soil's long term fertility by stretching it to its limit. Although they were greatly improved in quality they never fundamentally changed the balance of their qualities from that of the old varieties. They remained hardy; lower yielding but more resistant to drought than the soft wheats. They were more tolerant of poor soil cultivation but retained a susceptibility to excess moisture that had characterised Biskri AC/2.

The development of the soft wheat followed a different pattern. The principal difference was that up to the 1950's there was, instead of several good varieties, one excellent variety, F/A, which dominated all the others. Both the yield and the industrial qualities of F/A were highly prized.

F/A arrived on the scene at a time when the soil fertility was being greatly enhanced by changing methods of cultivation and when rich virgin soil was being brought under cultivation for the first time. The qualities of F/A were ideal to exploit these conditions and capitalise on the good rainfall of the 1930's. Furthermore F/A had a short life cycle so that it matured early making it more independent of the late spring rains.

But the success carried with it certain disadvantages. Firstly because F/A stood alone the soft wheats were never given the adaptability to different soils and changing climates that the hard wheats had. Secondly to give high yields F/A not only required but demanded highly fertile soils. It had the power to exploit a soil's potential to the point of exhausting it. This happened in the case of the lighter soils which were not intrinsically of great fertility but whose fertility was temporarily boosted because they were virgin lands. Thirdly F/A had very high nitrogen requirements making it vulnerable to the leaching effect of heavy autumn and winter rainfall. Lastly the short life cycle of F/A, while making it independent of late spring rains, made it less flexible in adapting to mid-season rain shortage or a low rainfall year although it required less water to bring its harvest to maturity than the slower maturing varieties.

Only when Guelma and Etoile de Choisy were added to the list of osft wheats in the 1950's did the total range of the soft wheat characteristics make them more adaptable to the range of soils and climate. Interestingly enough the new varieties not only added to but effectively replaced F/A after 1955; once the export market for F/A had been closed the advantages of the other soft wheats were a match for it.

Mechanisation. Mechanisation was the key to the great expansion in the area under cereal cultivation in the modern sector during the 1920's and the early 1930's. Mechanical power not only made the preparation of the land, and all stages of cultivation, more rapid but allowed them to continue during a far greater range of soil moisture. Heavy duty tractors were instrumental in allowing the generalisation of deep ploughing which greatly enhanced the fertility of the virgin soils.

However the success of mechanisation encouraged the expansion of cereal cultivation from the plains to the foothills. Rough pastures on light, sloping soils were converted into wheat lands although that was not their natural vocation. There were two harmful effects of this action. Firstly the light soils were over-exploited and were becoming exhausted by the end of the 1930's. Secondly the hill soils, stripped of their protective cover of grass and brush, were exposed to the full erosive force of Tunisian summer drought followed by autumn and winter storms.

The 'apparent' effect on yield of changes in harvesting methods has never been examined in Tunisia. Gleanage rights, the prerogative of the harvest workers under Islamic law, certainly accounted for a significant part of the harvest that was never measured. But although the labour force has been greatly reduced by the introduction of the combine harvester (see ch. 5.3, p. 139 ff.) it is unlikely to have greatly increased the harvest; it may merely have increased the wastage of grain particularly when the harvester is not well maintained.

Ploughing and Tillage. Unlike mechanisation changes in the methods of ploughing and tillage did not directly effect the area which could be brought under cultivation. Their direct effect was on soil fertility and therefore the distribution and evolution of yields.

Ploughing, when done in spring, had the combined effects of evenly dividing the soil, killing weeds, retaining soil moisture into the summer and promoting soil nitrification, particularly when the ploughing was followed up by regular surface cultivation. Deep ploughing stimulated the effects of soil nitrifying bacteria over a greater depth and increased the volume of water stored in the soils; the amount depending on the date of ploughing. But while deep ploughing to bring a virgin soil into cultivation was considered essential the use of regular deep ploughing, every two years, may have done more harm than good by increasing leaching of nutrient salts. The common practice of regular deep ploughing in summer may have done least good and most harm. In addition to increasing leaching and burying weed seed (instead of killing the weeds) it exposed the soil to temporary dessication. Deep ploughing should have been used more sparingly (perhaps once in eight years) and not done until after the end of summer. The rougher seed bed thus prepared would have reduced leaching and maximised nitrification during the crop year.

The short term effects of deep ploughing on yield were good but the long term effects were more questionable. Probably the time span involved was not long enough for their worst effects to have been made manifest.

On the other hand, as far as tillage is concerned, the careful methods evolved by the French can only have increased yields, by eliminating competition from weeds.

<u>Fallow and Crop Rotation</u>. Although a good deal of attention was given to developing systems of crop rotation the one generally adopted for most of the arable land was Fallow-Wheat. The fallow undoubtedly stored additional rain water for the use of the wheat and acted as an intense 'factory' for nitrogen fixation. This greatly increased the average yields and, equally importantly, almost eliminated the risk of the 'null' year whose effects could be catastrophic on the delicately balanced farm economy. Fallow reduced the danger of the dry year but, in a wet period, it stored too much rain so that yields suffered (though less severely than from drought) from an excess of water

in the soil.

In the short term the influence on yield was undoubtedly good but in the long term the yields are likely to have been depressed by the use of fallow on the light non-cohesive hill soils because of soil erosion. On the other hand the total soil productivity in the wetter regions of the LMV could have been increased by gradually reducing the number of fallow years and introducing other crops into the rotation. There was a tendency in this direction (see ch. 7.4, p. 244ff.) from 1950 onwards. The area of fallow in the LMV dropped during the decade from 50% to 44% in the LMV but the rapid decline in the last three years to 38% must be ascribed to a panic reaction to approaching nationalisation.

The intensification of dry-land farming was not possible before the effects of nitrogen fertiliser were known in Tunisia in the mid-1950's. But even then the great importance of fallow in cleaning the land of weeds, pests and diseases could not be ignored. An increase in cropped area would probably have decreased yields by squandering the soil fertility in the multiplication of weeds, bacteria, fungal spores, nematode worms and other pests. Heavier cropping of the land in more recent years has, in all too many cases, led to infestation by wild oats, mustards and other weeds.

An alternative treatment of the sloping lands might have been terracing and, where the rainfall was high enough, planting with tree crops. But while terracing and planting were being undertaken Tunisia was in no position, as was pointed out in chapter 2.5 (p. 41 ff.) to radically cut back on the area under cereal cultivation.

Fertiliser. The importance of mineral nutrients to the yield were fully appreciated from before the start of the century. Yields in the north were being improved by the application of phosphates and by building methods of cereal cultivation round the principle of soil nitrification. The one weakness was the failure to appreciate the danger of leaching carrying the soluble nitrates beyond the range of the plants' roots. This meant that in wet years - particularly if the fallow year had been wet too - wheat yields were depressed through nitrogen deficiency. The effect was more marked on the lighter soils.

The short term effects of leaching were first measured by Poletaef from 1935 to 1939 and again after the war. The work of Yankovitch revealed, in addition, that the long term effects might be disasterous; complete exhaustion of the nitrogen in the soil within 150 to 200 years. The European farmers were misusing the soil and squandering its fertility.

However as soon as the SBAT began advocating the use of nitrogen fertilisers in the mid-1950's the response from the modern sector of agriculture was immediate. Within three years enough nitrogen was being imported to cover the requirements of 120,000 ha., though some of it at least must have been used on other crops. In 1958 demand exceeded supply.

Weed Control. The importance of weed control in affecting the distribution of wheat yields is often underestimated. The colonists did not make this mistake. Weed control, together with pest and disease control, was a major consideration in the development of all their methods of cultivation including the use of fallow. Until the advent of effective and cheap sprays in the last few years, and in areas like the LMV where root crops are not an economic proposition, fallow remained the most effective method of cleaning the land between crops of cereals. Furthermore experimenting with the system is not a light undertaking because once weeds and diseases have been allowed to multiply it can take several years to bring them under control. It is likely that one of the more important effects of any serious disruption in the continuity of agricultural practice (such as during the Second World War, the immediate post-decolonisation period, or the attempted introduction of total cooperativisation in 1969) is the damage done in the following years by allowing weeds and diseases to multiply.

Soil Erosion. It must be said that all agriculture upsets the natural balance of the soil/climate ecosystem. This is minimal when, as in pre-colonial days, the farming community is itinerant and barely scratches the fertility of the soil. However when the French brought land into continual cultivation and removed as grain the nutrients from the soil (after uprooting the protective cover of wild vegetation) it was inevitable that a certain amount of erosion and loss of soil fertility shoud set in.

It was only with the general expansion of the area under cultivation in the 1930's, when the Fallow-Wheat rotation was taken onto light hill soils, that an undue amount of erosion took place. The effects of this on agriculture were not known until just before the Second World War and then, because of the war, little could be done until the late 1940's. However it is probable that not much damage was done in the intervening years simply because the war years were marked by a great reduction of the area sown. In the post-war period the modern sector of agriculture, both at government and private levels, seriously undertook the work of restoring the soil and controlling erosion; Plate 26 (p. 230) shows an example of valley terracing near Medjez el Bab. These were long term measures whose effects were probably not manifested in the yields of the few years that remained of the colonial era.

During the final phase of colonisation the deterioration of the soils was being controlled but, it must be emphasised, least work was done on the peasant farms which being in the hills were the ones which needed it most.

Pte. 26. A Panoramic View of Wheat Farming near Medjez el Bab

source: Dutton, spring 1970

In the foreground are roadside weeds. The lighter bands in the middle ground are flowering weeds but they are confined to the edge of terraces. The whole valley was terraced by the French.

CHAPTER 7

CEREAL CULTIVATION IN THE WAR AND THE FINAL PHASE OF COLONISATION: 1939 - 1964

7.1 Introduction. As Tunisia was a theatre of war the effect of the hostilities on agriculture was intensified. The review of the impact that the war years had on cereal farming is intended to show the effort needed during the late 1940's simply to restore the pre-war position at the outset of the final phase of colonisation.

A study of this last phase of colonisation is needed to see whether the colonist farmers reacted to nationalist pressure in the post-war years by changing their farming methods, or by following less rigorously the rules for good farming practice that they had established.

The view of Hyslop and Dahl (1970) is a clear statement of the commonly held belief that; 'the struggle for independence in the early 1950's... caused a climate of uncertainty in the minds of the colon farmers. Such uncertainty tended to reduce the investments for maintaining soil fertility and in production resources such as machinery'.

The nationalist pressures that could have affected the colonists and their attitude towards farming will be outlined, followed by a careful examination of the limited evidence available that might show whether the views of Hyslop and Dahl, and others, can be substantiated. It has to be established when the independence struggle began to cause a real, 'climate of uncertainty', amongst the farmers and to see whether this had the effect of making the colonists work for short term gain at the expense of the long term fertility of their land.

Before analysing the individual farm data in the final section of this thesis it is important to see whether one can talk of a continuity of farm management practice during the final years of the colonial period. Or, on the other hand, is it likely that a significant part of any downward trend in yields might be explained by the relaxation of the standards of cultivation as the colonists came to realise more and more clearly that they had no long term future in Tunisia ?

7.2 Cereal Cultivation in the Second World War. The Second World War made a considerable impact on cereal cultivation, prior to the final phase of colonisation, from which the country did not recover for several years.

The outbreak of war in 1939 resulted in the mobilisation of numerous farmers and farm managers shortly before cereal sowing started. Partly as a result of this (Pocthier, 1943) the harvest of 1939/40 was poor - sowing being delayed - though the year was very dry as well.

The war was active in Tunisia for the six months starting in November 1942. Some of the toughest fighting was between Medjez el Bab and Tunis. As a result of the fighting which; 'spread throughout the LMV, sowing, which had hardly started, normally remained unfinished' (Pocthier, 1943, p. 9). The following spring many harvests were flattened or burned by the fighting.

By 1943/44 the shortage of spare parts for agricultural equipment and of fuel oil for the three preceding years was in part responsible both for a decrease in the area sown and a decrease in yields. Unfortunately these conditions prevailed during the longest spell of dry years, Table 13 (p. 60), that Tunisia has experienced this century. The disruption that this caused to cereal farming was profound; a situation impossible to reverse immediately the war ended. The first wet post-war year was 1948/49. As by this time the import of agricultural equipment had recovered (Fig. 21, p. 234) it may be said that 1948/49 marks the point when the cereal farmers no longer felt the effects of the war years. The Chief Inspector of the STONIC (Dumeige, 1953) marked 1949 as the year when cereal cultivation; 'regained its élan' (p. 44).

Fig. 20

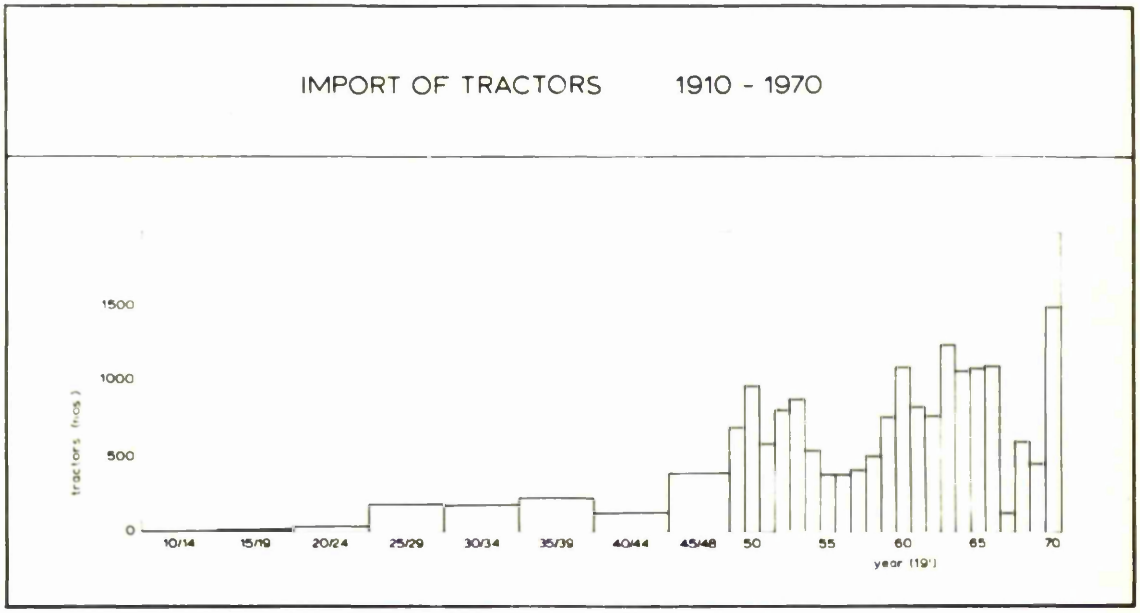
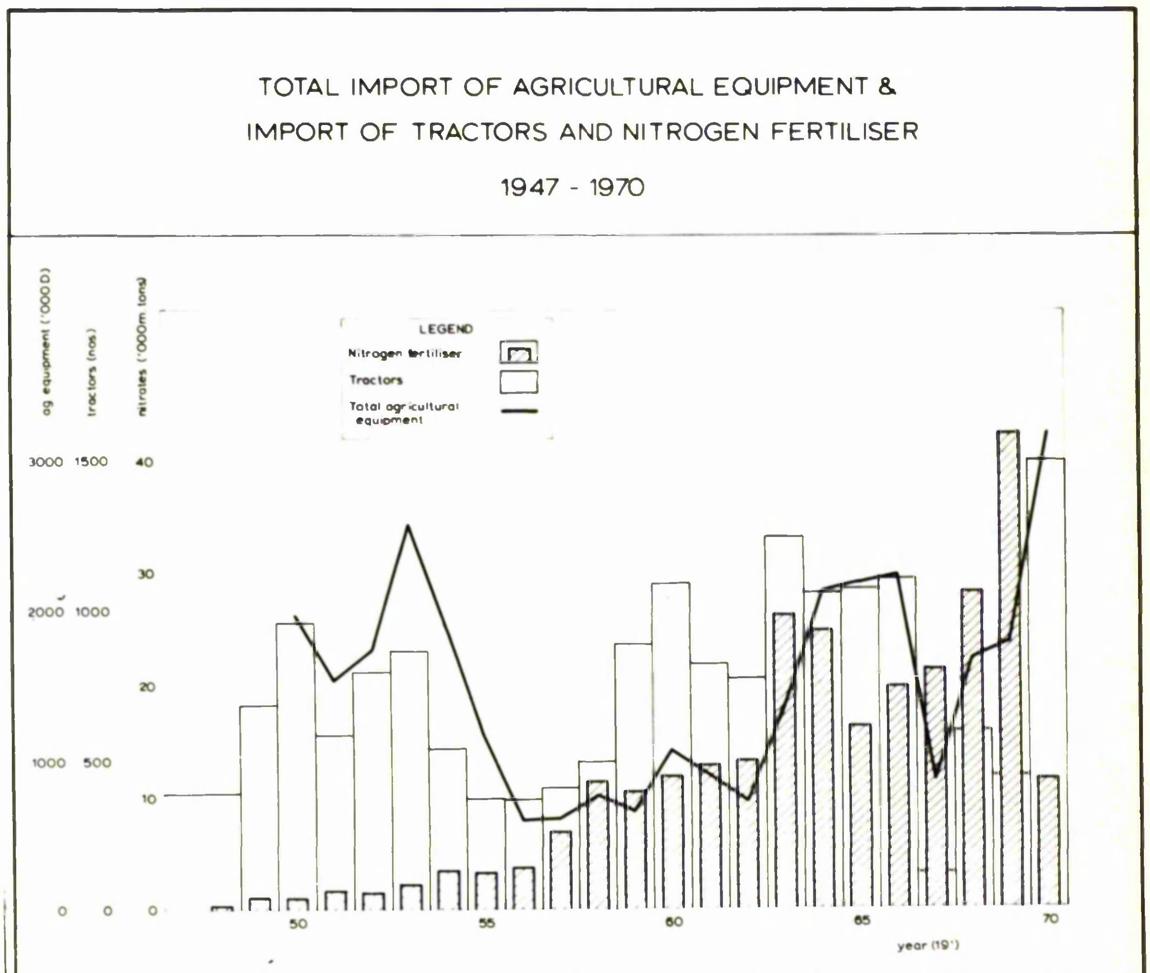


Fig. 21



sources: Statistiques du Commerce Extérieur de la Tunisie
Annuaire Statistique de la Tunisie
(various years)

7.3 Post-War Pressures of Nationalisation on the Colonists. A nationalist movement gathered strength in Tunisia after the Second World War. There was relatively little violence but much excited public debate during the early 1950's. Talks between the Tunisian leaders and the French government attained the nationalist goal in 1955 with the independence agreement signed in Paris. This itself eased the tension and uncertainty while the Tunisian people calmly awaited independence which came 20 March 1956. Afterwards the mood of reconciliation was strengthened by Bourgiba who resisted any tendency towards xenophobia on the part of his people and emphasised the need for the newly independent Tunisia to maintain cultural and economic ties with France.

The French people had foreseen the end sometime before. Immigration slowed down in the early 1950's and the tide was

Table 40. Migration of Europeans To and From Tunisia: 1954 - 1958.

source: Wolkowitsch, 1959

	1954	1955	1956	1957	1958
Entries	29,058	103,459	88,453	68,454	54,370
Exits	31,194	116,641	120,176	103,519	82,520
Emmi- gration	2,133	8,182	31,723	35,065	28,150

reversed in 1954 and the departure rate, Table 40, grew to a maximum in 1957. But the farming community was affected more slowly than the other professions. The farmers were dependent on their land for their livelihood which made them reluctant to leave. Living in the rural areas they were less in touch with the changes in the political climate and, moreover, their relationship with their employees normally remained good. But because the colonists farmed and owned such a high percentage of the cultivable land - 850,000 ha. farmed and 666,000 ha. owned out of 7.5 million hectares - and usually the better quality land, it was inevitable that pressure should be brought on them and the French government to relinquish it. The pressure increased with the deterioration of Franco-Tunisian relations after independence associated with the Algerian war. In May 1957 France temporarily stopped giving aid to Tunisia (Silvera, 1962) because Tunisia was helping the rebel Algerian forces. In June 1958 the French agreed to withdraw French troops from Tunisia but made an exception of Bizerte; fearing that the port facilities would be put at the disposal of the Algerians.

Repurchase of land began on independence along the Algerian border (Genoud, 1965) where, it was said, numerous colonists were leaving their farms frightened by guerilla, border activity. In 1957 a zone de rachat was agreed along the frontier affecting 127,000 ha.

In November 1958 Bourguiba asked for total decolonisation (Genoud, 1965) and undertook negotiations with the French government (Silvera, 1964) which led to the agreement of 13 October 1960. In addition the French government facilitated the repatriation of French colonists by offering grants and loans - the amount related directly to the value of the land, buildings and stock owned - to farmers wishing to leave Tunisia and settle in France.

The agreement of October 1960 said that Tunisia should recoup from the colonists 100,000 ha., mostly of cereal land, by 1 September 1961. By the late summer of 1961 98,000 ha. were ready for transfer and an additional agreement refers to a further 50,000 ha. to be dealt with at the same time; the whole operation to be completed by September 1963. Yet another 50,000 ha. would be prepared for transfer during 1963.

The remaining French land-owners were assured of keeping their land for at least five years but it was clear that the era of European land-owning in Tunisia was drawing inexorably to its conclusion.

As it happened the process was speeded up. The Bizerte crisis of 1961 halted the smooth flowing of the 1960 agreement and led to the eviction at short notice of a number of French land-owners in the autumn of 1961; including many from the LMV.

This act finally convinced the foreign farming community that the end was close at hand. No action took place during the year 1962/63 but this proved to be the quiet before the storm. On 12 May 1964 the storm broke; a decree was published saying that all agricultural land together with its buildings, live-stock and machinery was being sequestered.

There had been, in summary, an initial period of uncertainty and tension in Tunisia as a whole which was eased by the two steps to independence taken in 1955 and 1956 and by Bourguiba's pacific attitude towards the French. But the tension was re-created from 1957 as a reflection of events in Algeria. In 1958 it became declared Tunisian policy to terminate all agricultural colonisation but an orderly, and semi-voluntary, plan to effect this was worked out by Bourguiba and the French government. This plan was destroyed by the Bizerte crisis of 1961. Many French farmers were expelled in reprisal and the way prepared for imminent land nationalisation.

7.4 Colonist Reactions to Nationalist Pressure. There is no perfect way of measuring the manner and the date of the colonial reactions to the, 'climate of uncertainty', earlier refered to. In this brief study two sources of information will be used; the national statistics concerning the import of agricultural equipment, and the 126-farm data for the LMV. The former has the disadvantage of not distinguishing between Tunisian or European purchasers but as the European farming community formed such a high percentage of the modern sector of agriculture, trends in the national statistics must reflect the rate of purchase by the foreign farming community. The imports studied are, by definition, those used by the modern sector; tractors, fertiliser and fertiliser spreaders. On the other hand the 126-farm data, although it concerns only the colonial farmers, may not be completely typical of the European farming community as a whole because of its situation adjacent to the capital, Tunis.

National Statistics. In so far as investment in agricultural equipment as a whole was concerned the assertion by Hyslop and Dahl is borne out by the statistics. Imports dropped from a peak in 1953 (Fig. 21, p. 234) to remain at 1/3 of that level from 1956 to 1962. But imports of agricultural equipment essential to cereal farming show differing trends. For example, the number of fertiliser distributers imported closely follows the trend of the agricultural equipment as a whole.

However the number of tractors imported (Fig. 20, p. 234) recovering from a wartime low to reach a peak in the early 1950's, again fell at the time of independence but recovered once more to reach a record figure of over 1,000 in 1960.

The import of fertiliser is a useful index by which to judge the continuity of farming practice from year to year. If imports rise it suggests that the level of interest being taken in the soil's fertility is growing but if they fall it suggests the reverse; that the farmers, fearing that the crop might not be harvested by them, would choose to risk the soil's fertility in obtaining a harvest rather than invest in fertiliser to maintain the soil fertile for future useage.

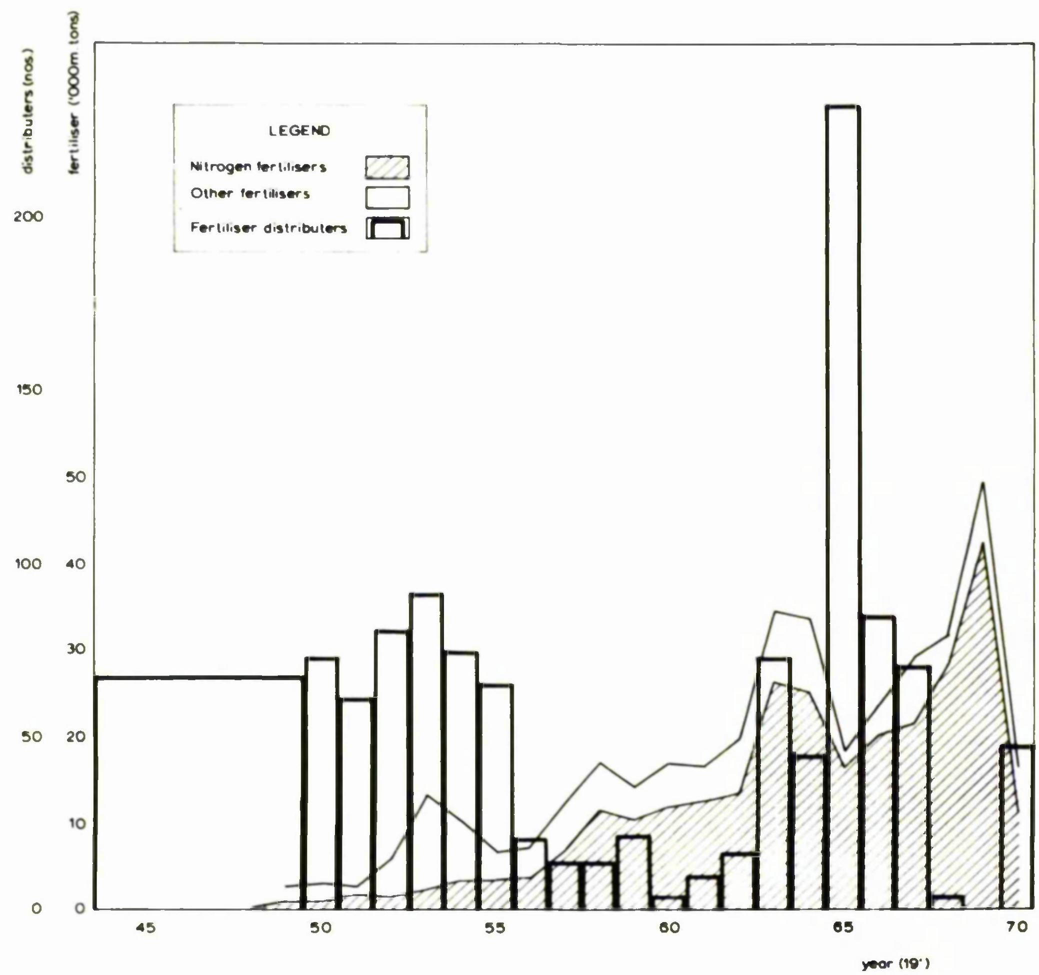
The only fertilisers which were entirely imported were the nitrate fertilisers. The useage of nitrates trebled (Fig. 22, p. 240) from 1956 to 1958 and continued to grow until after the departure of the European farmers in 1964. The rate of increase from 1958 to 1962, during which time much European land reverted to Tunisian management, was very slow. But the level of imports from 1958 to 1962 averaged about 12,000 metric tons; enough for 120,000 ha. (if it was all used for wheat which is unlikely) at the recommended rate of application. This was about half the area the colonists had under wheat in 1958. Clearly once the SBAT had shown the impact that nitrogen fertilisers could have on yield (see ch. 6.6, p. 196ff.) the response of the modern agricultural sector was immediate and strong in spite of uncertainty about the future.

It is worthwhile noting that to judge by these indices the standard of agricultural practice was much more severely affected (Figs. 21/22) by the Tunisian government plan for imposing total agricultural cooperativisation throughout the country by 1970. The policy was reversed in September 1969.

The study of the national statistics for agricultural imports does not indicate, as far as cereal cultivation is concerned, that the modern, largely European, sector lowered their

Fig. 22

IMPORT OF FERTILISER AND FERTILISER DISTRIBUTERS 1944 - 1970



source: Statistiques du Commerce Extérieur de la Tunisie (various years) standard of farming practice although long term investment in agriculture was reduced.

The 126-Farm Data. From the 126-farm data it can be seen that growing uncertainty was reflected in the rate of departure of the European farmers. The disturbances prior to independence caused the first departures (Fig. 23 p. 242) in 1954/55 and 1955/56. From 1957/58 the number of departures grew steadily after Bourguiba had made it clear that his policy was for total, if gradual, decolonisation, and as the French government schemes to facilitate repatriation came into effect. The Bizerte crisis was the cause of the high number of departures during 1961/62. No action was taken from then until 12 May 1964 when all foreign land was nationalised so that the growing crops of that year were harvested by the state with the exception of one farm, Montarnaud, whose manager stayed on until December as lessee.

There can be no doubt that when farmers began leaving others were feeling insecure about their future in Tunisia. A good index of confidence in the future is the rate at which the colonists were planting fruit trees and vines. No-one would risk the capital outlay of tree planting unless he felt reasonably confident of seeing a return on the outlay. Vines give their first harvest four or five years after planting and fruit trees take rather longer to mature. Neither would be profitable until several harvests had been gathered. Yet from 1948/49 until land nationalisation in 1964 the mean year of maximum area planted, Table 41, was 1952/53 and the mean year in which planting ceased was 1957/58. Some farmers even continued planting into the 1960's as the same table shows. The conclusions drawn from Table 41 probably err on the conservat-

Fig. 23

DEPARTURE OF EUROPEAN FARM-OWNERS FROM THE L.M.V.

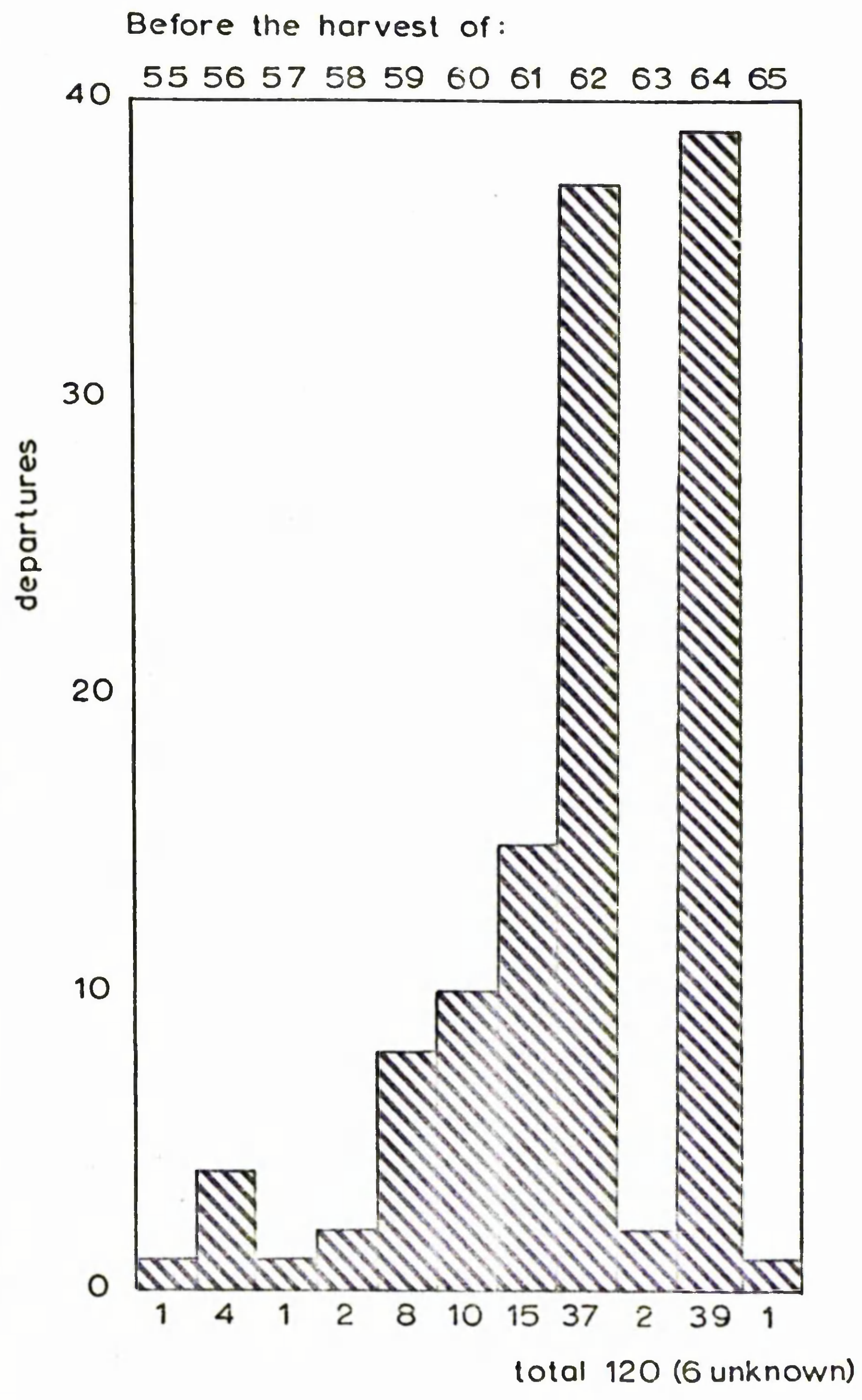


Table 41. Area of Fruit Trees, Olives and Vines by Farm Group in the LMV. 1949 - 1964. (ha.)

Farm Group		Area of Plantation 1949	1963		Key Years for Area Planted	
No.	Area	Area	Area	%F.Grp.	Maximum	Final
1	464	0	0	0.0	-	-
2	658	31	31	4.7	-	-
3	757	103	175	23.1	52/53	56/57
4	1,390	27	69	5.0	51/52	58/59
5	878	78	565	64.4	52/53	61/62
6	575	47	89	15.5	49/50	61/62
7	685	3	45	6.6	49/50	55/56
8	928	34	110	11.9	50/51	54/55
9	1,508	188	574	38.1	51/52	57/58
10	957	8	152	15.9	52/53	58/59
11	7,277	1,185	1,644	22.6	49/50	56/57
12	2,339	5	101	4.3	57/58	59/60
13	649	2	2	0.3	-	-
14	603	13	95	15.8	52/53	54/55
15	539	111	188	34.9	50/51	57/58
16	996	47	274	27.5	54/55	55/56
17	2,255	121	245	10.9	51/52	56/57
18	826	9	15	1.8	50/51	57/58
19	2,370	883	1,017	42.9	55/56	62/63
20	2,025	104	460	22.7	53/54	57/58
21	628	240	391	62.3	57/58	57/58
22	542	325	487	89.9	49/50	55/56
				Mean Key Years:	52/53	57/58

ive side. There were other reasons apart from approaching land nationalisation for ceasing to plant vines and fruit trees. One affecting vines was the legal maximum area which each farmer could plant. This area had been reached, on at least some farms, by the early 1950's as a result of rapid replacement of the vines which had been decimated by phylloxera during the war. But where farmers were planting vines and olives it is a good indication that they had retained a long term interest in the fertility of their cereal land.

The area left for growing secondary cereals and legumes is also an index of interest in the soil's fertility. The farmers of the LMV did not concentrate solely on the more exacting Fallow-Wheat rotation. Depending on the region some 15-25% of the cropped land grew barley, oats or legumes in rotation with fallow, or occasionally in the place of fallow. The overall tendency from 1949 to 1964 was for a slight decline in this area with a more rapid decline up to 1957 followed by a partial recovery. There is, therefore, no clear evidence of the colonists changing established practice to grow a much higher percentage of the taxing wheats in spite of the price differential moving in their favour and away from barley.

If the colonists strictly adhered to the Fallow-Wheat rotation 50% of their land should be under fallow each year. In practice the percentage would vary to some extent from year to year depending on the climate prior to sowing but there should be no significant change from 1949-1963. However most Farm Groups, Table 42, show that there is an overall drop in the area of fallow with the most rapid decline occurring in the two or three years before the farmers departed. But Table 42

Table 42. Percentage of Arable Land Under Fallow on European Farms in the LMV. 1948/49 Onwards. (ha.)

% Fallow: Selected 3 Year Means

	Farm Group	First	%Decrease	Next to Last	%Decrease	Last	Final yr(19')
*	1	66	12	54	28	26	57
*	2	52	14	38	8	30	63
	3	48	0	48	0	48	63
*	4	44	2	42	10	32	61
	5	46	20	26	-8	34	61
	6	52	-4	56	10	46	61
	7	52	0	52	6	46	61
*	8	54	8	46	10	36	61
*	9	46	10	36	16	20	63
	10	43	6	37	0	37	62
	11	62	10	52	4	48	63
	12	48	8	40	2	38	63
	13	52	4	48	2	46	63
	14	34	-6	40	-10	50	62
	15	52	2	50	-2	52	63
*	16	50	2	48	12	36	63
*	17	54	4	50	16	34	63
*	18	44	9	35	18	17	63
	19	62	16	46	-6	52	63
	20	52	4	48	4	44	63
	Mean:	50.60	6.05	44.55	6.00	38.55	

* Farm Groups with greatest decrease in the fallow area as percentage of arable land.

shows that this is not a consistent pattern. Of the 20 Farm Groups with enough arable land to make measurement worthwhile; two have a fairly constant percentage of fallow; in four the fallow remained stable or increased in the last three years; and in one the percentage of fallow steadily increased throughout the 15 year period.

A slight drop in the area of fallow, as witnessed up to the beginning of the last three year period, could be interpreted as a response to expert advice saying that the area of fallow should be reduced. It is probably associated with increased useage of nitrogen fertiliser. In any case, whatever the motive, it will have done no harm to the land. But in eight of the 20 Farm Groups (those marked with a star in Table 42) the evidence suggests that during the last three years of their tenancy the colonists were no longer considering the long term interests of their soils but were motivated by a desire for short term gain. The cropped area was increased to maximase production at the risk of exhausting the soil.

Conclusion. In conclusion there is no evidence to suggest that the colonists began to over-exploit their land as a result of the climate of uncertainty created in the early 1950's by the independence movement. Only by 1958/59, when most farmers had stopped tree planting, does evidence suggest that the European farming community had finally accepted that they had no long term future in Tunisia; probably as a result of Bourguiba's unequivocal policy statement in 1958. Only in the 1960's was there a clear tendency, and this by no means uniform, to abandon the care with which the established agricultural system was practised.

PART III

THE RELATIONSHIP BETWEEN CLIMATE AND WHEAT YIELDS.

CHAPTER 8

THE CLIMATE OF THE LMV.:

ITS EFFECTS ON CEREAL GROWTH, HEALTH AND YIELD.

8.1 Introduction. The purpose of this chapter is to demonstrate the complex ways in which deficiencies of climate from season to season and year to year affect the yield of the principal cereal crops in Tunisia; the hard and soft wheat.

The climatic factor which plays a major role is rainfall but in the LMV the mean rainfall is sufficiently high and regular (compared with the centre and south of the country) to ensure that low rainfall is not always the controlling factor. Sometimes high rainfall limits yields. In addition temperature can sometimes play the principal controlling role. Other climatic factors, including insolation, wind and dewfall can act in concert with rainfall and temperature to shape the total climatic environment and its effect on yield.

The complex interaction of the climatic factors during the successive critical phases of the wheat's life cycle was well summarised by Montlaur (1941, p. 67) when he concluded that his experiment to demonstrate the effect of climate on yield; 'shows the importance for the germination and life of the young plant, when considering the yield,,, of the two elements; temperature of the soil and precipitation.

'Later when the plant fully occupies the soil, the variations of air temperature, rainfall and insolation intervene. Lastly, at certain times, the relative humidity of the air has to be taken into consideration because of its consequences on the development of rusts. Evapotranspiration must not be neglected... for the period extending from heading to the month after flowering'.

The critical growth phases of wheat's life cycle, and the way they are related to yield, are listed below:

Sowing and Germination	-	Number of plants
Tillering	-	Number of heads per plant
Heading	-	Number of heads per plant and flowers per head
Pollination	-	Number of grains per head
Maturation	-	Weight and quality of the grain

Of these pollination is least likely to be affected by conditions of climate in Tunisia.

In this chapter the effect of climate on each critical phase of the wheat's life cycle will be examined in turn. This will be followed by a study of the climatic causes of the most prevalent diseases in the north of Tunisia. Finally the conclusions will be extended into a separate chapter in an attempt to define qualitatively, and to some extent quantitatively, the concept of good and bad climatic conditions for wheat cultivation, with special reference to the LMV from 1948/49 to 1962/63. This is essential in order to provide a full mechanistic understanding of the way climate affects yield. The study should, therefore, be an objective basis from which to interpret the results of the climate/yield correlation in chapter 10.

The value to the development of Tunisian cereal agriculture of being able to interpret the ways in which climate affects yield was well expressed by Perrusset, a meteorologist interested in Tunisian agriculture. In 1950 (p. 73) he wrote that; 'the establishment of the correlations between the surpluses and shortages of the harvests and the principal meteorological factors with the aim of forecasting the harvests, constitutes one of the most remarkable applications of the use of meteorological observations from the economic viewpoint. No service for the forecasting of harvests exists in Tunisia'.

What was true in 1950 is true today. The problem of establishing a reliable basis for forecasting harvests has hardly been broached.

8.2 Phases of the Life Cycle.

Sowing. The date and to a lesser extent the area of cereals sown was dependent on rainfall even on the mechanised colonist farms although the tractor and plough allowed preparation of the soil to continue during the dry season. The actual date of sowing varied very widely and was determined by several factors. On each farm, within the same year, the date range from first to last field sown depended on total area and equipment available. Sowing might be spread between several periods of suitable weather conditions even in a good year.

When the ground was too dry it was the farmer's decision not to sow but after heavy rainfall, a not uncommon feature of the Tunisian autumn, he had no choice; neither the plough nor the drill could be taken onto the land.

The preparation of the seed bad could start early if the ground was wet by late August and September rain. An important part of this preparation was cultivating the land free of weeds which germinated after the first rains (see ch. 6.4, p. 165 ff.) This part of the programme could not be ignored so that if the first rains came late the sowing time-table was automatically delayed.

If the rainfall in December compensated for the previous excess or shortage then sowing could normally be finished before the New Year. If this was not the case the total area sown was liable to be reduced even though sowing of early maturing wheats (F/A) was thought worthwhile by some farmers even in January. If delayed beyond December wheat was sometimes replaced by leguminous forrage crops sown in February/March or else the land was left fallow.

The ideal date for sowing depended upon the rate at which the variety matured; slow maturing varieties were sown first. In the 1930's Montlaur (1941) experimented with two wheats with the greatest range of maturing rates of the varieties grown in Tunisia, Table 43, to determine which sowing date gave the best results. When sown late the plant is not well established before the coldest months of January and February (Fig. 24, p. 254) so that the growth rate until March is considerably slowed. Although the natural growth flexibility of wheat allows the grain to mature at the normal time the yield is reduced because maturation takes place too rapidly.

Sowing before the correct time is not advised because of the danger of a warm, sunny November causing premature development so that the critical phase of heading is passed when the weather is too cold and the grain matures when the ground and air are too wet.

As the date of cereal sowing affects the yield and the date is dependent on the quantity and distribution of rainfall in autumn it is important to define ideal rainfall and to determine whether shortage or excess of rain was the main cause of delayed sowing in the LMV.

The work of Yankovitch at the SBAT, Ariana, helps to define the range of ideal rainfall. During the period 1933/34 to 1954/55, in his experiment on the effect of methods of cultivation on yield of F/A, he recorded the rainfall and the date of sowing (1956, p. 46) each year. In certain cases he singles out an autumn as being 'too wet' or 'too dry' for sowing to proceed on time.

His work showed, Table 44, that in the Tunis region sowing

Table 43. Ideal Sowing Date and Life Cycle of Early and Late Wheats.

source: Montlaur, 1941, p. 32

	Early Variety (Pusa x Florence)		Late Variety (Biskri AC/2)	
Growth Phase	Date	No.Days	Date	No.Days
Sowing	20 Nov	-	1 Nov	-
Germination	30 Nov/1 Dec	10	12 Nov	11
End of 'Lawn'	1 Feb	62	1 Feb	80
Heading	20 March	48	10 April	69
Flowering	1 April	11	20 April	10
Milky Stage	1 May	30	10 May	20
Maturation	25-30 May	25-30	10-15 June	30-35

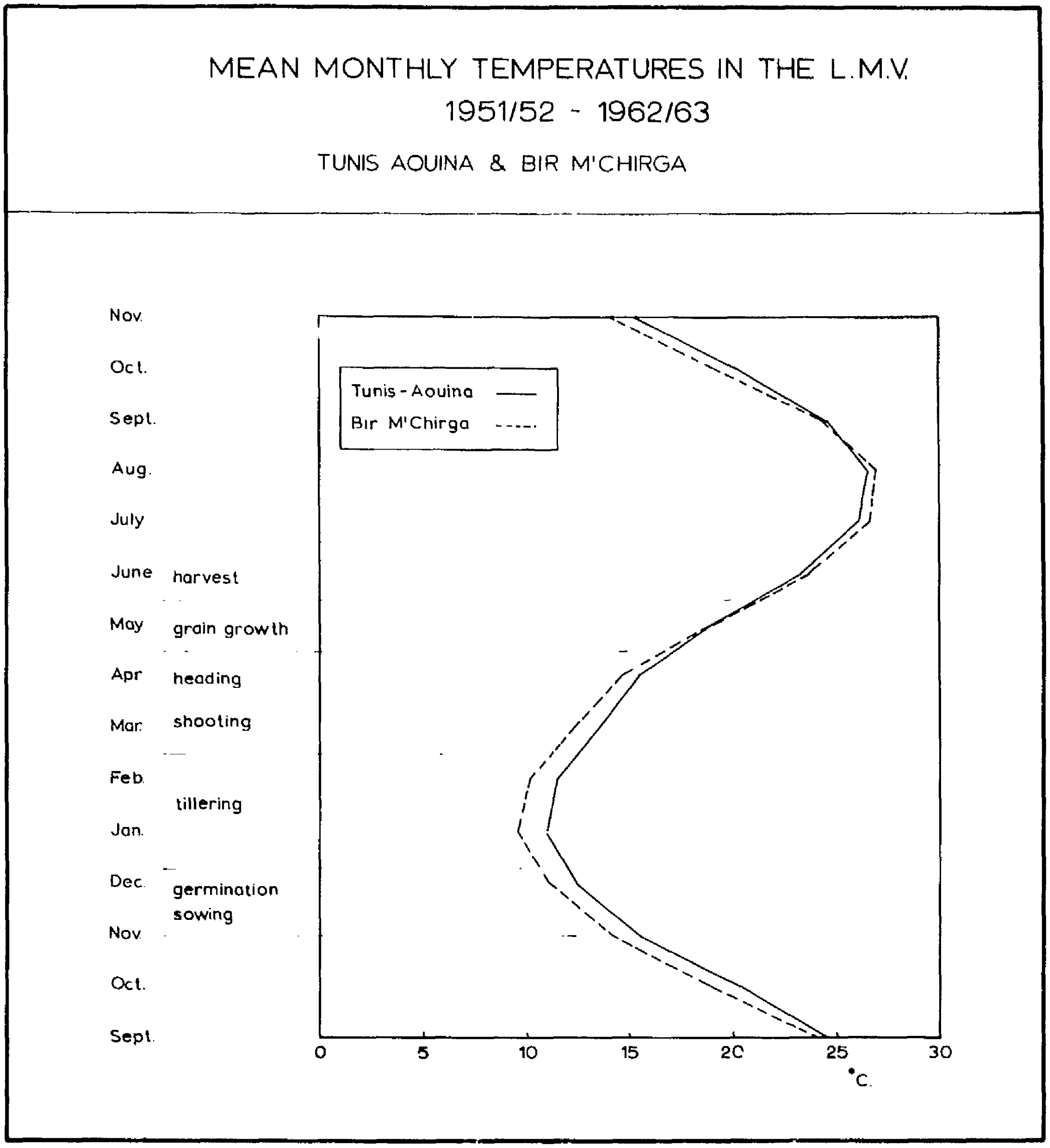
Table 44. Autumn Rainfall and Sowing Date of Florence x Aurore: Ariana 1933/34 to 1954/55.

source: Yankovitch, 1956, p. 46

Rain (S.O.N.):-	Right		Too Dry		Too Wet	
Sowing Date :-	On Time		Late		Late	
	Year	Rain(mm)	Year	Rain(mm)	Year	Rain(mm)
	37/38	192	33/34	99	34/35	208
	38/39	71	42/43	21	35/36	244
	40/41	175	43/44	125	39/40	231
	41/42	156	44/45	78	53/54	410
	48/49	144	45/46	48		
	49/50	90	46/47	66		
	50/51	139	47/48	39		
	51/52	223	54/55	94		
	52/53	142				
Mean:		148		78		273

* In 1936/37 sowing was early, for non-climatic reasons, and thus avoided the heavy rainfall of 282 mm.

Fig. 24


MEAN MONTHLY TEMPERATURES IN THE L.M.V.
1951/52 - 1962/63
TUNIS AOUINA & BIR M'CHIRGA
Tunis - Aouina
Bir M'Chirga
Nov.
Oct.
Sept.
Aug.
July
June
harvest
May
grain growth
Apr
heading
Mar.
shooting
Feb.
tillering
Jan.
Dec.
germination
sowing
Nov.
Oct.
Sept.
0
5
10
15
20
25
30
°C.

was delayed by both shortage and excess of autumn rainfall. However in his experiment the 8:4 ratio in favour of too dry may be misleading as six of the eight were successive years during the uniquely dry 1940's.

Generally speaking an autumn rainfall (September-November) falling between 100 mm. and 200 mm. is good for sowing. Above or below this range and sowing is delayed or, in extreme cases, prevented altogether. Occasionally the disadvantage of a high or low rainfall is offset by an unusually good distribution.

Yankovitch believed that early sowing and a good autumn rainfall were very important for the success of the plant. He concluded that after fallow; 'the wheat... succeeds... particularly well if the autumn rains permit sowing at the right moment;... the wheat rapidly develops its roots while the ground is still warm and damp and the temperature propitious for growth' (1956, p. 53).

When Yankovitch found it difficult to sow his experimental plots there is no doubt that the farmer with a much larger area to prepare and sow faced a far greater problem. The range of 'good' rainfall would be narrower and delays would be weeks instead of days. Sowing sometimes continued well into December and even January in exceptional years. In such years the full area was rarely completely sown. In the 126-farm data this resulted in an increased area of fallow, or fallow and spring sown leguminous crops. In wet years one effect of struggling to continue sowing in spite of very wet ground (Séguéla, 1959A) was irregular germination because the grain was sown too deep; the drill sinking 10-12 cm. into the soft earth.

For the period 1948/49 to 1962/63 the Director of the SBAT, in his annual lecture, often commented on the conditions under which sowing had taken place. These comments give a good general picture of the relationship between rainfall and the problem of sowing and help to define more closely what the ideal range of rainfall is. The comments are given below with the autumn rainfall at Ariana (SBAT) which are rather higher than for the main colonist farm regions of the LMV as a whole.

1950/51.	Aug.	Sep.	Oct.	Nov.	Dec.	S.-N.
Rain 50/51	29.9	21.8	55.1	61.7	32.1	138.5
Mean 1923/64	9.4	36.3	63.0	56.0	72.0	155.0

Yankovitch's (1956, p. 52) description shows that the autumn of 1950/51 had all the right conditions to favour sowing. The year; 'was distinguished from others chiefly by a large number of days of low rainfall in autumn. Happily there were also several abundant rains - 27 mm. on 23 October, 28 mm. on 5 and 13 November. It was thus possible to execute the sowing at a favourable time'.

1953/54.	Aug.	Sep.	Oct.	Nov.	Dec.	S.-N.
Rain 1953/54	28.5	4.8	210.0	195.0	22.3	409.8
Mean 1923/64	9.4	36.3	63.0	56.0	72.0	155.0

The autumn of 1953/54 was one of the wettest on record. The rainfall of October and November approached the mean annual total in the LMV. According to Ringwald (1955, p. 34) the year was characterised by; 'a very early rainfall (first half of August) which allowed good preparation of the soils destined for cereals. The rains were particularly abundant in October and November and... sowing was stopped; the wettest farms were to be sown in spring 1954 with legumes or spring cereals (chick-peas, peas, sorghum, maize etc.)'.

1956/57.	Aug.	Sep.	Oct.	Nov.	Dec.	S.-N.
Rain 1956/57	1.4	113.9	16.4	46.9	67.8	177.2
Mean 1923/64	9.4	36.3	63.0	56.0	72.0	155.0

Séguéla (1958) noted that sowing was early and played an important part in making the wheat resistant to the spring drought of February/March 1957.

1957/58.	Aug.	Sep.	Oct.	Nov.	Dec.	S.-N.
Rain 1957/58	0.0	20.3	175.5	80.0	142.8	275.8
Mean 1923/64	9.4	36.3	63.0	56.0	72.0	155.0

In discussing the year Séguéla (1959A, p. 13) stressed that: 'The rainfall... was very abundant in the cereal regions during the three months October, November, December.

'It greatly hindered the execution of sowing; in many cases this was done in January and many domaines were unable to complete it and therefore abandonned large areas'.

1958/59.	Aug.	Sep.	Oct.	Nov.	Dec.	S.-N.
Rain 1958/59	0.0	0.0	153.8	186.1	39.4	339.9
Mean 1923/64	9.4	36.3	63.0	56.0	72.0	155.0

An autumn similar to the previous one but made worse by having no rain until it flooded down in October. Séguéla (1959B, p. 139) reported that the: 'Excess of water has... greatly hindered sowing; on very many farms this was only finished in January. Flax sometimes replaced wheat after this period and large areas remained uncultivated'.

1959/60.	Aug.	Sep.	Oct.	Nov.	Dec.	S.-N.
Rain 1959/60	23.7	15.6	101.5	28.5	48.3	144.6
Mean 1923/64	9.4	36.3	63.0	56.0	72.0	155.0

The year 1959/60 was most unusually good. Séguéla (1960, p. 113) commented that; 'the rain at the end of summer and the beginning of autumn - September, October - was generally heavier than the average. During the month of November sowing was begun without delay and executed very rapidly under excellent conditions... the rainfall during these months INovember to DecemberI was rather low; however germination in most of the wheat lands, profiting from the reserves of water in the soil showed itself regular'.

In conclusion it seems that early rain - as early as August - is beneficial in speeding tillage and weed clearance. Then the ground should be thoroughly wet before the end of October building up the reserve of soil water so that little is needed during the weeks that sowing takes place. If then November and December are relatively dry sowing can be completed early and the seeds still have sufficient water to germinate well. Although the colonists tried to complete sowing during November it was not uncommon for it to extend into December.

In both the years noted as being good the autumn rain (Sep., Oct., Nov.) totalled about 140 mm. which corresponds closely with the mean of the good years in the Yankovitch experiment; 148 mm. In both the experiment and on the farms rainfall higher than 200-250 mm. meant delayed sowing.

Germination. Germination requires a wet soil. It is often seen to occur following the first rains after sowing. If these rains do not come but the soil is moist the seed (Boeuf, 1932) can become mouldy. But any tendency to mould stops immediately rain falls because the start of germination both stops the mould and makes the seed resistant to subsequent dry periods. Changes at this stage between active and slow development in response to rainfall can take place several times without serious damage to the seed. Once germination has begun a critical phase has passed.

The rate of growth of the primary roots and shoots of the young plantule is strongly affected by soil temperature which is in turn strongly affected by the rainfall. If the rains are light the lower soil remains warm (Boeuf, 1932) and the germination and development of the primary plant is rapid; 20°C. to 22°C. is the optimum temperature. As the soil temperature drops, usually a result of heavy penetrating rains, the rate of germination slows down and is very slow below 4°C. Thus, in certain conditions, two sowings separated by only a week to ten days can produce plants whose development is separated by several weeks.

Heavy rainfall can also waterlog the soil so that the primary roots, or the germinating seed, are asphyxiated through lack of oxygen.

When conditions are ideal for sowing - steady rain in early autumn followed by a below average November and December - they are poor for germination as in 1950/51 and 1959/60. In the latter year the high rainfall in October together with adequate rainfall in November and December allowed sowing under excellent conditions. However the combined rainfall of November, December and January was very low. Even so in most areas germination was good as the plants were able to use the reserves

1959/60.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.
Rain 59/60	23.7	15.6	101.5	28.5	48.3	39.3	14.4
Mean 23/64	9.4	36.3	63.0	56.0	72.0	80.1	57.6

of water in the soils. However Séguéla (1960, p. 113) noted that where the soils were heavy (Séguéla instances Pont du Fahs) and their retentive powers therefore high; 'the rainfall has been too slight... to leave a volume of water which the plants could utilise. Germination was sporadic, and even nil. Some farmers proceeded to resow'.

Tillering and Root Growth. Tillering, the appearance of the shoots from the primary plant, and the development of the secondary root system take place during late January and February. The late varieties complete this stage about half a month after the early varieties. In no case is tillering ever complete because the grains are deliberately sown too close together to allow this; a compromise done to obtain the highest yield per unit area.

A good tillering is dependent upon a complex balance of climatic factors. Boeuf (1932) summarised them in saying that: 'When the soil is sufficiently moist, high temperature and good insolation are favourable for tillering... an excess of moisture, above all when accompanied by low temperature, greatly reduces tillering'.

The phase of tillering is flexible, particularly for the slow maturing varieties, and takes place, within limits, when conditions of temperature and moisture permit. It can continue for an extended period if necessary. To some extent the flexibility makes the plant resistant to climatic change but Boeuf's conclusion that: 'It needs exceptional circumstances of drought or cold to allow this critical period to have a truly inauspicious influence on the development of the wheat', ignores the vital importance of good rainfall. Tillering is the most important phase of nitrogen absorbtion in the plant's life cycle, and the full secondary root system, through which the nitrogen and water are absorbed, replaces the simple primary roots during this phase. It is through the development of the roots that rainfall affects the plant at this stage.

In Tunisia root growth is mainly dependent on the concentration of water in the soil. When the rains of autumn and winter are abundant (Séguéla, 1959A) and moisten the soil deeply the roots of the wheat follow the penetration of the water. It is the soil moisture, as long as it is not excessive, that is the factor which determines the orientation of the roots. When the rains are light and only penetrate the upper soil, the roots remain superficial exposing the wheat to the effects of drought.

In a well prepared soil, easily penetrated by rain, roots can grow to a depth of 1 m. to 1.5 m. Yankovitch (1956) showed that wheat roots could tap water up to a depth of 140 cm. At and below a depth of 175 cm. the soil remained constantly saturated even in dry years except in the two exceptional years of 1942/43 and 1945/46. Below 150 cm. soil water and its contained nitrogen salts are rendered useless for the plant.

Heavy rainfall in autumn, and especially in winter, does ensure that the wheat is not short of water but it cools the soil too much and leaches nitrogen below the level of the roots. Moreover if the ground is extremely wet in December and January the roots not only remain superficial but fail to grow the absorbant root hairs which greatly curtails their ability to absorb water from a drying soil if the spring rains fail.

A good winter rainfall, encouraging full root growth, can make up for any deficiency in autumn and ensure an average to high yield depending on the spring climate.

A low winter rainfall, preventing deep penetration of rain, stops deep root growth. Not only is the absorbable water low but the plant's capacity to absorb is greatly reduced. Soluble nitrogen is in short supply. The plant receives a setback from which it cannot fully recover.

According to Yankovitch the best yields are obtained when there is sufficient autumn/winter rainfall to cause slight leaching of the soil provided that it does not occur before January. The penetration of both water and nitrates then encourages good, deep root growth allowing the plant to exploit a large volume of soil. This happened in 1949/50 and 1951/52

1949/50 & 1951/52	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	S.-J.	D.-F.
1949/50	0.0	0.0	42.1	51.3	24.4	143.3	12.4	261.2	180.2
1951/52	0.7	111.5	83.6	27.4	31.3	71.8	52.4	325.6	155.5
Mn.1923/64	9.4	36.3	63.0	56.0	72.0	80.1	57.6	307.4	209.7

in his experiment when good yields corresponded with an unusually high intake of water by the plant from the lower soil levels. The slight leaching in January in the two years was provoked by quite different distributions of rainfall with totals fluctuating widely around the mean for the station. It is likely that an average rainfall in February 1950 would have provoked heavy leaching and reduced the yield.

1946/47.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	S.-J.	D.-F.
1946/47	0.0	1.5	22.7	41.2	127.9	33.3	54.9	226.6	216.1
Mn.1923/64	9.4	36.3	63.0	56.0	72.0	80.1	57.6	307.4	209.7

The year 1946/47 was similar in winter - slight leaching occurring in late December - so that the roots penetrated very deeply and were able to absorb sufficient nutrients and water to allow a fairly high yield in spite of a virtual drought from the beginning of March until harvest.

The year 1948/49 had high rainfall in the four months from November to February with more than double the mean in November and December. Harvests were generally poor. Valdeyron (1949,

1948/49.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	S.-J.	D.-F.
1948/49	0.0	12.2	22.3	109.8	145.9	84.1	95.6	374.3	325.6
Mn.1923/64	9.4	36.3	63.0	56.0	72.0	80.1	57.6	307.4	209.7

p. 115) commented that; 'the best harvests obtained in Tunisia were normally made on the traditional land; good cultivation did not pay... In the best lands, gorged with water, infiltration began early often carrying the nitrogen below the reach of the roots'. The wheat was made very sensitive to the dryish spring.

1956/57.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	S.-J.	D.-F.
1956/57	1.4	113.9	16.4	46.9	67.8	94.8	3.3	339.8	165.9
Mn.1923/64	9.4	36.3	63.0	56.0	72.0	80.1	57.6	307.4	209.7

The distribution of rain up to the end of February 1957 was good; a rainfall which could have produced excellent yields. Sowing was early and the winter rain encouraged strong root growth. Unfortunately the drought in February was followed by an equally dry March but in most northern regions the plant was sufficiently well established to endure the two months drought and still be in good enough condition to benefit from the rain of April and May. According to Séguéla (1958), the regions of the worst yields were those which received the least water during the period which preceded the drought. In these regions the cereals were not able to regain their normal development after their new start in April.

1957/58	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	S.-J.	D.-F.
1957/58	0.0	20.3	175.5	80.0	142.8	69.3	25.3	487.9	237.4
Mn.1923/64	9.4	36.3	63.0	56.0	72.0	80.1	57.6	307.4	209.7

In 1957/58 the yields were below average in spite of average spring rainfall. The explanation must be the excess of autumn and winter rain. A detailed study of plants at Ariana

(Séguéla, 1959A) showed that in spite of the wheat appearing normal and promising 'excellent results' the grain suffered badly from shrivelling. The root system was seen to be very superficial. It had dried the surface soil and was incapable of drawing water from the subsoil.

During the period 1948/49 to 1962/63 in the LMV four

Table 45. Low Winter Rainfall At Ariana 1948/49-1962/63.(mm.)

source: data from BIRH

Year	Dec.	Jan.	Feb.	Total
1950/51	32.1	48.7	13.8	94.6
1954/55	22.3	53.6	15.5	91.4
1959/60	48.3	39.3	14.4	102.0
1960/61	47.5	80.3	7.7	135.5
Mean 1923/64	72.0	80.1	57.6	209.7

years, Table 45, had very low winter rain. All four are associated with poor to very bad harvests.

Heading. After the wheat plant has produced its shoots during tillering these lengthen (the growth of the internodes) and, during heading, the embryonic head rapidly enlarges and develops before it is mature when flowering takes place.

The date of heading, Table 46, depends upon the variety

Table 46. Date of Heading for Different Varieties of Wheat.

source: Boeuf, 1932 and Montlaur, 1941

Variety	Date
Early	20 March/1 April
Medium Early	15 April
Late	20-25 April

and the date of sowing. Montlaur gives as ideal dates the 20 March for the earliest and the 10 April for the latest varieties. Boeuf gives rather later dates reckoned from normal farm practice. The actual date depends to some extent on the temperature in winter and the fertility and humidity of the soil but the date is nevertheless not very flexible. It normally takes only two days to occur though this can extend to a week in dull, cool weather. According to Boeuf under the north African climate the date of heading is much easier to estimate with precision than that of maturity.

The date is important because heading is a critical phase in the growth of the wheat; a phase when the plant is much less well protected against the vagaries of the climate than normal. Drought is the main danger but the young head is exposed both to frost and drying winds though fortunately both are rare at this time of the year.

Both the exact stage and the length of time when the plant is most sensitive to drought have been questioned. Boeuf (1932) thought that the period of vegetation of the wheat which included the three weeks before heading and the week during which the head grows was particularly important for the influence which it had on yield. At this time it is vital that; 'the plant has at its disposal an abundance of nutrients and water'(Boeuf, 1932, p. 182).

But Vernet, Mousset and Saglio (1968), with reference to work done by two other workers, put the critical phase rather later. They noted (p. 77) that; 'Azzi placed the critical phase for the wheat in the month which preceded and the week which followed heading; but following the work of Coic one tends to delay this period to the week which precedes and the month which follows heading'.

Assuming that the true position lies within these two extremes it appears that the climate of March and April is of great importance in controlling the yield. Montlaur (1941) demonstrated the importance of March/April rainfall by comparing water loss through evapotranspiration, Table 47, from wheat and fallow. His figures, taken from only one year, 1934/35, at Ariana cannot be accepted as quantitatively accurate but they are indicative.

From the start of February to harvest loss of water from the wheat was consistently greater than from the fallow but the greatest contrast between them was for March and April up to 8 May; 369.1 mm. from the wheat and only 74.6 mm. from the fallow.

According to Montlaur the top 2 m. of soil at the SBAT can hold only 590 mm. of rainfall as a reserve available to the plant. But 590 mm. of rainfall minus the 370 mm. used during March and April leaves only 220 mm. whereas the plant can no longer absorb water from the soil if it contains less than 320 mm. Montlaur concluded from this that at least 100 mm. of rain must fall during March and April.

However Montlaur's conclusion is invalid. Of the 639 mm. in the soil on 1 March only 2.5 mm. were lost by percolation; the rest was absorbed by the plant and transpired. This makes nearly 50 mm.; or half the 100 mm. which Montlaur thought essential during March and April.

The experiment in fact indicates that if the winter rainfall has been good the reserve of water in the soil at the beginning of March should ensure a good yield with only a moderate spring rainfall. The year 1951/52 is an excellent example.

However if the winter rainfall is on the low side some

Table 47. Water Loss by Evaporation and Transpiration by the Plots at the SBAT. 1934/35 (mm.)

source: Montlaur, 1941, pp. 58-59

	Wheat (after fallow)		Fallow (after wheat)	
	Soil Water	Evapotran.	Soil Water	Evapotran.
18 Sep 1934	745.7		342.1	
		82.7		16.5
10 Dec	650.3		601.0	
		34.4		38.9
6 Feb 1935	664.6		659.6	
		44.6		4.0
1 March	639.1		662.0	
		106.4		46.8
26 March	591.6		651.6	
		158.4		23.8
23 April	434.2		608.8	
		104.3		33.2
8 May	336.4		582.1	
		32.6		22.4
29 May	309.7		565.6	
		29.8		108.7
28 June	280.4		457.4	
		36.5		25.6
9 Sep	285.6		473.5	

Table 48. Wilting Experiment on Wheat at Ariana.

source: Boeuf, 1932, p. 192

	Percentage reduction of available water to induce wilting in:-	
Growth Phase	Wheat(Marquis)	Barley
Germination	137	98
Tillering	50	95
Heading	34	47
Milky Stage	77	100

100 mm. to 150 mm. are essential in March and April. The difference between the years 1954/55 and 1960/61 was that their extremely dry autumns and winters were followed in spring by, respectively, 140 mm. and 45 mm. of rain. This meant the difference between a reasonable though low yield and complete failure.

The importance of these conclusions is underlined by the results of an experiment quoted by Boeuf. In the experiment water available to the plant was limited at different stages of growth to the point where wilting occurred. At wilting point the percentage reduction of water, below the control level of 100, Table 48, was recorded. This showed that wheat and barley is most sensitive to water shortage at heading. Tillering is also sensitive to water shortage illustrating how easily wheat is damaged by a dry winter.

Heavy rainfall during March and April is unlikely to cause much direct harm to the growing plant. This is partly because even heavy rain for this season is rarely sufficient to cause much leaching and it does not harm the roots which are already fully formed. But heavy rain can have an indirect effect on yield by producing humid conditions in which pests and diseases thrive. These are discussed in chapter 8.3.

Temperature normally plays a secondary role at heading although the plant development is favoured if April is on the cool side. Extreme heat was not considered sufficient in April to do other than exacerbate the effect of drought.

Occasionally, however, spring temperatures drop below $0^{o}C$. When this coincides with heading it can cause a sharp reduction in yield. In the LMV it is the southerly regions, both higher and further away from the moderating influence of the sea, which are most likely to suffer damage. Unfortunately the temperature record of this region is not very detailed or complete. Data for the southern part of the LMV comes only from Medjez el Bab and Bir M'Chirga which lie near, but beyond, the south-western and south-eastern boundary of the LMV. See Fig. 24, p.254

For Bir M'Chirga the absolute minimum in March, from 1951 to 1963, fell only eight times below zero; notably -2.4°C. in 1953 and -4.6°C. in 1957. In April the temperature dropped below zero only twice; -2.8°C. in 1956 and -0.2°C. in 1957.

Of these temperature minima the one likely to have caused significant damage was the -2.8°C. of April 9/10, 1956. The frost appears to have been localised and was less severe further west in the LMV. At Medjez el Bab -0.6°C. and at Djedeida -0.5°C. were recorded. There was no frost at the stations lying nearer to or on the coast:- Bizerte, Ghar el Melah, Mateur, Grombalia and Tunis.

The end of heading leads straight into flowering which lasts for two days, and perhaps only a week for an entire field. The flowers are well protected so that it is not a particularly critical phase in Tunisia.

<u>The Ceiling Phase and Maturation</u>. When the grain matures properly it reaches its maximum size four to five weeks after flowering. Afterwards its size diminishes somewhat because it loses water during the three to four weeks before maturity. However, this time guide is only approximate because the rate of maturation varies greatly from year to year. It can be hurried by a rapid rise in temperature or by hot winds. Thus in the Yankovitch experiment the extreme dates for maturity of

F/A were 8 May in 1946/47 and 3 June in 1938/39 with an average about 20-25 May. Slower maturing, associated with cool, moist weather, produces a larger grain of better industrial value.

The first phase of grain growth takes place in April for the earliest varieties but from mid-April to mid-May for the later maturing hard wheats. This first phase corresponds with the rapid formation of the envelope of the grain (Ferhat, 1962) while the photosynthetic activity - and therefore evapotranspiration - is still important. The plant is still absorbing large quantities of water and nutrient salts and forming reserves of dry matter in the vegetative organs. The grain has only just started absorbing reserves of food from the plant. A few days before the end of this phase reserves in the wheat plant reach a maximum and the grain attains its full length, although its width and thickness are only slowly increasing.

During this phase the plant is still dependent on ready supplies of soil moisture. If the plant is short of water the grain cannot develop normally and the yield suffers but because the rate of maturation is flexible rain falling at the end of April can restore health to the early maturing wheats, while the late varieties can make use of late rains falling up to mid-May.

During the second phase of maturation, which lasts ten to twelve days, the water requirements of the plant are greatly reduced. Photosynthetic activity and evapotranspiration slow right down and the leaves begin to turn yellow. The water content of the grain remains practically constant but the food reserves in the plant are actively transferred to the grain under very complex and delicate biochemical control. This phase is the most critical of all for obtaining high yields. Temperatures of 30°C. or above occurring during the ceiling (the 10 to 12 days of active dry matter absorbtion by the grain), particularly near the start of the period, can completely dislocate the delicate biochemical processes. Occurring at the start of the ceiling a coup de chaleur (Ferhat, 1962) can decrease yields by up to 50%; five or six days later by only 20%. A slighter effect is recorded if the high temperature comes just before the end of the ceiling.

In Tunisia May is the month in which the first hot sirocco occur which raise the temperature 5°C. to 10°C. in a few hours. It is not uncommon for such temperatures to reach 30°C. to 35°C. and remain there for three or four days.

In the final phase of maturation, lasting two or three weeks, the dry weight of the grain does not change. The only activity is the purely physical one of gradual grain dessication. Again the plant is not dependent on rainfall and at this stage a sirocco only marginally affects yield.

Rainfall heavy enough to directly affect yield is very rare but both shortage and excess rainfall provoke certain diseases which are discussed in chapter 8.3.

The following comments on the effect of late spring climates on the yields of particular years, within the period 1948/49 to 1962/63, illustrate the above-mentioned points.

1950/51.	A.	S.	O.	N.	D.	J.	F.	M.	A.	M.	J.	Total (mm)
Rain 50/51	0	22	55	62	32	49	14	23	15	35	6	313
Mean 1923/64	9	36	63	56	72	80	58	50	42	22	12	500

In 1950/51 there was a great deficit in rainfall in each month from December to April. The May rainfall was high and the temperature relatively low.

On 1 April Bigourdan (1951) estimated extremely low yields. The hard wheats looked slightly more healthy than the others. The yields were in fact poor though not as poor as expected and the quality of the grain was good to very good both for F/A as well as for the other soft wheats and the hard wheats.

The quality was due to the good climatic conditions of May; cool and damp favouring slow maturing of the grain. Everywhere where local rains of the latter half of April and May (varying between 25 mm. and 75 mm.) occurred with a marked lowering of the temperatures the effect on the harvest was marked. It caused surprise that on soils where the penetration of the water hardly passed 10-15 cm. the cereals were able to regain their vigour in such a manner. Bigourdan (1951, p. 147) wrote: 'everywhere soft and hard IwheatI accelerated the formation of their heads and of their grains; rain and low temperatures persisting up to the end of May. It was a veritable resurrection at which we were present'.

In this case the rains came too late to ensure even an average yield - April would have been much better - but all the wheats were able to utilise rain falling as late as May.

1957/58.	A.	S.	O.	N.	D.	J.	F.	M.	A.	M.	J.	Total (mm.)
Rain 57/58	0	20	176	80	143	69	25	69	31	5	17	635
Mn. 1923/64	9	36	63	56	72	80	58	50	42	22	12	500

The year 1957/58 suffered an extremely wet October to January but the spring rainfall was good until April. May was not only dry but hot, and a sirocco in early May coincided with the ceiling of the earlier varieties of wheat; particularly of F/A.

1959/60.	A.	S.	O.	N.	D.	J.	F.	M.	A.	M.	J.	Total(mm)
Rain 59/60	24	16	102	29	48	39	14	57	43	19	11	402
Mn.1923/64	9	36	63	56	72	80	58	50	42	22	12	500

In 1959/60 the dry winter was compensated by good rainfall during the rest of the year. During his field visits at the beginning of May Séguéla (1960) noted that high yields seemed inevitable; the crops looked so healthy. Yet the yields were often poor and even abandonned in some parts of the north - an event which had become extremely rare. Part of the explanation is due to unusually heavy rust infection but the principal cause of the poor harvests was the sirocco of 12-16 May, with mean maximum temperatures of 33.5°C. at Tunis and 35.5°C. at Medjez el Bab. This corresponded with the ceiling phase of the medium-early and late varieties of wheat; F/A practically escaped damage. Séguéla (1960, p. 118) noted that the grains in consequence were; 'malformed, thin, shrivelled up. In a word: échaudés'.

8.3 Maladies of Wheat.

Mitadinage. Mitadinage is a malady of hard wheats. The grain forms with a higher percentage of flour making it unsuitable for production of pasta products.

A grain of wheat suffering from mitadinage shows whitish, flowery spots instead of the normally vitreous and amber coloured surface. The results of experiments and laboratory tests at Ariana in 1958 (Séguéla, 1959A) showed that mitadinage is a condition of the albumen in the wheat grain associated with a shortage of nitrogen. Fertilisers and the introduction of legumes into the crop rotation reduced the incidence of mitadinage.

If nitrogen is in short supply the level of mitadinage rises if other factors ensure a high yield. Shortage of nitrogen has a greater effect on the quality than of the quantity of the grain produced if it occurs during the late phase of nitrogen absorbtion.

The malady was first drawn to the attention of the SBAT in the early 1950's partly because the wetter climate of the 1950's favoured the disease but more because of the new interest being taken in hard wheat growing by the colonists as the era of F/A drew to its close; as explained in chapter 6.2.

It appears that a dryish spring helps to ensure the quality of the grains of hard wheat. This is why the hard wheats in 1950/51 produced high quality grain although the yield was low. On the other hand the years when the rate of mitadinage was high enough to cause comment all had very wet springs, Table 49, coinciding with the early phase of grain growth when the plant is still actively absorbing both water and nutrients from the soil. The years 1952/53 and 1958/59 were the worst affected.

A condition resembling mitadinage, called false mitadinage (Séguéla, 1959B), can be produced by an excess of rain during the weeks before harvest; in the latter part of May and the first half of June.

Table 49. The Heaviest Spring Rainfalls at Ariana 1948/49 to 1962/63. (mm).

source: data from BIRH

Year	Mar.	Apr.	May	June	Mar.-May	Mar.-June
1952/53	68.5	30.6	60.1	50.4	159.2	209.6
1953/54	48.4	121.8	16.7	4.1	236.9	241.0
1958/59	89.1	161.3	32.3	66.1	282.7	348.8
Mean 23/64	49.8	42.3	21.8	11.6	113.9	125.5

In this case (Séguéla, 1959B, p. 139) grains are found; 'which have become white and lost their horny appearance'. The excess moisture penetrates the grain reducing its industrial qualities and making the grain more or less flowery and whitish. Séguéla showed a good correlation between the height of June rainfall in 1959, in different parts of the country, and decreasing specific weight of the grains. The specific weight is strongly correlated with yield: Yield = Volume x Specific Weight. He wrote (1959B, p. 148): 'It is indeed to the low specific weight of the wheats of the last harvest that one must attribute the reduction in yield generally noted and which ... was produced during the maturing of the grain... False mitadinage and mitadinage itself act in the same direction'.

Shrivelling. There are two types of dessication from which the wheat plant is likely to suffer in Tunisia while the grain is forming. They may be distinguished by the climatic conditions which cause them and the effect on the grain.

The first is caused by a shortage of spring rain which reduces the dimensions of the grain leaving it of regular form but small. The second is caused by a rapid rise in temperature during the ceiling phase of grain maturation (see ch. 8.2, p. 269 ff.) and the effects are exaggerated if water is in short supply. The high temperature acts by increasing the rate of evapotranspiration so that the water lost exceeds the possibilities of water absorbtion by the roots. Recent work in Australia (Asana and Williams, 1965) also shows that temperature can act directly on the plant to reduce yields even when sufficient water is available. In either case the temperature of the plant therefore rises and the complex biochemistry of grain formation is irrevocably disrupted. The grain is not only small but its shape and composition, and therefore its industrial qualities, are strongly affected. Ferhat (1962, p. 121) described these grains as; 'wrinkled, rough in appearance, the faces hollowed, as if shrivelled up. In extreme cases the grain appears as if almost empty of matter and reduced to its envelope'. In other words they have all the attributes of shrivelling.

Shrivelling cannot occur, even if the soil is dry and the wheat lies in the path of drying winds, if the heat-wave occurs after the end of the ceiling phase (during the grain's final drying phase) or if the temperature does not exceed 28°C. On the other hand shrivelling can occur even if the crop is irrigated provided that during the heat-wave the rate of transpiration exceeds the water absorbing capacity of the roots. The likelihood of this is greatly increased if the root development is poor; a result of a very wet or a very dry winter.

The continual damage caused by shrivelling and the efforts to control it undertaken by the SBAT were stressed by Boeuf

(1932, p. 217) when he wrote: 'Shrivelling is perhaps the misfortune most feared by the cereal farmers of North Africa and research into the proper means to avoid its most regrettable consequences has been one of our principal preoccupations in the choice and creation of varieties of wheat'.

During the period 1948/49 to 1962/63 the years when high temperature and sirocco are most likely to have caused substantial reduction in yield through shrivelling, Table 50, are 1957/58 and the three year period of 1959/60 to 1961/62. Remembering that the spring of 1958/59 was right for <u>mitadinage</u> the farmers suffered four successive years of unusually bad spring and late spring conditions for wheat growing.

Ferhat (1962) noted that in the month before harvest of 1960, 1961 and 1962 a heat-wave above 28°C. came about in mid-May (between 9 May and 16 May). The wheats whose ceiling phase coincided with this date were strongly shrivelled.

The year 1957/58 was marked by exceptionally heavy autumn rain and by the near absence of rain from 20 April until harvest. During the dry May the mean temperature was the seventh highest of the period 1933/34 to 1962/63; 20.1°C. The temperatures from 8 May to 13 May were consistantly very high at Tunis-Carthage and considerably above the level at which shrivelling becomes possible. In fact the conditions of the year were almost perfect for shrivelling to occur; very wet after autumn encouraging poor, superficial root growth (see ch. 8.2, p. 260ff.), drought after 19 April and very high temperatures in the first half of May.

The climate of 1959/60 was much less likely to cause shrivelling; both autumn and early spring rainfall were good and the

Table 50. May Temperature Maxima and Sirocco at Tunis-Carthage: 1948/49 to 1962/63. ($^{\circ}$C. x 10).

source: data from Tunis-Carthage (-Aouina)

	1 // 5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
*1948/49																				292		293	295	325	301		
*1949/50																			290	318	350						
1950/51														322				—	<u>294</u>	<u>314</u>	295						
1951/52																							<u>290</u>				
1952/53									312									<u>301</u>									
1953/54																										291	302
1954/55													303	328		308											
1955/56														<u>313</u>	<u>342</u>	296	300	<u>312</u>						290	288	300	
1956/57																									260		
1957/58		295		286	290		290	293	287											293	<u>324</u>		304			<u>308</u>	
1958/59																				268							
1959/60									302	<u>357</u>	<u>328</u>							297									302
1960/61				—	—	—					<u>311</u>	<u>369</u>	<u>339</u>				—										—
1961/62					<u>331</u>	<u>310</u>		297														313					301
1962/63																										254	

* sirocco not recorded

— sirocco (difference between wet and dry bulb 11°C. or more) mean May temperature was not exceptionally high. At the beginning of May the wheat crops looked in excellent condition but the yields were low to very bad. The explanation of this was the very high temperatures and sirocco of mid-May which caused strong shrivelling and therefore low yields. Séguéla (1960, p. 116) wrote that; 'it is on the quality of the grain which depends once more the reduction in yield recorded; the grain... is strongly shrivelled and of very low specific weight'.

Fungal Diseases and Pests. There are few diseases which are capable of seriously reducing cereal yields in Tunisia. Those that do only cause significant damage when climatic conditions are favourable.

Rust is the most important disease, so much so that resistance to rust is one of the characteristics which has to be selected for when developing new varieties of wheat. In general the wheats grown post-war were rust resistant though in the right conditions of moisture and temperature rusts sometimes made significant inroads into yields.

The year 1958/59 was extremely wet. The winter had no very cold month and March was both extremely warm and extremely wet - ideal conditions for rust to develop. But rust damage was not severe. Séguéla (1959B. p. 148) remarked that; 'thanks to the high resistance of our varieties, thanks also perhaps to the lateness of the first infection the attack of rust was very late and extremely limited'.

But the fact that the land had become infected was one of the causes of the greater damage done in 1959/60. In this year the climate was not favourable to rust until March (the winter had been hot and dry) which was only slightly less warm and wet than March of the previous year. But the damage done by black rust was surprisingly extensive, according to Séguéla, considering that the varieties are normally rust resistant. Yellow rust also attacked EAP 63A(Guelma).

The late varieties of wheat and the early varieties which were sown late were strongest attacked.

The year 1958/59 provided ideal conditions for a number of other diseases. Firstly smut, a fungal disease, caused serious damage in Tunisia for the first time. Smut interferes with the metabolism of the wheat plant causing the grains to show all the attributes of shrivelling - a condition normally associated with drought and high temperatures. Séguéla commented that drought and prolonged sunshine were detrimental to smut.

Secondly, it was remarked in 1958/59 that the ground was invaded by nematode worms in areas where the soil had been leached of nitrogen salts. Nematodes attacked the wheat roots.

The warm dryish winter of 1959/60, following the wetter than average autumn, provided excellent conditions for intense vegetative growth at tillering, particularly for the early sown fields. At the same time conditions were ideal for attack by mildew.

The only other troubles to be mentioned were, firstly, the danger of grain mould after sowing when the ground is not moist enough to permit germination. Secondly, Yankovitch found a root fungus in his experimental plots associated with a reduction in yields, in each year after 1948/49 except in the plots where no nitrogen had been added. He believed that an excess of nitrogen in the soil made the wheat susceptible to the disease.

<u>8.4 Conclusions</u>. Of the climatic factors which affect cereal productivity in the LMV, rainfall and temperature are the most significant. Separately and in combination they affect the wheat plant both directly and indirectly.

Directly, water, and therefore rainfall, is used by the plant in chemical combination with nitrogen and carbon dioxide to form the chemical constituents of the plant; particularly during the process of photosynthethis. Water is also the medium in which soluble reserves are absorbed into the plant and transferred from one organ to another. Finally, by transpiration from the leaves, water prevents damage being done to the plant through overheating.

For these reasons a shortage of water reduces the rate of photosynthesis and the level of all other physical and chemical activity within the plant. Inevitably grain formation is hindered or even, in extreme cases, prevented.

Physical and chemical activity is also curtailed by extremes of heat or cold. And it is important to realise that there is a close interdependence between temperature and rainfall. For example, as has been pointed out, heavy rainfall in November and December cools the ground and therefore slows the rate of germination. Again the damaging effect of high temperature in May is offset if the plant has sufficient water to increase the transpiration rate accordingly. For May, and April, it would therefore be useful to know the evapotranspiration potential (principally a function of temperature, wind speed, and relative humidity) but unfortunately such data does not exist.

Indirectly extremes of temperature and rainfall combine to affect the plant in many ways and at all stages of its life cycle. The most important indirect effects on yield are through the agency of plant maladies; particularly shrivelling of the grain and rust which are favoured by warmth and, respectively, shortage or excess of moisture.

Having examined the effect of climate on yield at the different stages of the plant's life cycle and the close relationship between climate and disease we are now in a position to move towards a definition of good and bad climatic conditions for cereal cultivation in the LMV.

CHAPTER 9

TOWARDS A DEFINITION OF GOOD AND BAD CLIMATIC CONDITIONS FOR CEREAL CULTIVATION IN THE LMV.

9.1 The Range and Distribution of Rainfall.

Introduction. From the study of the life cycle of the plant it emerges that a simple formula correlating total rainfall with yield would not give a meaningful result. The rainfall has to be examined by season, or even by month, or even by individual dry spell and storm, to see how it affects the wheat at each stage of its development. Even the rainfall of the previous year must not be forgotten because of the effect this has on the soil during the summer and autumn before sowing. Lepidi's comment on the correlation of climate and yield of the 1940's is equally true for the subsequent and all other periods. In 1949 (p. 25) he wrote that: 'The recent period gives a remarkable example of the determining action of rainfall on production. This dependence is moreover subtle, above all concerning cereal crops. There is no significant association between yield and total quantity of rain; the important thing is the useful quantity and its distribution throughout the agricultural year. The European crops suffer less strongly from the effects of the rain as a result of working the fallow which preserves in the soil part of the water fallen the previous year'.

The effect on yield of the previous year's rainfall and of the rainfall during the crop year will be examined on an approximately seasonal basis in order to obtain a seasonal definition of good and poor rainfall years. The possibility of establishing critical climatic ranges by month will also be examined.

But the limited amount of detail in the available evidence and the flexibility of wheat's growth phases may make this impossible except in extreme cases.

The seasons, as defined in Table 51, coincide as closely as possible with critical phases of the plant's growth cycle assuming that the seed are sown within a fortnight, or at most a month, of the ideal period. If this is so the growth of the head will occur during March/April and the ceiling occur during May. The rate of maturation of the grain will then depend on the climate, normally being ready for harvest during June.

Table 51. Growth Phases by Season for an Early Variety of Wheat in the LMV.

Season	Months	Growth Phase.
Autumn	August	
	September	Soil Preparation
	October	
	November	Sowing and Germination
Winter	December	
	January	
	February	Tillering
Early Spring	March	Shooting, Heading
	April	and start of Maturation
Late Spring	May	Ceiling and Grain
	June	Drying

The hard wheats are sown before the soft wheats, which are earlier maturing, and mature rather later. The development of both coincides during tillering but from then on the slower maturing varieties are about a half month later than the early varieties.

In this chapter where reference is made to rainfall in the LMV the figures given are the means of the rain stations scattered throughout the area. For this reason the rainfalls given are rather higher than those which actually fall in the driest parts of the LMV. But in this case the mean is a useful concept; Kendall's Coefficient of Concordance (giving a $X^2 = 332$) on the eight rain stations with 50 year records shows that the pattern of high and low rainfalls in one area correlates very closely (significance far in excess of the 0.1% level) with all other areas. For monthly rainfall and wheat growth phases see Fig. 25.

Rain of the Fallow Year. In Tunisia one reason for having fallow (see ch. 6.5, p.173 ff.) was to make part of the rain of the fallow year available for wheat during the crop year. So yield should be affected by the rainfall of the previous year. This possibility has not been considered by anyone trying to find correlations between yields and rainfall in Tunisia which is surprising because water conservation was widely accepted as a principal benefict of fallow.

The effectiveness of the Fallow-Wheat rotation as a water store (see ch. 6.5, p. 179 ff.) was shown by Yankovitch. He

Table 52. Rainfall Needed to Saturate 2 m. of Soil after Fallow and after Wheat. (mm.)
source: Yankovitch, 1956, pp. 29-33

	Mean	Maximum	Minimum
Following Fallow	199	321	91
Following Wheat	340	538	162

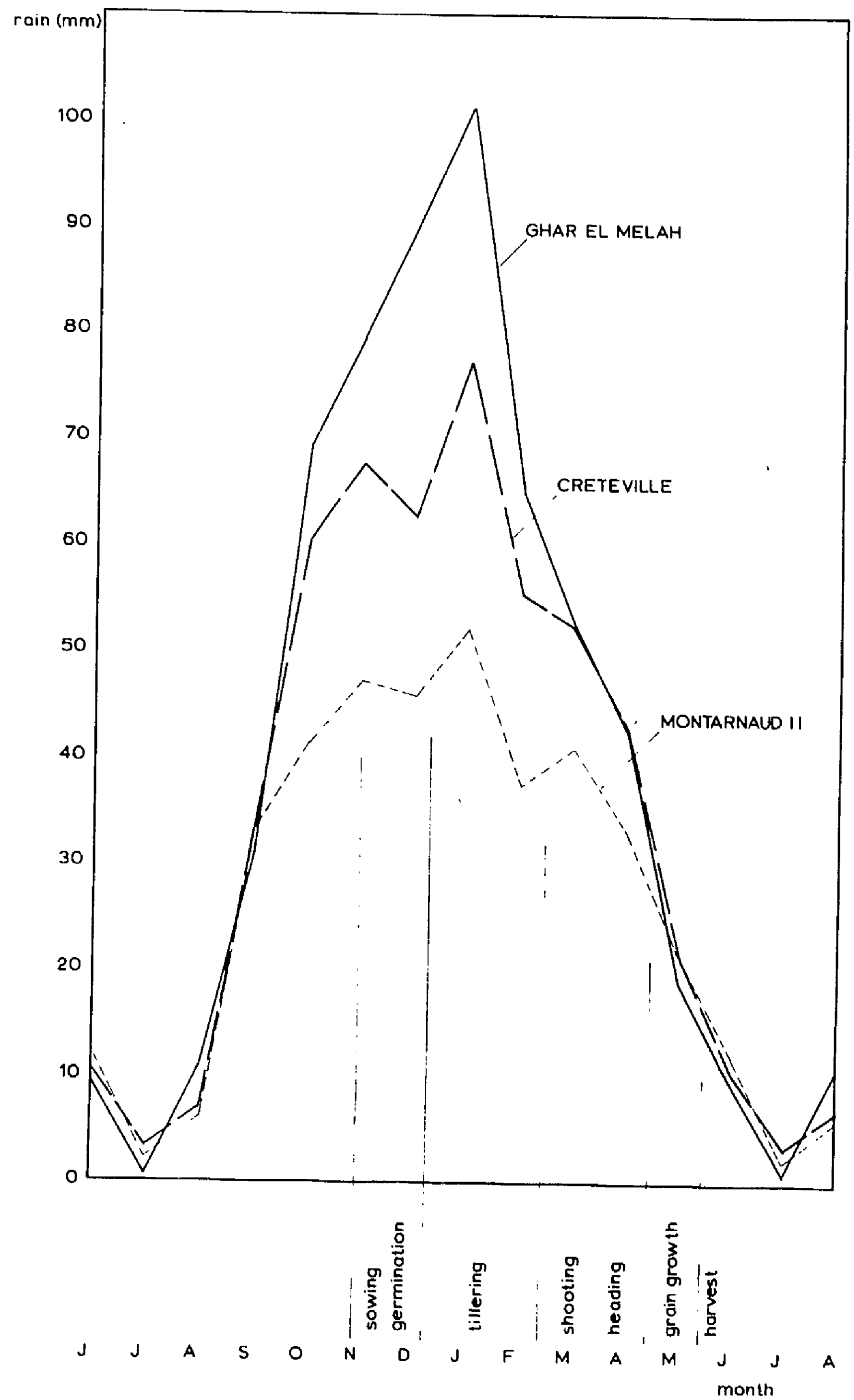
found that the rainfall needed to saturate a field after fallow was much less than after wheat, Table 52, although the exact amount varied greatly from year to year depending on several factors (Yankovitch, 1956, p. 208); 'amongst which the character of the preceding spring... (wet or dry) appears to be very important'.

Ferhat (1962, p. 113) noted that although the yield and

Fig. 25

MEAN MONTHLY RAINFALL IN THE L.M.V.

1911/12 - 1959/60



quality of wheat depended to a large extent on the amount and distribution of rainfall during the crop year it was equally important to; 'note that the question of the reserves of water in the soil at the start of the period of vegetative growth is not without importance, very much to the contrary'.

Yankovitch had shown that the foundation of this reserve could be laid down the previous spring so that the quantity of autumn rain needed to saturate the fallow was much reduced.

The years 1948/49 and 1951/52 of the Yankovitch experiment gave very good harvests but with different rainfalls during the crop year. The explanation is that the poorer rain of 1949/50 came on top of a saturated fallow while the stronger rainfall of 1951/52 came after a fallow only 2/3 saturated. In both cases filtration through the 2 m. soil only started in January and was not very strong; probably ideal, according to Yankovitch (see ch. 6.5, p. 181ff.), to carry the nitrates down to the roots at tillering - the most critical phase for nitrate absorbtion.

Note that in both cases one of the two rainfalls - fallow year or crop year - was low (1950/51 was extremely low) suggesting that yields would be reduced by the use of fallow in a wetter region or by two successive wet years. The rain of the fallow year might then have the effect of limiting the yield.

Indeed the yield of 1954/55 gave one of the lowest yields of the experiment in spite of a good distribution of rain. This, Yankovitch believed, was because 1953/54 had been extremely wet.

When rainfall of the fallow year is beneficial it acts in two ways. Late spring rain, particularly April and May (and June when this month is wet) increases the reservoir of water in the fallow. This both ensures a moister soil in autumn and, more importantly, it provides ideal conditions of soil humidity to activate nitrogen fixing bacteria during the summer of the fallow.

The importance of spring rain for fixing nitrogen was shown in the Yankovitch continuous wheat experiment when he noted that the rains of May 1948, which were too late for the 1947/48 crop; 'made a certain moistness in the soil, sufficient for maintaining microbic activity and useful for the harvest of the following year, one of the best' (1956, p. 65).

Again the high level of soil nitrogen in November 1950 (in the deep ploughing experiment using the Fallow-Wheat rotation) was explained (Poletaef, 1954) by the spring of the year 1950 which was wet and prolonged and by the autumn which was equally moist and warm.

Monthly Extremes: Drought and Flood.

Drought. A meaningful definition of drought is difficult to determine; the term is rarely used in the literature referring to the north of Tunisia. Periods of low rainfall and relatively dry years are common hazards but drought is a rare phenomenon. This is partly because to have much effect on the cereal crops droughts have to occur between December and April whereas the driest months normally fall between June and August or September.

For the period 1948/49 to 1962/63 the only period to get much attention as a drought was February/March 1957 when a mean of only 3.9 mm. of rain fell in two months in the LMV. These and other months receiving comparable totals of rainfall are listed in Table 53 ; there were only six of them in 15 years.

A drought in November or December after sowing would be critical for germination. Fortunately this is very rare in the

Table 53. Drought Months from December to May in the LMV : 1948/49 to 1962/63. (mm.)

source; data from BIRH

Year	Month	Rainfall
1954/55	May	5.1
1956/57	February	1.8
	March	1.1
1957/58	May	3.0
1960/61	February	4.7
	April	0.8

LMV and the north of Tunisia. However when there is no further rainfall (but only hot, dry weather) after sowing wheat into damp soil the seed can go mouldy and reduce the germination rate.

The significance of drought during March and April was established experimentally by Ferhat (1962) at Gabès. He grew wheat under identical conditions apart from water supply during March and April when four irrigation regimes were differentiated. He gave to the plots the amount lost by evapotranspiration less 1 mm., 2 mm., 3 mm., and 4 mm. respectively. He considered the fourth plot to be equivalent to a prolonged drought.

Table 54. Wheat Yields with Experimentally Differentiated Spring Rainfalls. (gram wt./1,000 grains).

source: Ferhat, 1962, p.117

Plot	Yield	Difference
I	56.0	
		2.5
II	53.5	
		4.5
III	49.0	
		6.5
IV	42.5	

The weight of the grain produced, Table 54, fell increasingly rapidly as the 'drought' increased in intensity. This is associated with an increasing percentage of gluten stored in the grain; gluten being the lightest of the food reserves stored.

The drought of 1956/57 provided a perfect natural experiment for the effect of late winter to early spring drought on wheat. Séguéla noted that during March the cereals; 'no longer found in the soil the water necessary for their subsistence and they visibly wasted away. They had certainly reached the limit of their resistance when the first rains fell at the beginning of April' (1958, p. 7)

But with normal rainfall in April and May the wheat in general recovered to give a fairly high yield especially where the rainfall before the drought had been greatest. This rainfall had been sufficient to wet the ground thoroughly and as the wettest month had been September sowing had been completed early. The wheat roots, therefore, were generally well developed before the drought began.

The late varieties withstood the drought best indicating that the earlier sowing date and the slower vegetative growth of these varieties renders them more flexible; better able to adapt to the fluctuating pattern of mid-season rainfall from year to year.

The effect of the drought on the very early maturing F/A was generally more marked but also depended to some extent on the date of sowing. Séguéla reported that where it had been sown on time it was shooting when the drought came. Its root system, almost fully developed, certainly occupied a moist zone of the soil and because of this it only suffered slightly from the lack of water. On the other hand the late sowings of this variety were strongly affected; it proved itself very sensitive to adversity during the period of tillering. The yield of F/A was closely related to the state of the vegetation during the period between germination and the end of tillering.

But perhaps the most interesting point is that the two month drought had such a small effect, being largely offset by good rains both immediately before and after the two month dry period. During a prolonged dry period wheat can get some sustenance from the ground and also survive drought in mid-season by slowing the growth rate and reducing the rate of evapotranspiration for a month or more. In 1957 when the rains finally restarted in April Séguéla (1958) noted that in most places wheat had made a new start. In June he estimated that the yields would be generally normal, or even high on some farms.

This prophecy was borne out; the yields of 1956/57 were one of the highest of the 1950's.

Unlike 1956/57 the two drought months of 1960/61, Table 53, are associated with the worst yields of the period 1948/49 to 1962/63. As far as rainfall is concerned there are two explanations for this. The first is the generally dry year so that there was no reserve of water in the soil to tide the plant over the drought months. Secondly the drought in April coincided with the early part of the sensitive reproductive phase of the plant's growth which is not nearly so flexible as the vegetative stage; it cannot slow down to await sufficient rain in the following month, May, when, in any case, heavy rain is uncommon.

<u>Flood</u>. The months of high rainfall, Table 55, are mostly con-

Table 55. Months of Heavy to Very Heavy Rainfall in the LMV: 1948/49 to 1962/63. (mm).
(Including mid-month to mid-month totals).

source: data from BIRH

Year	Aug		Sep		Oct		Nov		Dec		Jan		Feb		Mar		Apr		May
1948/49						88	85		164	229									
1949/50										87	149	87				88			
1950/51						111													
1951/52				81							81	112							
1952/53						98		90	92	102	107			84	95				84
1953/54					149	209	120			86	80					132	94		
1954/55																	92		
1955/56			98	90	86	83				127	119	119	126						
1956/57			121	120				103	83										
1957/58				113	152		148	152	118	135									
1958/59					133	148	164	116									125		
1959/60																			
1960/61																			
1961/62				95								105							
1962/63					136	141						100	82						
Total Very Heavy(100+ mm):	-	-	1	2	4	4	3	3	2	4	3	4	1	-	-	1	1	-	-
Total Heavy/V. Heavy(80+ mm):	-	-	2	5	5	7	4	4	4	6	5	5	2	1	1	2	3	-	1

fined in the LMV to the five month period mid-September to mid-February. Occasionally the spring months can be equally wet but this is rare. High autumn and winter monthly rainfalls occurred in years of both poor and good yield showing that very rarely is the rainfall of one month sufficiently high to cause a significant reduction in yield. It only does so in association with other wet months. In a year like 1949/50 the extremely high January rainfall undoubtedly played a major part in obtaining the excellent yields of that year which would otherwise have been too dry. Possibly the yield would have been even better if the rain had been more evenly distributed.

Perhaps the only clearly excessive single months' rainfall in autumn and winter, Table 56, were when the rainfall exceeded

Table 56. Excess Rainfall Months in the LMV. 1948/49 to 1962/63. (mm.).

source: data from BIRH

Year	Month	Rainfall
1948/49	16 Dec-15 Jan	229.0
1953/54	16 Oct-15 Nov	209.0

200 mm. Rainfall of this order is likely to cause undue leaching unless the ground beforehand was exceptionally dry for the time of year.

In spring, also, a heavy rain after a dry autumn and winter can be extremely beneficial, as in 1954/55, but otherwise the highest of the spring monthly rainfalls, Table 57, are all associated with diseases, mitadinage and false mitadinage. The total in a spring month need not be as high as in a winter month to be detrimental to yield.

Seasonal Rain Shortage. The problem of rain shortage, even when there is no period when it stops completely, is much more common than drought in the LMV and its consequences can be more deeply felt. The year 1950/51 is an excellent example. In the LMV no month experienced a drought but the yield of wheat was very low; the result of a continually dry growing season.

In theory a low rainfall of 250 mm. is sufficient for a yield of 20-25 ql/ha. but this depends on the rain being perfectly distributed throughout the crop year so that none is wasted. Better yields could be obtained from similar rainfalls if they were expected but the farming methods have to effect a compromise; ready for wet, average or dry years. What normally would be regarded as a low rainfall can have a dramatically good effect on a crop weakened by shortage early in the season. This was true of 1950/51 when both winter and early spring had very low rainfalls but, according to Bigourdan (1951, p. 145); 'the 25 mm. to 75 mm. of rain falling from 15 April to 15 May 1951 singularly lightened the problem. Truly, very little rain is needed in April to radically change the harvest prospects'.

Table 57. Months of Heaviest Spring Rainfall in the LMV : 1948/49 to 1962/63. (mm.).

source: data from BIRH

Year	Month	Rainfall
1949/50	16 Mar-15 Apr	88.0
1952/53	March	95.0
	May	84.0
1953/54	16 Mar-15 Apr	132.0
1954/55	April	92.0
1958/59	April	125.0

When a month's rainfall is low it is important to know its character. If such a rainfall is localised and falls in a series of small showers it does least good - and may do positive harm. On the other hand if it is general and concentrated its effect can be surprisingly beneficial for its size. In spring, and particularly late spring, the good effect of any small rainfalls is heightened by the increased air humidity and drop in temperature that are normally associated with it. These are factors which slow the rate of maturation which increases the size and quality of the harvest.

A dry year usually helps to clean the ground of weeds, pests and disease. Although little nitrogen is fixed in a dry year none is leached and as the soil requires more rain to saturate it in the following year there is less likelihood of leaching then also.

Autumn. Three of the autumns, Table 58, from 1948/49 to 1962/63 had very low rainfalls. Low autumn rainfall, like heavy autumn rainfall, delays and can prevent sowing (see ch. 8.2, p. 251ff.) even on the highly mechanised colonist farms. If there is too

Table 58. Low Autumn Rainfall in the LMV : 1948/49 to 1962/63. (mm.).

source: data from BIRH

Year	Aug.	Sep.	Oct.	Nov.	Total
1949/50	4.2	3.4	35.4	53.6	96.6
1954/55	2.5	5.3	25.8	55.4	89.0
1960/61	0.3	13.5	6.0	22.4	42.2

little rain after sowing germination is impaired and the young plant makes a poor start from which it is difficult to fully recover.

On the other hand the nitrifying bacteria continue their activities until much later in the year and none of the precious nitrogen is leached so that if good rains follow sowing, as happened in 1949/50, the conditions are right for an excellent harvest.

Winter. Low rainfall is more critical in winter than in autumn. During the period under discussion there were, Table 59, four dry winters. They are associated with four of the worst yields

Table 59. Low Winter Rainfall in the LMV : 1948/49 to 1962/63. (mm.).

source: data from BIRH

Year	Dec.	Jan.	Dec.	Total
1950/51	41.9	37.8	26.0	105.7
1954/55	34.5	40.8	21.8	97.9
1959/60	44.3	37.3	14.3	95.9
1960/61	45.7	64.4	4.7	114.8

in the LMV; particularly in the drier southerly part. Low rainfall in December coming after a dry autumn - as in 1954/55 and 1960/61 - finally makes impossible (see ch. 8.2, p. 251 ff.) sowing of the full area desired and ensures that the germinating plant has a very poor start.

Low rainfall throughout the winter weakens the plant and curtails its growth during tillering which reduces the number of heads per plant and per hectare; which inevitably reduces yield. The plant is rendered more susceptible to all adverse climatic conditions in the early spring.

Early Spring. During March and April the plant's needs of water and nutrient salts remain high. Without them the grain cannot begin to form. But the rainfall required depends on the previous two seasons so a low early spring rainfall after a wet winter may not be too low for a good harvest. Conversely a low rainfall after a dry winter, Table 60, ensures crop failure as in 1960/61. But, as has been noted earlier, the dry year of 1950/51 ended with a drought from 16 March to 15 April followed by the wettest month of the growing season, up to mid-May. Although it arrived so late and was no more than an average total it caught a lot of wheat just before it died and initiated a restart which produced some reasonable to good yields.

Table 60. Low Early Spring Rainfall in the LMV: 1948/49 to 1962/63. (mm).

source: data from BIRH

Year	March	April	Total
1950/51	20.9	15.3	35.9
1960/61	44.8	0.8	45.6

Low spring rainfall can cause shrivelling especially if, for some reason, the roots have not developed properly and cannot absorb water from the deeper soil.

Late Spring. As the wheat absorbs very little water in the May/June period (particularly the earliest varieties) the smallest rain would satisfy its needs provided there was some moisture left in the ground. But because very low late spring rain is associated with cloud-free skies, hot, drying sunshine and low air humidity it is also associated with shrivelling and small grains of low specific weight. Yield is reduced.

On this basis two late spring rainfalls, Table 61, were unquestionably too low; 1954/55 and 1957/58.

Table 61. Low Late Spring Rainfall in the LMV: 1948/49 to 1962/63. (mm).

source: data from BIRH

Year	May	June	Total
1954/55	5.1	7.0	12.1
1957/58	3.0	9.1	12.1

A dry late spring, and a dry early spring, leaves the following fallow too dry for a high rate of nitrification and demands a high autumn rainfall to prepare the soil for drilling. But heavy autumn rains may leach the few nitrates formed.

Seasonal Rain Excess. 'The excess of water... is this year... the sole cause of the bad harvest'.

This quotation from Séguéla (1959B, p. 152) referring to the extremely heavy rainfall of the year 1958/59 (Fig. 11, p. 56), high-lights an extreme case of an occurrence which has received little attention in Tunisia because the country is normally described as semi-arid; where the major climatic problems are heat and drought. The following statement by Ferhat typifies the general assumption that it is only a shortage of rainfall that diminishes yield. Ferhat (1962, p. 122) stated that; 'in Tunisia,... where the limiting factor is water, it is the shortage of water which usually produces the modifications of photosynthetic activity or nutrition whose most evident result is the reduction of the weight of... the grains'.

But whilst only drought causes a 'null' year an excess of rain is the principal cause of reduced yields in many years. It can affect the harvest in several ways depending on when the excess rain falls. The year 1958/59, and to a lesser extent 1953/54, were unusual in having high to excess rainfall in all seasons so that the wheat suffered in many ways.

Autumn. During the period 1948/49 to 1962/63, which included

Table 62. High Autumn Rainfall in the LMV : 1948/49 to 1962/63. (mm.).

source: data from BIRH

Year	Aug.	Sep.	Oct.	Nov.	Total
1953/54	33.2	14.1	148.8	120.1	316.2
1955/56	13.4	97.6	86.1	34.6	231.7
1957/58	3.2	12.1	151.7	147.9	314.9
1958/59	0.0	14.8	133.4	164.2	312.4

the wettest decade of the 20th. Century, one autumn had high rainfall, Table 62, and three extremely high. In the three years of extremely high rainfall sowing was never completed so the area left under fallow was increased in the wetter low-lying regions. In all the years sowing was delayed into December, or even January, which shortened the growing season and pushed back the critical phase of grain maturation into the late spring/early summer when climatic conditions become steadily worse; drier and hotter with the risk of sirocco.

Apart from delaying sowing and thereby each phase of the plant's life cycle, excess autumn rain can affect the plant in

Table 63. Possible Effects of Excess Autumn Rainfall on Cereals in the LMV.

Effect	Cause	See Section on:-
Reduced sowing	Saturated land	Sowing
Delayed sowing	"	"
Poor germination	Lack of oxygen in soil	Germination
Poor germination	Deep sowing; drill sinking into wet soil	"
Shallow roots	Saturated soil	Tillering & Roots
Nitrogen deficiency	Leaching	Sowing; Maladies
Shrivelling	Shallow roots and leaching	" "

a number of ways by oversaturating the soil. These are listed in Table 63 and described in more detail in the relevant sections. All tend to reduce the quality and quantity of the yield.

Winter. During the years in question there were only two outstandingly wet winters - 1948/49 and 1955/56. The year 1948/49 included the wettest month of any during the 15 year period; see Table 56 (p. 293). But normally an excessive level of rain is only reached when successive months are very wet; as in 1955/56.

Very heavy rainfall in December may still delay and prevent sowing and also decrease the rate of germination. Heavy rains throughout winter can cause the plant to produce only a shallow root system which makes it less able to cope with a dry spring; increasing the incidence of shrivelling and decreasing yield.

But the main danger of heavy winter rains is the leaching of nitrogen salts. Late January and February are the months during which tillering takes place; the growth phase when the plant absorbs 40-50% of its total nitrogen requirements. Shortage of nitrogen reduces the number of tillers, weakens them and reduces their size. This makes the plant subject to flattening and tends to reduce the harvest.

Early Spring. The early spring period, March and April, is the last when the plant is actively absorbing nutrients and water from the soil.

There was one exceptionally wet early spring, 1958/59, and four others, Table 64, with high to heavy rainfall. Rain beyond

Table 64. High Early Spring Rainfall in the LMV : 1948/49 to 1962/63. (mm.).

source: data from BIRH

Year	March	April	Total
1949/50	70.7	57.3	128.0
1952/53	95.5	28.3	123.8
1953/54	63.1	94.2	157.3
1954/55	46.8	92.2	139.0
1958/59	71.2	125.0	196.2
1959/60	68.9	43.6	112.5

the requirements of the plant causes leaching during these last critical phases for nitrogen absorbtion which not only reduces the yield but increases the likelihood of mitadinage.

Moreover if these months are warm as well as wet the conditions are ideal for attack of pests and diseases. The diseases which attacked in the LMV in these wet years were the rusts, smut and mildew. The rusts were the most feared but even in 1958/59, when conditions were ideal for rust, the damage was not very extensive (see ch. 8.3, p. 279ff.) because the Tunisian varieties are relatively rust resistant.

Late Spring to Harvest. This period includes the months of May and June - though mid-May could be a more accurate starting point - when the plant has virtually stopped absorbing salts or water from the soil and the process of transferring food reserves to the grain is followed by the gradual and partial drying of the grain in the final phases of maturation.

But although the grain is no longer dependent on what the roots absorb anything which tends to slow and prolong the length of maturation increases the yield. Thus coolish weather with

Table 65. High Late Spring to Harvest Rainfall in the LMV : 1948/49 to 1962/63. (mm.).

source: data from BIRH

Year	May	June	Total
1952/53	83.6	41.1	124.7
1956/57	38.5	20.3	58.8
1958/59	36.8	47.7	84.5
1962/63	19.6	41.2	60.8

some cloud, and therefore some rain, is required. Damage is done by a lot of rain. During the period 1948/49 to 1962/63 there were four high to very high late spring rains, Table 65. Such rainfall can cause excess moisture to penetrate the grain thereby making it flowery and whitish in appearance (see ch. 8.3, p. 275), and impairing its industrial qualities. For the wet late spring of 1958/59 Séguéla proved a significant correlation between height of June rainfall in 1959 and reduction of specific weight.

Excess rain in the late spring can, however, increase the yield of the next crop on that land as explained in the discussion of the effects of the fallow year rainfall.

Summary and Definition of the Ideal Range of Rainfall. The ideal range of rainfall in a year or season is that which helps promote the highest yield. In each season, including the fallow, there is a real danger of an excess of rain which can be almost as damaging as a rain shortage. At no time of the year could one say the more rain the better. But there is a much slighter danger that the rainfall of an individual month will prove critical. A situation made bad by shortage or excess of rain in any one month (or even two months in the case of February/March 1957) can usually be redeemed if the rainfall and other climatic factors of the following months are good. This is less true when the period of vegetative growth gives place to the reproductive phase in April and May. In a single month, particularly when it is a case of rain shortage, the character of the rainfall can be as important as the total. Well spaced heavy showers are normally preferable to numerous light showers.

The optimum rainfall range in a given season depends to a considerable extent on the rainfall (and other climatic factors) in the other seasons. However there are limits beyond which irreparable damage is done. For example if the winter rain total is less than 100 mm. the harvest cannot be good. Similarly if the autumn or winter rainfall is above 250-300 mm. - or if any single month has more than 150-200 mm. - the yields will almost certainly be below average to poor.

Because of these reasons it is impossible from the evidence available to define the ideal rainfall range very closely. But the study in chapters 8 and 9 suggests the following.

In autumn rainfall below 100 mm. and above 200/250 mm. is detrimental to sowing and to the germinating seed. The ideal rainfall probably lies about 150 mm. (near the mean for the LMV) with a low rainfall in November. In winter rainfall below 100 mm. appears to be closely linked with very poor harvests. On the other hand very heavy rainfall can also depress yield by leaching nitrogen and compacting the soil. The ideal range may lie between 150 mm. and 200 mm., or rather below the mean for this season.

The two lowest early spring rainfalls - 36 mm. and 46 mm. - were both in years with very poor harvests. At the other extreme, rainfalls over 150 mm. normally encouraged the spread of disease and the occurrence of mitadinage. The ideal range may be 60 mm. to 120 mm. Although some rain is required in the late spring a total higher than 75 mm. is probably detrimental, by causing diseases to spread and being associated with false mitadinage. A useful quantity of rain may lie between 30 mm. and 60 mm.

Montlaur (1941) ran experiments in Tunisia to examine the relationship between climate, an early maturing soft wheat and a slow maturing hard wheat. By studying the optimum growth curve over a six year period he estimated the ideal quantity of rain for each phase of growth. The two varieties together gave a range of rainfall which may be combared with the best seasonal distribution of rainfall, Table 66, which emerges from the preliminary study, above, of the LMV region.

The major difference between the two sets of figures is in autumn because Montlaur did not consider the rainfall before October (before the month prior to sowing) as important. However it has been shown in studying the rainfall of the fallow year and autumn rainfall that the reserves of water accumulated in the ground in the month before sowing can have an important effect on yield and cannot be ignored.

Table 66. Ideal Seasonal Rainfall Range for Wheat in the LMV; Montlaur Compared with Preliminary LMV Study.
source: Montlaur, 1941, p. 47 & p. 55

	Montlaur		Preliminary LMV Study	
Season	Months	Rain(mm)	Months	Rain(mm)
Autumn	O.N.	70-100	A.S.O.N.	150-200
Winter	D.J.F.	185-220	D.J.F.	150-200
Early Spring	M.A.	75-130	M.A.	60-120
Late Spring	May	10- 25	M.J.	30-60

The late spring rainfall range is, according to Montlaur, lower than that estimated from the preliminary LMV study. This may be because, working with small plots, Montlaur's sowing and harvesting was done at the ideal moment. On the farms different fields come to maturity over a longer - and slightly later - period and delays in harvesting mean that the wheat grain is longer under the influence of the rainfall. In addition, under experimental conditions, the danger of shrivelling due to heat and low rainfall is much reduced.

9.2 The Effect of Temperature and Other Climatic Factors on Yield.

Temperature. Although in Tunisia the most important group of factors influencing the yields of wheats is to do with rainfall these must be seen in combination wth other climatic factors. Probably temperature is the most important of these. No study has been made on the correlation of temperature with yield in Tunisia although Boeuf (1932) envisaged doing so using monthly means and monthly (or daily) extremes of temperature as parameters.

Temperature affects yield by acting directly on the plant and indirectly because of its effect on the soil, weeds, pests and plant diseases.

Summer. The hot Tunisian summer causes moist soils to become excellent factories for fixing nitrogen. But the very high temperatures can also sterilise the soil, killing weeds and also beneficial organisms to a depth of 10-20 cm.

Autumn. The rate of germination depends on temperature. About 20°C. is optimum but germination slows down as the temperature is reduced. It is very slow at 4°C. The plant makes a poorer start if sowing is delayed into the cooler month of December or if heavy rain in early autumn cools the upper soil.

Winter. A cold winter depresses the growth rate particularly if there is a shortage of nitrogen in the soil. In the Tunis region the winter is never so cold as to damage the wheat and there is rarely a complete period of 'dormancy' although further up the Medjerda valley, Le Kef and the plain of Béja, this is normal. If the winter is wet and the temperatures low then tillering is reduced, cutting down the number of ears per plant.

1949/50 - one of the years of highest yield - had an unusually warm winter followed by a cool early spring.

Spring. Frost in the month of April is the worst danger, at the time of heading (see ch. 8.2, p. 268ff.). Fortunately these late frosts are very rare but when they occur they can cause a poor harvest. During the period 1948/49 to 1962/63 the only year badly affected was 1955/56 when a heavy frost (-2^{o}C. or more) on 9/10 April appeared to cut some harvests almost to zero.

All conditions which encourage slow maturation, including low temperatures, increase the volume of the grain and decrease the amount of gluten in the grain in favour of the denser amidon so increasing the weight of the grain and the yield. Below average mean temperatures are required.

High spring temperatures in April and May tend to cause shrivelling in a dry year or facilitate attack by rusts and other diseases and pests in a wet year.

Late Spring. Once again cool temperatures assist the proper formation of the grain. High temperatures increase either shrivelling or disease depending on the humidity but the main danger is of sudden increase in temperature associated with the sirocco. If this occurs for only two or three days during the critical part of the ceiling phase (see ch. 8.2, pp. 269-273) in May - the exact date depending on the variety and the year - the delicate biochemistry of grain maturation is disrupted and the grain is left shrivelled and small. If the temperature reaches 30^{o}C. the damage is greatly increased.

In summary, it appears that ideally the temperature should by high in the latter part of the fallow year to encourage nitrification but not high enough in summer to dessicate the soil.

During the crop year above average temperatures are probably only desirable during germination and perhaps in winter, although winters in the LMV are rarely cool enough to interrupt the wheat's growth cycle. In spring and in May cooler than average temperatures benefit yield.

Other Climatic Factors. Other climatic factors normally play minor roles in influencing yield but they can be important in certain circumstances.

High winds can - particularly under storm conditions - flatten the growing plant at tillering. Wind, and indeed any air movement, tends to increase the rate of evapotranspiration and therefore, during the warm months of March and April, the tendency towards wilting and the disruption of plant development. After mid-May this is no longer true because transpiration virtually stops as the vegetative part of the plant yellows and dies.

The evapotranspiration potential is also a function of the humidity and temperature of the air.

Unfortunately data concerning the rate of evapotranspiration, air humidity and wind velocity is either too patchy to be useful or else non-existant.

Radiation and insolation may have an important role but this has not been tested under Tunisian conditions. Possibly a high insolation rate, together with warmth and moisture, helps to ensure a good tillering. Different wavelengths of light may have an influence on plant growth and yield but, again, data is not available. Dew may be a significant part of total precipitation in May but the heaviest falls are likely to be in summer, after the harvest. At this time of year their only effect would be on the fallow; increasing the soil moisture for nitrification.

CHAPTER 10

QUANTITATIVE STUDY OF THE EFFECTS OF CLIMATE ON YIELD.

10.1 Previous Work.

Previous Work in Tunisia. The first person to attempt a quantitative estimation of the relationship between climate and yield in Tunisia was Boeuf (1932, pp.292-298) who saw the importance of an objective estimation of the yield during the months before harvest rather than having to rely on individual opinions which; 'depend on the judgement and the personal experience of the observers', and need to be based on many years of field experience before they can begin to be reliable.

Boeuf used only the simple linear correlation (which by definition cannot record any reduction of yield caused by an excess of rain) which he applied to yields from peasant farms. He used the yields of peasant farms believing that as the peasants did not prepare a fallow to accumulate water during the year before sowing, so yield should respond closely to the climate of the growth year. The weakness of this approach is that the peasant yields were much more inaccurately recorded (see ch. 2.2, pp. 22-26) than the European yields. Moreover the European farmers made use of the climate of two years for one year's crop then it should be possible to correlate yield against two years' climatic span.

In spite of the limitations of his method Boeuf produced some surprising results from the Tunis region. His best figures were obtained from the accumulated rainfall of October to April which explained 88% of the variation in yield from year to year. The rainfall of the month of March alone accounted for 58% of the variation. These values are too good to be accepted at their face value.

A study of a single European farm in the Pont du Fahs/Siliana region (Terre, 1958) for the years 1937 to 1956 does not throw much more light on the problem. The author compared the mean soft/hard wheat yield of each year with the variation in percentage from the mean rainfall over the period September to April.

The yield against rainfall only showed a limited degree of correlation though in general increase in rainfall meant an increase in yield. The greatest deviation from the trend occurred in 1956 when the yield was very poor in spite of the good rainfall, This was explained as being a result of the April frost. No explanation was given for selecting the rainfall period from September to April, no mention was made of the effect of temperature and reference was made to neither the rainfall of the fallow year nor the possible effects of excessive rainfall.

The most recent work done (Hyslop and Dahl, 1970) was a graphic correlation of yield (measured as deviations above and below the 1946/56 and the 1957/66 trend lines) against 'wet years' and 'dry years'. The length of the year was defined as running from September to April. The information obtained from the correlation was limited as was implied in the conclusions: 'In the years of dry weather yields tend to be correlated below their average. A similar and even more definite relationship is observed in the case of bread wheat'.

Work in Other Countries. Two main methods of analysis of the relationship between climate and yield have been used in a number of countries. However most of the conclusions have very little value in the Tunisian situation because of differences in climate and other factors between the countries.

The first method regresses yield against one or several climatic variables either in a simple linear model, as used by Boeuf (1932) in Tunisia, or a multilinear model as used by Eck and Tucker (1968) in the USA and Lee and Connaughton (1969) on yields of spring wheat in Ireland. In the latter paper the possibility of regressing yield against a quadratic function of the climatic variable was considered to cope with the possibility of yields being adversely affected by, for example, excess as well as shortage of rain. However the quadratic function did not significantly improve the fit of the regresssion line.

An alternative approach was developed by Fisher (1924) for analysis of the wheat yields at Rothamsted. The method involved describing the year's rainfall week by week with a polynomial series of curves and regressing coefficients derived from the polynomial functions against yield. Fisher's results were significant though they did not explain a very high percentage of the variation in yield. Perhaps the point of greatest interest, apart from the method itself, was that with the exception of the pre-sowing period the rainfall was generally in excess of the ideal amount required and that heavy rainfall in the months after sowing had a strongly depressive effect on yield. Fisher put this down to the leaching of nitrogen from the soil. Hooker (1922) found the same effect but, when trying to explain it, put the emphasis on the poor aeration of the soil which may reduce or stop respiration of the germinating seed.

Modifications of Fisher's technique have been used with success for wheat in India (Gangopadhyana and Sarker, 1965), Australia (Millington, 1961) and again at Rothamsted by Buck (1961). Buck compared the results of curve fitting of weekly rain totals with those of monthly totals and found the loss of definition to be slight.

<u>10.2 Organisation of the Data</u>. It was decided to adopt a multivariate approach to the problem and the first step was the organisation of the data.

For reasons discussed earlier (see ch. 6.2, pp. 148-154) it was considered acceptable to assume a basic similarity between the different varieties of hard wheat so that they could be considered as one homogeneous group; varietal differences playing an insignificant role in determining yield compared with differences of climate, soil and farm practice. The same is not so true of the soft wheats. The post-war period saw the predominance of F/A challenged principally by one new variety, Guelma, which had a similar rapid growth cycle and gave equally high yields but could make better use of a poor soil. This meant that its response to the late spring climate should be similar to F/A but that it was likely to suffer less from heavy rainfall leaching the soil. Although the soft wheats are, in the analysis, treated as a group the difference between them will tend to blur the relationship between their yields and the climate.

Of the 126 farms some grew no wheat and many of them came under Tunisian management after the 1960/61 season. As, at any rate, the study of the final phase of colonisation in chapter 7 has suggested that the colonists' farming methods were deteriorating in the early 1960's the quantitative analysis is limited to the period 1948/49 to 1960/61. The data from the 126 farms was first combined into the 22 Farm Groups (Pre-cooperatives) which they form (Fig. 2 , p. 12) in an attempt to average the effects of good and bad farmers in a given locality. Three of the Farm Groups were abandonned at this stage; Kalaat el Andaleus because it stopped production in 1957 and Ouzra and Nassen because these were primarily concerned with fruit and vines; having arable land only sporadically used to grow wheat. The 19 remaining Farm Groups were further grouped to 12 Centres (Fig. 26 , p. 314) based upon a local rain station each with complete coverage for the whole period 1947/48 to 1960/61.

This gave a maximum of 156 observations - 13 years for each of the 12 Centres - from which to produce a composite picture of individual climatic factors which would best explain significant amounts of yield variation for the study area as a whole. In practice there were 155 observations for hard wheat and 152 for soft wheat; in the other cases no wheat was grown.

This large number of observations does not have the same validity as would 150 observations from 150 separate years. It is, however, justified by the wide disparity of yield means between Centres, Table 67, and by the wide variations of climate and/or soils in different parts of the LMV.

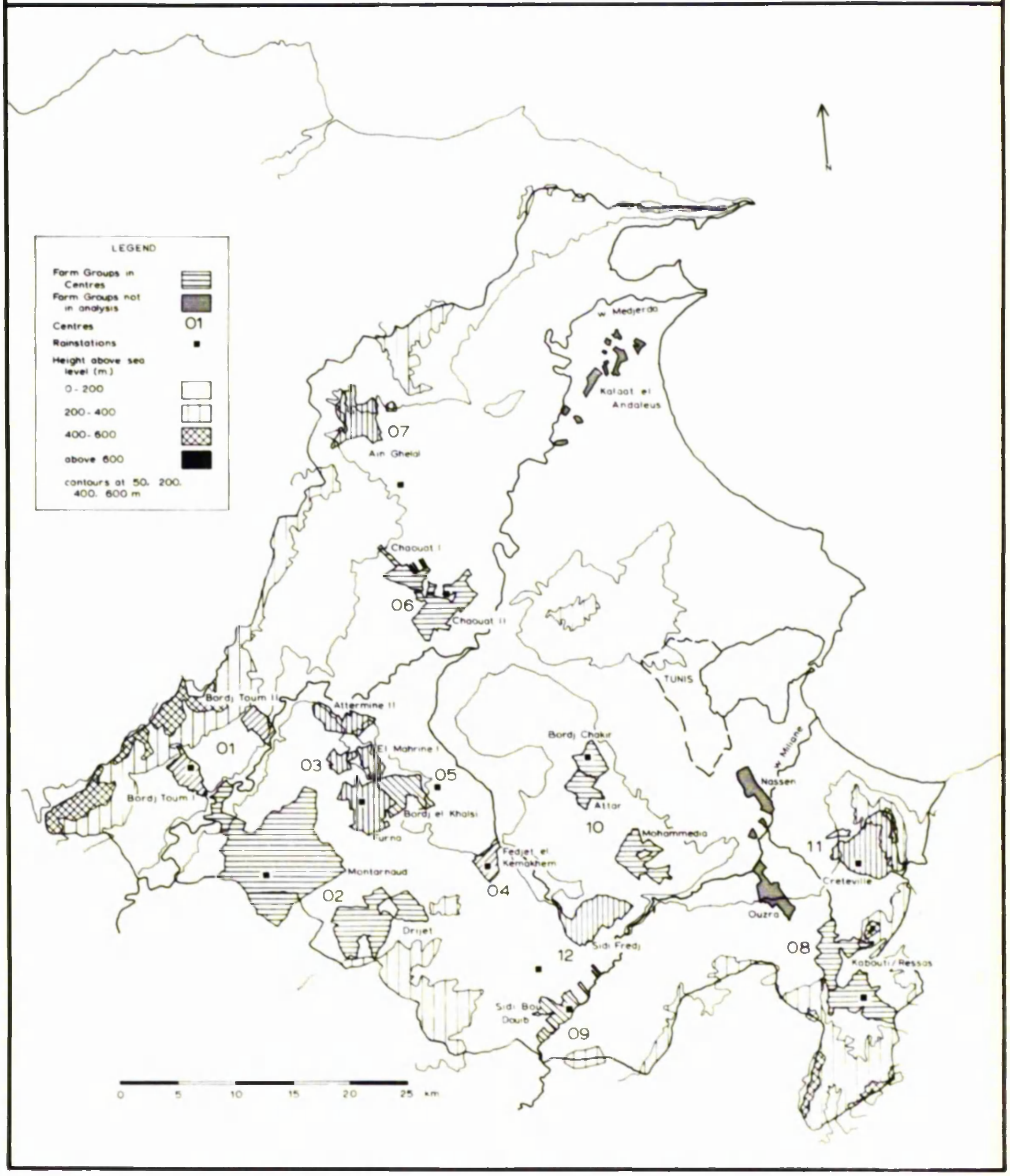
To what extent conclusions from this study area might be extrapolated to other areas and years will be discussed in the conclusions.

The variation between the Centres is surprisingly large. In fact for hard wheat analysis of variance gives an F-value - F(calc) = 3.67 - significant at the 0.1% level. There is an even greater variation between years than between Centres; F(calc) = 7.41. It is interesting to note at this stage that for the soft wheat the variation between the Centres is much greater - F(calc) = 4.99 - than for the hard wheats even, although the variation between different years is less.

This fact finds clearer expression in Table 67 where it is seen that in the different Centres soft wheat has most of the

Fig. 26

FARM GROUPS AND CENTRES IN THE L.M.V.



highest and two of the lowest mean yields. This in turn confirms that the soft wheats, led by F/A, had a higher yield pot-

Table 67. Weighted Average Yields of Hard and Soft Wheat for the 12 Centres in the LMV. 1948/49 - 1960/61 (ql/ha.)

Group	Hard Wheat	Soft Wheat
1	10.4	11.1
2	11.6	12.2
3	9.1	9.3
4	11.5	13.4
5	7.6	8.3
6	11.0	10.7
7	7.5	5.8
8	10.0	9.2
9	6.6	6.7
10	11.0	12.9
11	14.5	13.9
12	9.4	10.0

ential but were more susceptible to adverse soil conditions. Though the yield of the hard wheats fluctuated more from year to year these wheats were more tolerant of poor or saline soils. Of the four Centres where soft wheat yields were lower than hard wheat yields, numbers 08 and 11 were two of the wettest Centres of the LMV while the other two, numbers 06 and 07, were in the low-lying, saline river estuary.

10.3 Selection of the Variables. Linear and quadratic regressions were run of the rainfall in individual months and of running combinations of successive months, against yield. The significance levels of the correlation coefficients thus obtained were noted, Tables 68 to 71, together with the sign, positive or negative, of the regression coefficients. This produced a useful diagrammatic representation of the direction and degree of the relationship between rainfall and yield in successive months and seasons.

A two year span of months was chosen to see whether the rainfall of the fallow year made a significant impact on yields.

Hard Wheat. Table 68 shows that the key months in which there is a significant linear relationship between yield and rainfall are December, February (1.0% level), April and July (0.5% level) of the fallow year and January, March and May of the crop year. The only combination of months to improve the significance of the result of a single month was March/April of the fallow year.

Interesting also is the direction of the relationship. Apparently high rainfall in winter of the fallow year enhances yield, especially when it falls in December, though the rainfall of January - the wettest month - can be too heavy in which case it reduces yield by as much as in the driest Januaries as is seen from Table 69; F(calc:quad) = 6.4, which is significant at the 2.5% level. The explanation of this is seen in the changing direction of the relationship as spring approaches.

The effect of February rain is less helpful in increasing yields than is December and high rainfall in March and April actually decreases yield, accounting for over 12% of total

Table 68. Direction and Significance of the Linear Regression of Rainfall Against Yield of Hard Wheat For the Study Area of the Lower Medjerda Valley; 12 Centres by 13 Years.

	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J
A	−0.7																						
S	−0.0	+0.1																					
O	−0.7	−0.5	−0.9																				
N	−2.2	−2.0	−2.3	−3.1																			
D	+0.1	+0.1	+0.1	+1.1	**+14.2**																		
J	+0.0	+0.1	+0.0	+0.6	+6.6	−0.1																	
F	+0.7	+0.9	+0.8	+2.7	**+11.9**	+2.1	*+8.1*																
M	+0.1	+0.2	+0.1	+0.7	+4.5	+0.0	+0.4	−5.1															
A	−0.5	−0.4	−0.5	−0.2	+0.2	−3.1	−4.6	**−22.2**	**−19.8**														
M	−0.2	−0.1	−0.2	−0.0	+0.7	−1.2	−1.6	*−11.1*	*−7.4*	+4.7													
J	−0.4	−0.3	−0.4	−0.1	+0.2	−2.1	−2.8	**−11.5**	*−8.1*	+0.1	−5.3												
J	−0.3	−0.2	−0.3	−0.1	+0.4	−1.5	−1.9	*−9.6*	−6.2	+1.7	−1.2	*+11.1*											
A	−0.3	−0.2	−0.3	+0.1	+0.3	−1.4	−1.7	*−7.5*	−4.7	+0.4	−0.6	+1.2	−0.0										
S	−0.2	−0.1	−0.2	−0.0	+0.5	−1.0	−1.1	−6.5	−3.6	+0.6	−0.1	+0.5	+0.0	+0.1									
O	−0.1	−0.1	−0.1	−0.0	+0.5	−0.6	−0.6	−3.1	−1.2	+0.4	+0.0	+0.4	+0.1	+0.1	+0.1								
N	−0.0	−0.0	−0.0	+0.0	+0.5	−0.2	−0.2	−1.4	−0.5	+0.4	+0.1	+0.4	+0.2	+0.3	+0.2	+0.2							
D	+0.1	+0.1	+0.1	+0.3	+1.5	+0.0	+0.1	−0.3	−0.0	+1.5	+0.8	+1.7	+1.2	+1.3	+1.1	+1.8	+2.6						
J	+1.7	+1.8	+1.7	+3.0	+6.3	+2.5	+3.2	+1.1	+2.5	*+7.9*	+6.7	*+9.2*	*+8.0*	*+8.4*	*+7.8*	**+13.6**	**+22.3**	**+38.4**					
F	+2.0	+2.1	+2.0	+3.3	+6.3	+2.7	+3.2	+1.2	+2.5	*+7.1*	*+7.8*	*+7.9*	*+7.0*	*+7.2*	*+7.0*	*+11.3*	**+16.7**	**+18.1**	+0.6				
M	+3.2	+3.3	+3.2	+4.9	*+8.6*	+4.6	+5.3	+2.7	+4.2	*+9.8*	*+8.7*	*+11.1*	*+10.0*	*+10.4*	*+9.7*	**+15.1**	**+22.1**	**+24.1**	+6.7	**+11.5**			
A	+2.9	+3.0	+2.8	+4.3	*+7.6*	+4.3	+4.9	+2.6	+4.2	*+9.2*	*+8.1*	*+10.2*	*+9.3*	*+9.6*	*+8.9*	**+13.9**	**+23.7**	**+20.7**	+5.1	+5.3	+0.3		
M	+4.2	+4.3	+4.2	+6.1	*+10.1*	+6.4	*+7.3*	+4.5	+6.4	**+12.2**	*+11.1*	**+13.6**	**+12.5**	**+12.9**	**+12.1**	**+18.5**	**+30.7**	**+29.7**	**+11.9**	**+13.6**	+6.3	**+18.3**	
J	+4.0	+4.1	+4.0	+5.9	*+9.7*	+6.1	*+6.9*	+4.3	+6.1	**+11.6**	*+10.4*	**+12.6**	**+11.6**	**+12.0**	*+11.2*	**+16.7**	**+27.3**	**+25.2**	*+9.3*	*+9.2*	+3.7	+6.6	−0.1

LEGEND

- − Negative correlation
- + Positive correlation
- ——— F-value above 0.1% level
- --- F-value above 1.0% level

Note: The capitals A to J both above and to the left of the table indicate the 23 months; August at the start of the fallow year to June at the end of the cereal year.

The table is additive down the columns. For example, the second entry of the second column, −0.5, is the F-value(1 & 120+ df) of the correlation coefficient, and the direction of the regression line, of yield against total rainfall of September and October of the fallow year.

Table 69. Direction and Significance of the Quadratic Regression of Rainfall Against Yield of Hard Wheat For the Study Area of the Lower Medjerda Valley; 12 Centres by 13 Years.

	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J
A	−0.5																						
S	+0.7	+0.8																					
O	−0.9	−0.3	−0.0																				
N	−0.1	+0.2	−0.1	−0.2																			
D	+1.4	+1.3	+1.4	−0.6	+0.2																		
J	+0.2	+0.1	+0.3	−1.5	−1.1	+6.4																	
F	+0.6	+0.3	+1.0	−1.2	−1.7	+1.9	+0.8																
M	+0.0	−0.1	+0.0	−4.7	−8.7	+0.0	−1.4	−3.9															
A	+0.3	+0.2	+0.3	−1.8	−8.3	+0.2	−0.1	−10.3	−16.1														
M	+0.5	+0.3	+0.4	−1.8	−6.9	+0.3	−0.0	−7.8	−0.7	+0.3													
J	+1.1	+0.9	+1.0	−0.5	−3.8	+0.5	−0.0	−8.4	−0.9	+0.2	−0.2												
J	+1.0	+0.7	+0.8	−0.8	−4.5	+0.4	+0.1	−5.9	−0.1	+0.7	+3.1	+3.3											
A	+1.3	+1.0	+1.2	−0.3	−2.8	+0.6	+0.3	−5.6	−0.0	+1.2	+2.7	+3.1	+0.6										
S	+1.4	+1.2	+1.7	−0.0	−1.3	+1.0	+1.5	−2.0	+0.8	+4.3	+3.9	+3.1	+0.6	+0.1									
O	+1.5	+1.6	+1.8	+0.2	+0.0	+0.4	+0.2	−4.3	+0.1	+1.1	+1.1	+3.0	+1.9	+1.9	+2.4								
N	+2.1	+2.4	+2.3	+0.7	+0.9	+0.4	+0.1	−1.9	+0.2	+2.7	+2.2	+5.0	+3.8	+4.2	+5.0	+5.4							
D	+5.6	+6.0	+6.2	+3.4	+3.6	+1.6	+0.8	−0.1	+0.6	+4.4	+3.8	+6.3	+5.1	+5.5	+7.4	+4.7	+0.0						
J	+5.8	+6.1	+6.4	+3.0	+4.0	+4.7	+5.3	+3.2	+8.0	+14.3	+15.0	+19.4	+18.8	+19.9	+23.3	+21.3	+6.9	+0.9					
F	+6.7	+7.2	+7.1	+4.0	+5.5	+5.5	+5.9	+3.8	+8.6	+14.1	+16.8	+22.6	+21.8	+23.3	+22.7	+19.7	+11.3	+11.8	+1.5				
M	+7.2	+7.4	+7.7	+4.2	+5.1	+5.8	+7.5	+5.7	+10.8	+14.9	+18.0	+23.1	+23.0	+24.8	+19.4	+14.0	+5.1	+0.3	+0.6	−8.2			
A	+9.1	+9.1	+9.5	+5.7	+6.7	+6.8	+9.2	+7.8	+14.4	+20.0	+23.7	+29.8	+29.1	+31.9	+29.7	+25.7	+7.8	+8.6	+18.5	+11.3	+10.4		
M	+10.2	+10.1	+11.0	+6.9	+7.6	+7.3	+10.1	+9.6	+15.1	+19.7	+23.0	+27.7	+27.3	+30.0	+30.0	+25.1	+8.5	+9.9	+21.2	+13.3	+20.4	+0.5	
J	+9.7	+9.6	+10.9	+7.1	+8.0	+7.1	+10.2	+9.9	+15.5	+21.4	+24.5	+29.2	+28.7	+30.8	+31.9	+25.6	+8.9	+12.9	+18.7	+8.5	+10.4	+0.4	−4.7

LEGEND

- − Negative correlation (concave)
- + Positive correlation (convex)
- ——— F-value above 0.1% level
- - - - F-value above 1.0% level

Note: The capitals A to J both above and to the left of the table indicate the 23 months; August at the start of the fallow year to June at the end of the crop year.
The table is additive down the columns. For example, the second entry of the second column, 0.3 (−), is the F-value(1 & 120+ df) of the correlation coefficient, and the direction of the regression line, of yield against total rainfall of September and October of the fallow year.

yield variation. The explanation of this effect of spring rainfall cannot lie in any direct effect of excess water on the plant (which is still seven months from being sown) so is most probably connected with the activities of the soil nitrifying bacteria, as discussed in chapter 6.6 (pp. 191-202). Having obtained an adequate supply of moisture in winter their activity is promoted by the increasing soil temperature as spring advances. Heavy spring rain would keep the upper soil too cool for nitrogen to be fixed rapidly. In addition (or perhaps alternatively) the heaviest of the spring rainfalls may themselves have caused leaching - illustration of the danger of using the Fallow-Wheat rotation when the climate is too wet.

In July the soil tends to be too dry. In these conditions the heaviest rainfalls, in this driest of months, made a very significant improvement in yields. It is likely that the rain acted by increasing the activity of nitrifying bacteria for whose work the limiting factor would no longer be temperature but the degree of soil moisture. In addition July rain, associated with reduced insolation and low temperatures, may reduce damage to soil structure caused by dessication.

The effects of spring and July rainfall are unexpected. Although no detailed analysis of their effects has been made previously it had been assumed (see ch. 9.1, pp. 285-288) that spring rainfall increased yield and July rainfall reduced it; the spring rains preparing the ground for the nitrifying bacteria but the July rainfall compacting the upper soil.

The rain in the autumn of the crop year appears to play a negligible linear role in controlling the yields of the LMV. That is to say there is always sufficient moisture at sowing (in

November) for effective germination in December. One reason for this is that even on the European farms (see ch. 8.2, pp. 251-258) the sowing time was not independent of the weather; it was delayed to await improved conditions if the ground was either too wet or too dry. The low significance of November/December rainfall is partly due to this and partly to the complexity of the effects of high rainfall on the germinating seed (see ch. 9.1, pp. 298-299) - some acting positively and some negatively - and the relative flexibility with which the seed can move from an active to a dormant state as conditions demand. Nevertheless this finding contrasts with those of Millington (1961) in Australia.

The most important single month in which to have rain up to its maximum, over 150 mm., is January when there appears to be a dominant, beneficial effect of rainfall on the young plant. The seedling has now passed the phase at which heavy rain could harm it in germination before it has become established. On the other hand it has not reached the phase of rapid nitrogen absorption, impaired by leaching rains, which takes place at tillering. In February, when tillering takes place, Table 38 (p.200), there is no linear correlation between yield and rainfall - F(calc) = 0.6 - but there is a very significant quadratic relationship between yield and total January and February rainfall. This means that the highest rainfalls are as damaging as the lowest. The quadratic relationship reaches its highest values for the total rainfall of September, or October, to the end of spring. The F-value reaches 30.0 or more. The reasons for which highest rainfalls decrease yield will include leaching of nitrates from the soil though heavy rainfall can also harm soil structure or lead to damage done by diseases - rust, smut and mildew - which flourish in moist warm conditions in early spring.

In March there is again a very significant need for high rainfall. It is from the beginning of March to about mid-May, Table 47 (p. 267), that water requirements for evapotranspiration are very high whilst at the same time the rainfall is decreasing. The importance of March rainfall is confirmed by the results of the experiment quoted by Boeuf, Table 48 (p. 267), which showed that the plant is at its most sensitive to water shortage at this time, during shooting and heading.

In April - F(calc:linear) = 0.3 and F(calc:quad) = 10.4 - it seems that there can be too much rain. There is no immediate explanation for this except in terms of disease. The two wettest Aprils, 1954 and 1959, were both in years when smut and rust damage was at its greatest.

In May high rainfall is at a premium although the plant is reaching the end of its life and its water requirements are limited. The analysis does not show that in extreme cases, as discussed in chapter 9.1 (pp. 301-302), excess rain can damage the grain. But it must be remembered that high rainfall totals are associated with cool, cloudy conditions which allow maturation to proceed more slowly so that the grain increases in weight over a longer period of time.

In summary it appears that for the growing season as a whole, September to May, the damage done by excess rainfall is almost as great as that done by the lowest rainfalls. High rainfall is, however, very beneficial in January, March and May, and to a lesser extent in February and April. This implies that rainfall through autumn to December should be below average. In spite of high January rainfall being closely correlated with high yield the analysis shows that winter rainfall - December and January/February - can be too high. The explanation of the way in which heavy autumn and winter rains can be detrimental to yields is summarised in chapter 9.1 (pp. 297-300). In the same chapter it was concluded from the discussion of the effects of late spring rain that May rainfall could be too high. This has not been confirmed by the above analysis. But apart from this and the unexpectedly strong negative effect of heavy spring rainfall in the fallow year the analysis confirms the study in chapters 8 and 9 which also provide a good mechanistic explanation for the results obtained.

Even for the fallow, it was shown (p. 287) that during a wet period, such as the 1950's was, fallow might store too much water and therefore facilitate leaching and limit yields.

Soft Wheat. The pattern of correlation between rainfall and yield of soft wheat over the 24 month period is similar to that of hard wheat. The key months again include December, March/April and July of the fallow year, Tables 70 and 71, and January and May of the crop year. But there is one important difference between the results for hard and soft wheat. In the soft wheat the positive linear correlations are all smaller and the negative correlations larger. That is to say increasing rainfall in the months when the plant requires water up to the rainfall maxima for the study area, is of less significance in increasing yields. This is not simply because rainfall, relative to other growth factors, is less significant for the soft wheat. This is shown by the significance of the quadratic

Table 70. Direction and Significance of the Linear Regression of Rainfall Against Yield of Soft Wheat For the Study Area of the Lower Medjerda Valley; 12 Centres by 13 Years.

	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J
A	-0.2																						
S	+0.2	+0.3																					
O	-0.4	-0.3	-1.1																				
N	-1.3	-1.3	-1.8	-1.9																			
D	+0.0	+0.0	-0.0	+0.5	+7.1																		
J	+0.1	+0.1	+0.0	+0.5	+4.7	+0.1																	
F	+0.6	+0.6	+0.4	+1.9	+7.6	+2.2	+4.6																
M	+0.0	+0.1	+0.0	+0.3	+2.3	+0.0	+0.0	-5.7															
A	-0.8	-0.7	-0.9	-0.6	-0.1	-3.4	-7.4	-24.8	-21.5														
M	-0.4	-0.4	-0.6	-0.2	+0.0	-1.9	-4.3	-15.2	-11.1	+2.1													
J	-0.7	-0.7	-0.9	-0.5	-0.1	-2.9	-5.5	-14.8	-10.8	-0.0	-4.8												
J	-0.6	-0.5	-0.7	-0.4	-0.0	-2.3	-4.5	-13.1	-9.1	+0.2	-1.4	+7.4											
A	-0.5	-0.4	-0.6	-0.3	-0.0	-1.8	-3.4	-9.3	-6.1	+0.2	-0.3	+1.9	+0.1										
S	-0.3	-0.3	-0.4	-0.2	+0.0	-1.1	-2.0	-7.0	-3.7	+0.7	+0.1	+1.3	+0.5	+0.4									
O	-0.4	-0.3	-0.5	-0.2	+0.0	-1.1	-1.8	-4.4	-2.2	+0.1	-0.0	+0.2	+0.1	+0.0	-0.1								
N	-0.4	-0.4	-0.6	-0.3	-0.0	-1.2	-1.7	-3.3	-1.7	+0.0	-0.1	+0.0	-0.0	-0.0	-0.2	-0.2							
D	-0.2	-0.1	-0.2	-0.1	+0.1	-0.4	-0.6	-1.8	-0.6	+0.2	+0.1	+0.3	+0.2	+0.1	+0.0	+0.1	+0.2						
J	+0.2	+0.3	+0.2	+0.6	+1.7	+0.3	+0.3	+0.0	+0.3	+3.1	+2.6	+3.9	+3.3	+3.3	+2.5	+5.4	+13.2	+24.3					
F	+0.2	+0.2	+0.1	+0.4	+1.3	+0.2	+0.1	-0.0	+0.1	+2.1	+1.6	+2.5	+2.1	+2.0	+1.6	+3.2	+7.1	+7.4	-0.2				
M	+0.5	+0.5	+0.4	+0.9	+2.0	+0.6	+0.5	+0.1	+0.5	+3.1	+2.6	+3.7	+3.2	+3.2	+2.6	+4.6	+9.2	+9.7	+0.9	+4.9			
A	+0.5	+0.5	+0.4	+0.8	+1.9	+0.7	+0.6	+0.1	+0.6	+3.0	+2.6	+3.6	+3.1	+3.1	+2.5	+4.5	+10.1	+8.7	+1.0	+2.5	+0.2		
M	+1.0	+1.1	+0.9	+1.6	+3.1	+1.5	+1.5	+0.6	+1.5	+4.6	+4.2	+5.5	+4.9	+4.9	+4.2	+7.1	+14.4	+14.1	+4.5	+8.3	+5.0	+15.0	
J	+0.9	+1.0	+0.8	+1.5	+2.8	+1.4	+1.3	+0.5	+1.3	+4.3	+3.8	+4.9	+4.5	+4.4	+3.7	+6.2	+12.6	+11.7	+3.2	+5.2	+2.6	+4.8	-0.2

LEGEND

- \- Negative correlation
- \+ Positive correlation
- —— F-value above 0.1% level
- ---- F-value above 1.0% level

Note: The capitals A to J above and to the left of the table indicate the 23 months; August at the start of the fallow year to June at the end of the crop year.

The table is additive down the columns. For example, the last entry of the third column, +0.8, is the F-value(1 & 120+ df) of the correlation coefficient, and the direction of the regression line, of yield against total rainfall from October of the fallow year to June at the end of the crop year.

Table 71. Direction and Significance of the Quadratic Regression of Rainfall Against Yield of Soft Wheat For the Study Area of the Lower Medjerda Valley; 12 Centres by 13 Years.

	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J
A	−1.4																						
S	+0.1	+0.0																					
O	−1.0	−0.5	−0.0																				
N	−0.1	−0.0	−0.3	−2.4																			
D	−0.0	−0.0	−0.2	−6.3	−1.6																		
J	−0.3	−0.4	−0.5	−4.8	−1.1	+6.6																	
F	−0.2	−0.4	−0.1	−3.7	−2.0	+1.3	+0.9																
M	−0.9	−1.4	−1.1	−8.1	−8.4	−0.1	−1.2	−0.1															
A	−0.1	−0.1	−0.1	−3.6	−7.5	+0.1	−0.0	−3.9	−10.8														
M	−0.0	−0.0	−0.1	−2.9	−5.5	+0.5	−0.1	−4.2	−0.4	+1.4													
J	+0.0	−0.0	−0.0	−1.6	−3.4	+0.4	−0.0	−7.0	−1.3	+0.5	−1.4												
J	+0.0	−0.0	−0.0	−1.9	−4.0	+0.4	−0.0	−5.5	−0.5	+1.1	+0.4	+3.3											
A	+0.2	+0.1	+0.0	−1.1	−2.8	+0.3	−0.1	−5.8	−0.2	+1.1	+0.5	+0.3	−0.0										
S	+0.1	+0.1	+0.2	−0.3	−1.6	+0.3	+0.8	−1.5	+0.4	+3.0	+1.8	+3.0	+0.9	+0.0									
O	+0.3	+0.4	+0.4	−0.0	+0.0	+0.3	+0.2	−2.2	+0.1	+1.5	+1.9	+4.5	+3.4	+4.2	+3.0								
N	+0.8	+1.0	+0.8	+0.3	+1.0	+0.6	+0.4	−0.7	+0.4	+3.6	+3.6	+6.6	+5.5	+5.7	+5.0	+3.5							
D	+2.2	+2.6	+2.7	+1.9	+3.3	+1.8	+1.3	−0.0	+0.7	+4.5	+3.7	+5.7	+4.8	+4.7	+4.9	+2.6	+0.1						
J	+2.6	+2.8	+2.9	+1.9	+4.2	+5.2	+6.4	+3.6	+7.6	+14.5	+14.5	+18.2	+17.7	+17.5	+17.7	+15.8	+8.5	+1.1					
F	+3.5	+4.0	+3.8	+3.1	+6.4	+7.0	+8.3	+5.1	+9.5	+15.9	+18.4	+24.0	+23.2	+23.5	+20.0	+15.4	+10.6	+10.5	+1.2				
M	+4.3	+4.5	+4.5	+3.4	+6.3	+8.2	+10.7	+7.6	+12.2	+16.9	+19.5	+24.2	+24.1	+24.1	+16.7	+10.3	+4.1	+0.3	+0.8	−8.1			
A	+5.2	+5.5	+5.4	+4.3	+7.3	+8.5	+11.9	+9.4	+15.8	+21.4	+24.6	+30.5	+30.0	+30.5	+25.3	+18.8	+5.6	+6.4	+14.3	+8.7	+10.5		
M	+6.6	+6.8	+7.1	+5.8	+9.1	+10.1	+14.4	+12.9	+18.9	+23.6	+26.8	+31.8	+31.4	+32.5	+29.0	−21.3	+7.3	+9.3	+20.0	+11.9	+21.7	+0.7	
J	+6.2	+6.3	+6.8	+5.7	+9.3	+9.8	+14.5	+13.2	+19.1	+25.2	+27.6	+32.2	+31.7	+32.0	+29.4	+20.7	+6.8	+10.6	+16.0	+8.3	+13.9	+0.0	−0.3

LEGEND

- − Negative correlation (concave)
- \+ Positive correlation (convex)
- —— F-value above 0.1% level
- - - - F-value above 1.0% level

Note: The capitals A to J both above and to the left of the table indicate the 23 months; August at the start of the fallow year to June at the end of the crop year.

The table is additive down the columns. For example, the fourth entry of the fifth column, 8.4 (−), is the F-value(1 & 120+ df) of the correlation coefficient, and the direction of the regression line, of yield against total rainfall of December to March of the fallow year.

relationships which are just as strong (compare Tables 69 and 71) and, for the period autumn to late spring of the growth year, rather stronger.

For soft wheat winter rainfall of the fallow year is of less importance - F(calc) = 7.6 for December/February - though still significant. On the other hand March/April rainfall has a stronger negative linear correlation. This supports the suggestion that spring rainfall hinders the work of the nitrifying bacteria. It would affect soft wheat, notably F/A, with its high demands for nitrogen, more than hard wheat. July rainfall increases yield.

In the growing season January and May rainfall are strongly associated with high yields though less strongly than for the hard wheats. The March rainfall/yield relationship is positive but not significantly so. However the March quadratic relationship is significant - F(calc) = 8.1 - but negative meaning that it is the middle range of rainfall that gives the worst yields. This may suggest that we are here dealing with two important but conflicting factors; low rainfall leaching no nitrogen while high rainfall covers the plant's water losses during stem growth and heading. On the other hand this may be a coincidental correlation thrown up by chance in the analysis. This point would need the confirmation of further research.

The very strong, positive quadratic correlations of yield with total rainfall from late summer to the end of the plant's life cycle show that high totals cause as much damage (the linear relationship is not significant) as the lowest rainfalls within the range experienced during the 1948/49 to 1960/61 period in the LMV. The reasons for this, as explained above, are leaching of soil nitrogen, harming the structure of the soil and providing ideal conditions for disease.

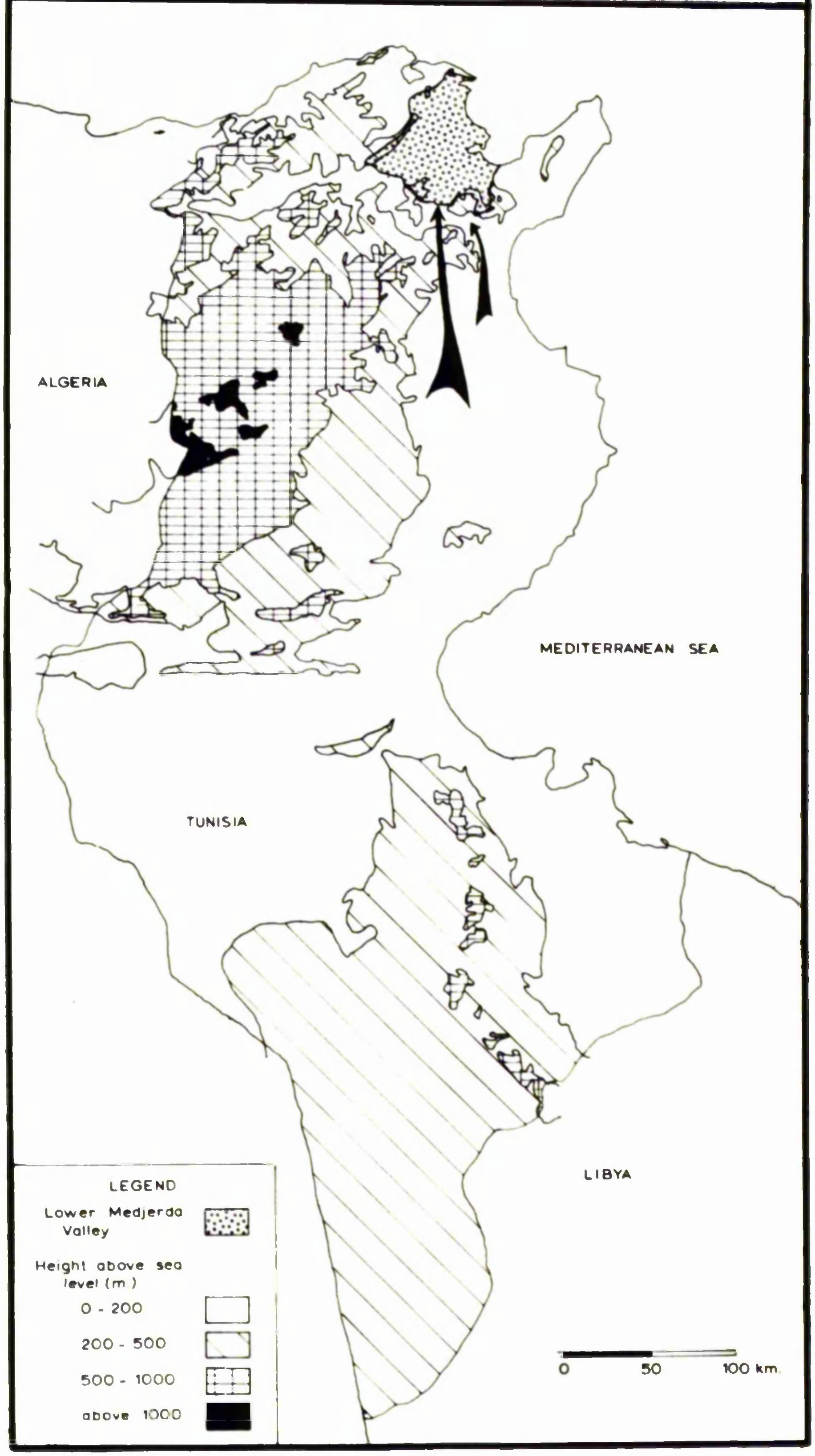
Temperature Variables. Boeuf (1932) suggested the possible use of monthly temperature means and extremes in correlation with yield to explain yield variations. Reference has several times been made, and summarised in chapter 9.2 (pp. 305-307), to the need for a warm winter and a cool spring, and particularly a cool May. Special reference has been made (see ch. 8.3, pp. 275-279) to the danger of extremely high temperatures during the ceiling phase of maturation. Critical levels of 28°C. and 30°C. were mentioned by different authors.

Unfortunately temperature records were not kept at the subsidiary rain stations in the LMV so that there is only one complete temperature record, at Tunis-Carthage, from which the monthly means during the growing season and the daily maxima of May were noted. It has been seen (in ch. 3.1, p. 61) that there is a slight degree of continentality exhibited between the temperature record of Tunis and Bir M'Chirga (just south of the LMV) but the difference is slight (Fig. 24, p.254) and non-existant in May, which is the critical month. For this reason it may be presumed that the Tunis-Carthage records are reasonably representative of the area as a whole although Centres at the geographical limits of the LMV might well be under distinctive temperature regimes. For example the Centres 08 and 11, in the rising land at the eastern boundary of the region (Fig. 26, p. 314) would be sheltered from the full force of the sirocco bearing the hot southerly air in May, whereas the Centres 09 and 12 lie fully exposed to it; a fact brought out by comparing Figure 26 (p. 314) and Figure 27 (p. 327). However the

Fig. 27

MAY SIROCCO IN THE L.M.V.

EASIEST PATHS OF ACCESS



Tunis temperature records will provide an average response of the region as a whole to the temperature variables which most clearly and fully explain the relationship with yield. The response of different Centres to temperature should show up in the final stage of the quantitative analysis; when each Centre is separately regressed against all the selected climatic variables in a stepwise multivariate correlation.

For the May daily temperatures a dividing line was taken at 29.0°C. Maxima below this point were given the value 1.0. Maxima of 29°C. and above were given a value according to the following formula:

$$T = 1.0 + (\text{Temperature} - 28.0)$$

In this way the effect of the upper range of temperature maxima could be clearly illustrated. Note that high temperature maxima are also associated with high daily mean temperatures and with dry, sunny weather.

As with rainfall, yields were regressed against single day maxima and combinations of successive day maxima to find the combination, or combinations, which best express the relationship that exists between yield and temperature.

For both hard and soft wheat the relationships found were very similar; a very strong negative correlation, Tables 72 and 73, between yield and the extreme temperatures of the days in mid-May - from 14 May to 18 May - for the years 1948/49 to 1960/61. By including the days from 6 May to 19 May the significance of the correlation was only slightly diminished.

In the latter part of May an important different relationship is seen. High temperatures in the fourth week of May appear to increase yield. In the study period the best correlation was

Table 72. Direction and Significance of the Linear Regression of May Daily Temperature Maxima Against Yield of Hard Wheat For the Study Area of the Lower Medjerda Valley; 12 Centres by 13 Years.

	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
6	-0.4																						
7	-0.4	-0.0																					
8	-0.4	-0.4	-0.4																				
9	-0.4	-0.4	-0.4	-0.0																			
10	-0.4	-0.4	-0.4	-0.0	-0.0																		
11	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4																	
12	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4																
13	+0.1	+0.3	+0.3	+0.7	+0.6	+0.7	+1.1	+1.7															
14	-2.9	-2.8	-2.8	-2.7	-2.7	-2.7	-2.5	-2.2	-6.9														
15	-9.4	-9.3	-9.3	-9.1	-9.1	-9.1	-8.8	-8.3	-14.7	-25.5													
16	-22.6	-22.3	-22.3	-22.0	-21.9	-21.9	-21.4	-20.6	-28.6	-28.1	-18.6												
17	-28.7	-28.3	-28.3	-27.8	-27.6	-27.8	-27.2	-26.2	-32.6	-28.0	-20.7	-21.7											
18	-45.4	-44.5	-43.5	-43.5	-43.5	-43.5	-42.3	-40.6	-49.0	-42.6	-32.6	-28.2	-8.8										
19	-47.5	-46.3	-45.2	-45.2	-45.2	-45.2	-43.9	-42.0	-49.5	-41.8	-30.4	-20.0	-5.5	-0.8									
20	-47.0	-45.8	-44.6	-44.6	-44.6	-44.6	-43.4	-41.5	-48.0	-39.6	-27.9	-16.2	-5.2	-1.7	-2.4								
21	-45.2	-44.0	-44.0	-43.0	-42.9	-42.9	-41.8	-40.0	-45.9	-37.3	-25.9	-14.3	-4.7	-1.5	-2.3	-0.0							
22	-37.0	-36.3	-36.3	-35.4	-35.4	-35.4	-34.5	-33.1	-38.7	-32.3	-22.5	-11.3	-3.5	-1.0	-1.0	-0.2	-0.0						
23	-37.4	-36.4	-36.4	-35.4	-35.4	-35.4	-34.5	-33.1	-38.5	-32.0	-22.0	-10.8	-3.2	-0.8	-0.7	-0.0	+0.1	+0.7					
24	-33.0	-32.3	-32.3	-31.4	-31.4	-31.4	-30.6	-29.4	-34.0	-26.9	-17.1	-6.9	-1.3	-0.0	+0.4	+1.8	+3.3	+3.6	+0.1				
25	-18.0	-17.8	-17.8	-17.6	-17.6	-17.6	-17.4	-17.0	-19.4	-13.6	-6.7	-1.0	+0.1	+2.7	+6.2	+8.5	+9.9	+9.3	+10.7	+13.0			
26	-17.8	-17.6	-17.6	-17.4	-17.4	-17.4	-17.1	-16.7	-19.1	-13.3	-6.4	-0.9	+0.2	+3.1	+7.1	+9.6	+11.1	+10.3	+11.8	+15.3	+2.0		
27	-17.0	-17.1	-17.1	-17.0	-17.0	-17.0	-16.9	-16.7	-19.0	-12.9	-5.9	-0.6	+0.3	+3.7	+7.8	+10.0	+11.4	+10.3	+11.4	+13.0	+1.8	+1.0	
28	-15.0	-15.0	-15.0	-14.9	-14.9	-14.9	-14.8	-14.8	-16.5	-10.7	-4.5	-0.2	+0.7	+4.4	+8.7	+10.8	+12.2	+11.3	+12.1	+13.0	+1.9	+1.8	+1.1

LEGEND

- \- Negative correlation
- \+ Positive correlation
- ——— F-value above 0.1% level
- \- - - F-value above 1.0% level

Note: The numbers 6 to 28 both above and to the left of the table are dates in May at the end of the crop year.

The table is additive down the columns. For example, the last entry of the first column, 15-0, is the F-value(1 & 120+ df) of the correlation coefficient, and the direction of the regression line, of yield against the sum of the daily temperature maxima from 6 May to 28 May.

Table 73. Direction and Significance of the Linear Regression of May Daily Temperature Maxima Against Yield of Soft Wheat For the Study Area of the Lower Medjerda Valley; 12 Centres by 13 Years.

	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
6	-0.1																						
7	-0.2	-0.0																					
8	-0.1	-0.1	-0.1																				
9	-0.2	-0.1	-0.1	-0.0																			
10	-0.1	-0.1	-0.1	-0.0	-0.0																		
11	-0.2	-0.1	-0.2	-0.1	-0.1	-0.1																	
12	-0.2	+0.7	-0.2	-0.1	-0.1	-0.2	-0.1																
13	+0.3	-2.5	-0.7	+1.1	+1.1	+1.1	+1.6	+2.0															
14	-2.5	-8.5	-2.5	-2.5	-2.5	-2.5	-2.4	-2.2	-7.5														
15	-8.4	-19.0	-8.5	-8.4	-8.4	-8.4	-8.2	-7.9	-14.5	-23.3													
16	-19.0	-23.6	-19.0	-18.8	-18.8	-18.8	-18.5	-17.9	-25.5	-33.6	-14.9												
17	-23.8	-35.8	-23.6	-23.4	-23.4	-23.4	-23.0	-22.4	-28.3	-23.3	-16.6	-17.5											
18	-36.2	-38.5	-35.7	-35.1	-35.1	-35.1	-34.4	-33.2	-40.6	-33.6	-25.0	-20.7	-6.2										
19	-39.1	-38.2	-38.5	-37.7	-37.7	-37.7	-36.8	-35.5	-42.3	-34.4	-24.6	-16.3	-4.9	-1.3									
20	-39.0	-38.1	-38.2	-37.5	-37.5	-37.5	-36.6	-35.3	-41.2	-32.8	-22.8	-13.6	-4.8	-2.3	-2.7								
21	-37.8	-30.9	-37.1	-36.4	-36.4	-36.4	-35.6	-34.3	-39.7	-31.3	-21.5	-12.3	-4.4	-2.1	-2.9	-1.3							
22	-31.5	-30.5	-30.9	-30.3	-30.3	-30.3	-29.6	-28.6	-33.7	-27.3	-18.8	-9.9	-3.4	-1.4	-1.3	-0.3	-0.1						
23	-31.0	-26.4	-30.1	-29.8	-29.8	-29.8	-29.1	-28.1	-33.1	-26.6	-18.0	-9.2	-3.0	-1.1	-0.8	-0.0	+0.1	+1.6					
24	-26.9	-14.0	-26.4	-25.9	-25.9	-25.9	-25.3	-24.4	-28.5	-21.8	-13.6	-5.6	-1.1	-0.0	+0.3	+1.9	+3.6	+4.3	+5.3				
25	-14.0	-14.2	-14.0	-14.0	-13.9	-13.9	-15.8	-13.6	-15.8	-10.5	-4.9	-0.7	+0.2	+2.2	+5.9	+8.2	+9.8	+9.5	+10.4	+12.3			
26	-14.2	-13.9	-14.2	-14.1	-14.1	-14.1	-14.0	-13.8	-16.0	-10.6	-4.9	-0.6	+0.2	+2.3	+6.2	+8.6	+10.3	+9.8	+10.7	+13.1	+0.2		
27	-13.7	-13.6	-13.9	-13.9	-13.9	-13.9	-13.9	-13.8	-16.0	-10.3	-4.6	-0.5	+0.3	+2.7	+6.7	+8.9	+10.3	+9.6	+10.2	+10.9	+0.7	+0.7	
28	-13.5	-13.1	-13.6	-13.6	-13.6	-13.6	-13.6	-13.5	-15.5	-9.8	-4.2	-0.4	+0.3	+2.5	+5.8	+7.7	+9.0	+8.5	+8.7	+8.2	+0.2	+0.2	+0.0

LEGEND

- \- Negative correlation
- \+ Positive correlation
- ——— F-value above 0.1% level
- \- - - F-value above 1.0% level

Note: The numbers 6 to 28 both above and to the left of the table are dates in May at the end of the crop year.

The table is additive down the columns. For example, the last entry of the second column, 13-1, is the F-value(1 & 120+ df) of the correlation coefficient, and the direction of the regression line, of yield against the sum of the daily temperature maxima from 7 May to 28 May.

in fact between yield and the temperature of 25 May. While there is reason to believe that high temperature conditions, associated with low rainfall (see ch. 8.3, p. 275) in this part of May do increase yield it is very unlikely that in reality the role is specific to 25 May or any other single day.

These results confirm expectation. It is during the first half of May that the grain is at the ceiling phase of maturation - a phase whose mechanism is easily disrupted by great heat - while the fourth week is at the height of the drying phase of maturation when rapid water loss is desirable and when cool moist conditions may cause loss of specific weight.

Considering that soft wheat is said to mature earlier than hard wheat it is perhaps surprising that for both crops the critical days for temperature should be the same; 14 May to 18 May. The critical period for the soft wheat should be nearer the beginning of May (Geslin and Vernet, 1952).

Three comments are relevant here. Firstly, as mentioned above, the significance of the combined daily extremes 6 May to 19 May is only slightly less than for the shorter mid-May period. Secondly, the grain matures at a considerably different rate, from the date of seed setting, so that the definition of the critical period must be blurred. Lastly, with data from only one temperature record for 13 years, there are not enough observations to allow the difference between hard and soft wheat to stand out.

In Rhodesia, Wilson (1969) tested different plots of wheat with one period of severe soil water stress (drier than wilting point for eight days) at different stages of the life cycle. The sensitivity of the crop to this stress increased after heading and was most acute during the grain filling or dough phase (equivalent to the ceiling phase) with the overall effect of greatly reducing the yield. This indicates that in addition to temperature maxima, acute shortage of water, to the point where wilting is induced, plays a part in the mechanism of disrupting grain growth. However, Asana and Williams (1965) have shown, by subjecting wheat from eight days after anthesis until maturation to different regimes of daytime temperature while the plant was always adequately supplied with water, that temperature alone, independent of soil water stress, can greatly reduce yield. Raising the daytime mean from 25°C. to 31°C. reduced yield by 16%. But it must be noted that raising the temperature from 25°C. to 28°C. produced half this reduction. The effects of variation in this part of the temperature range could be of equal importance in Tunisia and need further examination.

Further work in Australia (Wardlaw, 1970) has suggested another important relationship. Wardlaw tested the effect of temperature during the first eight days after anthesis. Again high temperatures reduced yield but the cause was different; not by reducing the weight of individual grains but by cutting down the number of seeds which set. In Tunisia this would correspond, in time, with the latter part of April when occasionally the first of the year's sirocco can raise the temperature to near the 30°C. mark.

Having examined the effect of May temperature maxima on yield the same method was used to test the effect of monthly mean temperatures on yield. Again for both hard and soft wheat the most important relationship found was similar; strongly negative for the whole period January to April taken together.

The relationship was rather more significant for hard wheat than for soft wheat, Table 74, but significant at the 0.1% level for both.

A mean temperature figure is much more than a measurement of temperature. It is a measure, albeit an imperfect one, of a whole climatic situation. Low mean temperatures are associated with grey skies, reduced hours of insolation and heavier than average rainfall. It is likely, therefore, that the variation of yield explained by adding mean temperature to the multivariate analysis will be small. Nevertheless low mean temperatures may have a significance independent of rainfall in limiting pests; wet but warm conditions being ideal for smut and rusts.

The only month when increased mean temperature appeared to be associated with increased yield, Table 74, was December when, as Boeuf (1932) pointed out, higher temperatures speed germination. But this effect must be excluded from the final analysis because the significance of the explanation is not acceptable for hard wheat and is barely above zero for the soft wheat.

Of the variables finally selected for the multivariate analysis, Tables 75 and 76, the only one to require a further comment is the September/May total rainfall. Although the quadratic correlation is highly significant the linear relationship is much less strong for hard wheat and not at all significant for soft wheat. It is not surprising, therefore, that attempts to explain yield on this basis by Hyslop and Dahl (1970) and in the single farm study (Terre, 1958) produced unimpressive results.

Table 74. Direction and Significance of the Linear Regression of Monthly Mean Temperatures Against Yields of Hard and Soft Wheat For the Study Area of the Lower Medjerda Valley; 12 Centres by 13 Years.

Hard Wheat

	Nov	Dec	Jan	Feb	Mar	Apr	May
Nov	-4.5						
Dec	0-.1	3+.0					
Jan	4-.8	2-.5	14-.0				
Feb	12-.1	9-.2	16-.9	7-.9			
Mar	18-.3	14-.7	22-.0	14-.0	11-.3		
Apr	24-.9	23-.9	34-.3	22-.8	19-.0	1-.8	
May	22-.5	22-.7	31-.4	23-.3	19-.0	4-.7	4-.8

Soft Wheat

	Nov	Dec	Jan	Feb	Mar	Apr	May
Nov	3-.7						
Dec	1-.0	0+.2					
Jan	8-.5	6-.2	16-.3				
Feb	15-.2	12-.3	16-.5	6-.4			
Mar	19-.9	16-.6	19-.6	10-.7	8-.1		
Apr	25-.8	25-.5	29-.3	16-.8	13-.1	1-.1	
May	22-.7	23-.6	26-.6	17-.5	13-.3	3-.3	3-.7

LEGEND

- \- Negative correlation
- \+ Positive correlation
- —— F-value above 0.1% level
- \--- F-value above 1.0% level

Note: The table is additive down the columns. For example, the last entry of the first column, for hard wheat, 22-.5, is the F-value(1 & 120+ df) of the correlation coefficient, and the direction of the regression line, of yield against the weighted mean temperature of November to May.

Table 75. Selected Climatic Variables for Regression Against Yields of Hard Wheat.

Variable	Degree of Polynomial
A. Rainfall Totals	
1. December to February of the fallow year	1st
2. April of the fallow year	1st & 2nd
3. July	1st
4. September to May of the crop year	1st & 2nd
5. January	1st
6. February to April	1st & 2nd
7. May	1st
B. Temperature Maxima	
8. 14 May to 18 May	1st
9. 25 May	1st & 2nd
C. Temperature Means	
10. January to April	1st

Table 76. Selected Climatic Variables for Regression Against Yields of Soft Wheat.

Variable	Degree of Polynomial
A. Rainfall Totals	
1. December to March of the fallow year	(1st) & 2nd
2. April of the fallow year	1st & 2nd
3. July	1st
4. September to May of the crop year	1st & 2nd
5. January	1st
6. April to May	(1st) & 2nd
7. May	1st
B. Temperature Maxima	
8. 6 May to 19 May	1st
9. 24 May to 25 May	1st & 2nd
C. Temperature Means	
10. January to April	1st

10.4 Multivariate Analysis: Including all Observations. Using a stepwise multiple regression procedure the total number of the observations was regressed against groups of the selected variables with the following results.

Hard Wheat. Together, the rainfall variables accounted for 42% of the total variation of hard wheat with the level of significance well above the 0.1% level. By taking out the variation explained by the rainfall and testing the distribution of the remaining variation between Centres and between years it was seen that the difference between years, Table 77, was no longer at all significant whereas the difference between Centres was highly significant. In other words differences in rainfall effectively accounted for variation in yield from year to year but there remained between the Centres yield differences intrinsic to their soils, topography and, perhaps, quality of farm management.

The most convincing explanation offered by rainfall is by the rainfall of January and May of the crop year, April of the fallow year (both linear and quadratic functions) and the total September/May rainfall of the crop year, again, both linear and quadratic functions.

The rainfall variables and the temperature variables, together, account for 47.2% of the total yield variation with an F-value (8.3) significant at the 0.1% level. Analysis of variance showed that the variation between years was almost entirely eliminated, Table 77, whereas the variation between Centres was even more highly significant than before.

Most of the explanation - 40.1% - is given by the rainfalls of July, September/May and January, Table 78, and the

Table 77. Analysis of Variance: Hard Wheat Yields After Taking Out Explanation by Rainfall.

Difference Between Means of Years.

F(calc: 12 & 142 df) = 0.80
F(5.0%: 12 & 120/inf. df) = 1.83/2.74

The 'null' hypothesis of no significant difference is maintained.

Difference Between Means of Centres.

F(calc: 11 & 143 df) = 7.64
F(0.1%: 11 & 120 df) = 3.11

The 'null' hypothesis is rejected

Analysis of Variance: Hard Wheat Yields After Taking Out Explanation by All Climatic Variables.

Difference Between Means of Years.

F(calc: 12 & 142 df) = 0.32
F(5.0%: 12 & 120/inf df) = 1.83/2.74

The 'null' hypothesis of no significant difference is maintained.

Difference Between Means of Centres.

F(calc: 11 & 143 df) = 8.19
F(0.1%: 11 & 120 df) = 3.11

The 'null' hypothesis is rejected

Table 78. Relationship Between Climate and Hard Wheat Yields in the LMV. All 155 Observations.

Multiple Regression

Step	Variable Entered	Explanation % By Step	Explanation % Total	R adj.for df	F	SEE of Yield adj.for df
1	T.mid-May	24.3	24.3	0.49	49.0	3.90
2	R.Jan	9.2	33.5	0.58	38.2	3.68
3	R.July	2.0	35.4	0.59	27.7	3.65
4	R.May	1.5	36.9	0.60	22.0	3.63
5	R.S/May Q	1.3	38.3	0.61	18.5	3.62
6	R.S/May L	1.8	40.1	0.62	16.5	3.59

F(calc: 6 & 148 df) = 16.51
F(0.1%: 6 & 120 df) = 4.04

$$Y = a + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + b_5X_5^2 + b_6X_5$$

Regression Coefficients

	b-coefs(x 10^4)	SEE(x 10^4)	t-value
b_1	-2410.3	785.6	3.1
b_2	301.2	98.3	3.1
b_3	950.2	557.0	1.7
b_4	278.2	147.8	1.9
b_5	-0.3	0.1	2.5
b_6	256.4	120.5	2.1

a = 3.876

temperature maxima of mid-May. The mid-May temperatures, when entered first in the regression, alone accounted for over 24% of total variation.

Soft Wheat. The rainfall variables between them explained 37.6% of the total yield variation. As with the hard wheat the F-value is highly significant at the 0.1% level. As before, the analysis of variance between Centres and years, after taking out the explanation given by rainfall, shows a difference between Centres which is highly significant, Table 79, but between years the difference between means is no longer at all significant.

Most of the explanation - 33.9% - was given by the first seven variables entered. These were, in order, the rainfalls of January, April of the fallow year (linear and quadratic), May, December/March of the fallow year, and April/May of the crop year.

When considered together all the temperature and rainfall variables explained 41.9% of the total variation; again rather less than for the hard wheats. Analysis of variance between years and between Centres showed that the difference between years had been eliminated but the difference between the means of the Centres was even more significant than before. For soft wheats, the same as for hard wheats, non-climatic factors such as soil, topography and management played a substantial part in controlling yield from one part of the LMV to another.

The importance of explaining the variation in yield between years is seen when viewed in the context of yield trends, and conclusions normally drawn from these trends (outlined in ch. 7.1, p. 231 ff.), during the final phase of colonisation.

Table 79. Analysis of Variance: Soft Wheat Yields After Taking Out Explanation by Rainfall.

Difference Between Means of Years

F(calc: 12 & 139 df) = 0.76
F(5.0%: 12 & 120/inf df) = 1.83/2.74

The 'null' hypothesis of no significant difference is maintained.

Difference Between Means of Centres.

F(calc: 11 & 140 df) = 12.11
F(0.1%: 11 & 120 df) = 3.11

The 'null' hypothesis is maintained.

Analysis of Variance: Soft Wheat Yields After Taking Out Explanation by All Climatic Variables.

Difference Between Means of Years.

F(calc: 12 & 139 df) = 0.33
F(5.0%: 12 & 120/inf df) = 1.83/2.74

The 'null' hypothesis of no significant difference is maintained.

Difference Between Means of Centres.

F(calc: 11 & 140 df) = 13.35
F(0.1%: 11 & 120 df) = 3.11

The 'null' hypothesis is rejected

Table 80. Relationship Between Climate and Soft Wheat Yields in the LMV. All 152 Observations.

Multiple Regression.

Step	Variable Entered	Explanation % By Step	Explanation % Total	R adj.for df	F	SEE of Yield adj.for df
1	T.mid-May	20.7	20.7	0.46	39.1	4.13
2	R.Jan	6.9	27.6	0.52	28.3	3.98
3	R.S/May Q	3.3	30.9	0.55	22.0	3.91
4	R.S/May L	3.7	34.6	0.58	19.5	3.81

F(calc: 4 & 147 df) = 19.45
F(0.1%: 4 & 120 df) = 4.95

$$Y = a + b_1X_1 + b_2X_2 + b_3X_3^2 + b_4X_3$$

Regression Coefficients.

	b-coefs(x 10^4)	SEE(x 10^4)	t-value
b_1	-2851.1	669.9	4.3
b_2	334.2	93.3	3.6
b_3	-0.4	0.1	3.4
b_4	331.6	114.5	2.9

a = 7.197

The yields in the study area followed the national, downward trend (Fig. 3 , p. 20) during the post-war period. In the 12 Centres yields decreased quite rapidly from the early 1950's to the early 1960's. In most of the Centres the maximum yield was in 1950 and the minimum in 1960 or 1961. Normally this is taken as evidence that the colonists were lessening the interest they took in their land. According to this argument the low yields of the late 1950's and the early 1960's were a result of using less fertiliser and paying progressively less attention to maintaining standards of agricultural practice. Because of these reasons it is assumed that the soil was losing its fertility and as the French left, the new Tunisian farmers were inheriting lands which had been badly misused for a decade.

In a contemporary context the argument was put most succinctly in the evaluation for the farm of Montarnaud in the discussion of cereal yields 1948/49 onwards. The evaluation said; 'we see a progressive lowering of yields. This fall has its causes in a less careful cultivation (upkeep of the land, fertiliser...) and in particular in the abandon of the rigorous Fallow-Wheat rotation, a general phenomenon in Tunisia following recent events'.

This view, naturally popular in Tunisia, has been uncritically reiterated time and again. However it has been shown, in chapter 7, that the decrease in area of fallow was not rapid until after 1960. The decrease in the 1950's, neither a general phenomenon nor rapid, is explainable in terms of a revised opinion about the value of fallow by the SBAT. Nor it there any evidence to suggest that the care of the land or the use of fertiliser was less in the late years of the colonial period.

Finally, although yields did drop between 1950 and 1961/62, the theory that the land had lost its fertility was upset by the yields of 1963. In many cases these were one of the highest on record. At Montarnaud they were the highest of the whole period of the STONIC records - 1937/38 to 1962/63.

So the decreasing yields of the post-war period are not to be explained in terms of worsening management or declining soil fertility. But the decrease is real enough. Analysis of variance between the mean yields of the Centres and, secondly, the mean yields of different years, shows that there is not only a significant difference between Centres but between years also. There was, in fact, a significant decline in yields.

But after the yield variation explained by rainfall and temperature factors is removed the difference in yields from year to year is negligible. This is strong evidence, to add to the other evidence presented in chapter 7, that the colonists did not allow their farming standards to deteriorate during the post-war period. It also underlines the strongly significant role played by the climate in determining yields.

10.5 Multivariate Analysis by Centre.

Correlation Coefficients. Before seeing to what extent combinations of variables explain the yield of each separate Centre some information may be obtained from studying the correlation coefficients of the independent variables against yield for each Centre.

The correlation matrix for hard wheat, Table 81, shows, above all else, that there is considerable variation from Centre to Centre in the way yields respond to climate. Although some of the patterns are clear, and similar for each Centre, others are not so easy to identify or explain.

In all except one Centre, as expected, the rain in the spring of the fallow year decreases yield. In this respect and in many others Centre 07 is atypical. The explanation for this will be discussed below.

In the three Centres at the south-west of the LMV July rainfall has a negative effect on yield, very significant by itself in Centre 02. In five of the remaining nine Centres the correlation coefficient is strongly positive; 0.50 or more. This high, positive value for July rainfall is difficult to explain particularly when its relationship to yield is weakly to very strongly negative in the first three Centres. Can it really be that such a small quantity of rainfall, so long before sowing the seed, can have such a profound effect on yield ? If so it must be, as suggested above, through its effect on nitrifying bacteria. The boost given to their activities by these mid-summer showers must be enormous. This is just possible in a region where a dry summer is liable to bring the activity of all soil micro-organisms to a halt and where the need to in-

Table 81. Correlation Coefficients Between Individual Climatic Variables and the Yields of Hard Wheat of Each Centre in the LMV. (x 100).

	Fallow Rain				Crop Rain						Temperature			
Centre	D/Feb	Apr(L)	Apr(Q)	July	S/May(L)	S/May(Q)	Jan	F/Apr(L)	F/Apr(Q)	May	14/18 May	25 May(L)	25 May(Q)	J/Apr
01	58	-52	-41	-38	41	32	79	48	37	47	-62	37	49	-57
02	41	-50	-44	-76	24	8	57	44	33	27	-79	34	42	-43
03	43	-36	-32	-24	47	36	65	49	39	52	-73	36	45	-55
04	50	-39	-25	66	19	8	48	23	12	35	-45	55	62	-20
05	21	-28	-27	58	51	44	72	54	45	36	-63	26	35	-64
06	24	-42	-26	50	35	22	61	2	-10	69	-56	27	35	-59
07	-9	7	16	71	-36	-43	60	-31	-39	18	23	50	58	1
08	-6	-25	-17	5	34	28	16	42	36	-18	-58	-12	-8	-62
09	29	-70	-61	13	28	17	27	1	-4	66	-77	21	23	-56
10	50	-55	-50	44	18	7	49	-25	-34	33	-63	50	51	-52
11	28	-70	-67	69	8	6	68	-17	-19	26	-45	36	42	-51
12	5	-70	-70	43	57	47	37	13	9	58	-86	24	26	-81

crease soil nitrogen is of major importance.

However the weakness of this argument is that one is dealing with a variable many of whose values are zero so that the degree of definition obtained in comparing the range of yields against July rainfall is limited. But the strength of the correlations found makes the association worth closer examination. Furthermore there is a strong sub-regional pattern of correlation. The highest negative correlation is for Centre 02 which occupies the driest part of the LMV. The other Centres showing negative and weakly positive correlation with July rainfall all line the southern and south-western border of the LMV.

The overall rainfall, September/May of the crop year, has a positive beneficial effect on yield though not very strong. In Centre 07 the relationship is negative.

The significance of January rainfall is positive and strong in each Centre except for those in the south-east of the LMV, the wet 11 and the dry 08 and 09, where the relationship is much less important.

Rainfall in February/April can be of importance in the south-west (Centres 01 to 05) though of much less value - positively or negatively - elsewhere.

High May rainfall can be very useful in the dry southerly Centres 09 and 12 and also in 06.

The most important single factor is, however, the temperature maxima of the mid-May period. These are particularly significant in the dry south - Centres 02, 09 and 12 - where they have a strongly detrimental effect on yield. Once again Centre 07 is atypical; the relationship is weakly positive.

The only remaining variable to have consistently high degrees of correlation with yield is the mean January/April temperature. The corrleation is negative and generally strong (once again with the exception of 07) but this mean temperature being an expression of a range of climatic factors, is not likely to add much to yield explanation given by rainfall and temperature.

The correlation matrix for soft wheat, Table 82, has the same general features as for the hard wheats. The rain of the previous winter has less effect on yield but the beneficial effect of low spring rainfall in the fallow year is a consistent feature throughout the LMV. The rainfall of the growth season plays at all seasons a similar though slightly less positive role. In January and in May the Centres with the least need of above average rainfall, according to the correlation coefficients, are those which combine highest rainfall - Centres 01, 08 and 11 - with better soils and high standards of cultivation - Centres 04 and 10.

The pattern of reaction to mid-May temperatures is very clear. The wet and sheltered Centres - 01, 07, 08 and 11 - are not affected by May temperature extremes. The others are all strongly affected by them, particularly the Centres 09 and 12 which, see below, are fully exposed to the late spring sirocco.

Individual Centres. The multivariate analysis by individual Centre, using the same selection of variables in each case, leaves limited room for manoeuvre as the number of observations has now been reduced from 156 to 13. The use of all ten variables as independents in a multivariate analysis would practically exhaust the degrees of freedom available. Even when selecting a smaller number of variables from within the ten, the results of the analysis would be open to similar criticism. However when

Table 82. Correlation Coefficients Between Individual Climatic Variables and the Yields of Soft Wheat of Each Centre in the LMV.(x 100).

	Fallow Rain					Crop Rain						Temperature			
Centre	D/Mar(L)	D/Mar(Q)	April(L)	April(Q)	July	S/May(L)	S/May(Q)	Jan	A/May(L)	A/May(Q)	May	14/18 May	25 May(L)	25 May(Q)	J/Apr(mn)
01	20	27	-40	-27	-14	25	16	43	33	27	19	-44	32	44	-17
02	16	24	-47	-39	-47	9	-4	43	44	27	55	-60	40	48	-51
03	17	23	-33	-29	-16	44	34	72	44	32	50	-65	35	44	-61
04	51	59	-62	-56	48	-14	-25	36	5	-14	8	-66	40	43	-19
05	9	15	-48	-44	70	31	22	70	29	18	36	-68	41	49	-55
06	-12	-10	-40	-26	42	30	16	52	14	-6	65	-53	34	38	-55
07	6	3	-40	-29	-31	12	10	65	39	33	57	-7	-22	-16	-24
08	10	13	-39	-29	35	-38	-37	9	-38	-47	4	1	13	13	-46
09	4	14	-75	-77	5	57	47	36	24	19	50	-73	33	33	-84
10	-10	1	-28	-34	19	7	-7	34	-17	-34	-1	-54	24	22	-66
11	-9	-1	-40	-35	47	-30	-34	19	-16	-21	0	-11	19	23	-21
12	17	29	-77	-71	55	44	31	48	40	29	65	-83	40	41	-69

a substantial part of the total variation - 60-80% - is accounted for by the first two or three variables entered the correlation may be accepted as expressing a real cause and effect relationship. This is particularly true if a comparison of the analysis of all 12 Centres reveals a clear sub-regional patterning. The contribution to the total explanation given by entering further variables into the regression may or may not be significant; again it is more likely to be significant if sub-regional patterns emerge.

The difficulty of having too wide a choice of variables - and entering many of them into the regression - is that it strengthens the possibility of a strong association occurring by chance.

Nevertheless in the following discussion the effects of entering four, five and six variables are recorded to see whether useful patterns do emerge. The results are not expected to have an absolute validity. But if they provide a starting point to stimulate further research they will have served a useful purpose. They should do this if they conform to general patterns and if they are seen to reflect the conclusions of the climatic study drawn out in chapter 9.

In the following pages the line which divides statistically significant from possible indicative interest may be drawn between 60% and 75% explanation; after the entry of the first two or three variables. Where the percentage of yield variation explained is above 80% the figures can only be dubious. They leave too small a value to cover all the possible sources of error. These include inaccuracies in the initial rainfall, temperature and yield data, inaccuracies caused by grouping the data, error due to neglecting other climatic factors and variation due to changes in farm management practice during the study years. Two specific error sources which deserve special mention are, firstly, the frost of April 9/10 1956 which was said to have strongly affected some yields in the Bir M'Chirga region and, secondly, the increasing useage of nitrogen fertilisers from the mid-1950's.

Centre 01. Centre 01 consists of two Farm Groups, Bordj Toum I and Bordj Toum II (Fig. 26, p. 314); six farms totalling 1,450 hectares. Of this total 650 ha. were planted with vines and fruit trees and a further 150 ha. were too steeply sloping to be cultivated at all.

Both of the Farm Groups are in the Bordj Toum plain, a wide sloping plain on the left bank of the river Medjerda. The western extremities of the Farm Groups rise into the foothills of the *djebel* Lansarine.

The soils are formed from alluvial calcareous clays of recent deposition. Near the river these are fine and not very permeable though further from the river the soil is *hamri*, lighter, sloping and less fertile. In the lower-lying soil the water table has been raised by the dam at el Arroussia but the water, and the soil, has a high saline content.

It was on this soil that the leading, local, French farming family, Trouillet, had developed the techniques of spring ploughing and mechanised cultivation as discussed in chapter 6.4 (pp. 163 ff.).

During the period 1948/49 to 1960/61 the Bordj Toum plain was the wettest region of the LMV; with rather heavier rainfall than the Centres 08 and 11 on the eastern extremity of the LMV.

Under these conditions it was to be expected, Table 83, that the climate of May, at the end of the growth year, would not play a controlling role in limiting yield. This allows the effect of the previous year's rainfall to be strongly represented in the final analysis. In the crop year a high January rainfall and a moderate February/April rainfall then ensure a good yield. Of the 96% of yield variation thus explained, 75% was explained by the first two variables entered.

The explanation of soft wheat yields by the climatic variables is, individually, never very high. In combination also the explanation given never reaches a very convincing level of explanation. The reasons for this are not clear but it is true also for the two other wettest Centres - 08 and 11 - which also abut mountains at the border of the LMV.

Centre 02. The second Centre includes the two Farm Groups of Montarnaud and Drijet (Fig. 26, p. 314). Together they form easily the largest Centre, over 9,600 ha., including 7,150 ha. of ploughed land. Montarnaud, the Farm Group with the greater range of relief, has over 700 ha. of uncultivated mountain slopes and 1,650 ha. of olives and vines. On Drijet together these totalled only 150 ha.

Montarnaud is made up of the two largest French farms in the study area. The largest, the farm of Montarnaud itself, 4,567 ha., had an excellent reputation for being well managed and over the years made important contributions to the development of all branches of agriculture. Its contribution to cereal farming methods has been discussed in chapter 6.5 (pp. 176-178).

The Centre is the third highest - 122 m. above sea level - but its mean gradient is comparatively low; it is high rolling

Table 83. Centre 01. Hard Wheat.
Relationship Between Climate and Wheat Yields.

Yield Statistics 1948/49 to 1960/61

Mean:10.4ql/ha. S.D.: 4.8 C.V.: 46.3
Min.: 3.5ql/ha.(1951)
Max.:20.8ql/ha.(1950)

Multiple Regression

Step	Variable Entered	Explanation % By Step	Explanation % Total	R adj.for df	F	SEE of Yield adj.for df
1	R.Jan	62.6	62.6	0.79	18.4	3.08
2	R.D/Feb(fa)	12.6	75.2	0.85	15.2	2.75
*3	R.Apr(fa) L	1.8	77.1	0.85	10.1	2.92
*4	R.Apr(fa) Q	10.6	87.7	0.91	14.2	2.34
*5	R.F/Apr L	1.5	89.2	0.92	11.5	2.54
*6	R.F/Apr Q	6.5	95.7	0.96	22.0	1.86

F(calc: 6 & 6 df) = 22.0
F(0.1%: 6 & 6 df) = 20.0

$$Y = a + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_3^2 + b_5X_4 + b_6X_4^2$$

Regression Coefficients

	b-coef(x 10^4)	SEE(x 10^4)	t-value
b_1	753.2	195.7	3.85
b_2	122.0	57.6	2.12
b_3	-1564.5	521.6	3.00
b_4	10.3	4.6	2.24
b_5	1175.5	365.2	3.22
b_6	-3.5	1.2	3.00

a = -2.578

* of possible indicative value only

country but with little land beyond the reach of cultivation. The Farm Group of Montarnaud occupies the shallow synclinal plain (see ch. 3.3, pp. 81-82) between two parallel ranges of hills. Drijet lies on the eastern flank of the hills. Both are in a region of pliocene alluvium with occasional sandstone strata visible in the hills.

The water table is low although localised and small quantities of fresh to brackish water were tapped by most farms in shallow wells. In addition both of the farms in the Montarnaud Farm Group had deep bores tapping water from the sandstone beneath the pliocene alluvium, but only enough for the needs of livestock and the farm yards.

The soils on the different farms ranged from flat land, usually with deep soils, described as good (though occasionally too clayey), to inclined and steeply sloping land which was lighter (hamri) with shallower, even gravelly, soils. As the Centre lay in the driest part of the LMV the lighter soils, readily permeable and drying rapidly, would tend to be short of water. But overall the land was average to good quality for cereals and entirely free of saline deposits.

In spite of the disadvantages of climate the yields of hard wheat -

Mean Yield 11.6 ql/ha. St. Dev. 3.5

- were one of the highest and the standard deviation lower than average indicating a greater measure of independence from the climate's control than other Centres, perhaps conferred by better land and a high standard of farming practice.

The single variable which best accounted for annual differences in yield was the temperature maxima of mid-May; 62.5%

of the total. But the best overall explanation of yield was given by four rainfall variables, Table 84, indicating that the climate of the two year period, when favourable, had been effectively used to secure a high yield which could be cut but not decimated by a mid-May sirocco. The significance of this explanation is reasonably high; well over the 0.5% level.

For soft wheat the explanation of yield variation is less convincing; 80% to a significance level of only 2.5%. In contrast with the hard wheat yields the variables selected are all to do with the climate of the latter part of the growth year; especially the month of May. As the mean yield is high, 12.2ql/ha., this suggests that the soil is rarely, at other times of the year, critically wet or dry compared with the crucial importance of ideal rainfall and temperatures in the last two months of the growing season. Although soft wheat yields were higher than hard wheat yields their pattern over the 13 year period was more obviously shaped by the end of season climate. This is the converse of what is normally held to be true. However for soft wheat the level of significance is low so the result can only be accepted with caution.

Centre 03. Centre 03 includes the three Farm Groups - Attermine II, el Mahrine I and Furna - which lie along the road between el Bathan and Furna village. Between them they include 27 farms totalling 3,123 ha. About 2,200 ha. were ploughed, over 700 ha. were planted and the remaining 200 ha. were used as rough pasture.

The three Farm Groups lie on the north-western extremity of the hills on the right bank of the Medjerda. The area is much lower than Centre 02 (mean height 67 m.) and the gradient

Table 84. Centre 02. Hard Wheat.
Relationship Between Climate and Wheat Yields.

Yield Statistics 1948/49 to 1960/61

Mean: 11.6 ql/ha. S.D.: 3.5 C.V.: 29.9
Min.: 3.4 ql/ha.(1961)
Max.: 17.5 ql/ha.(1950)

Multiple Regression

Step	Variable Entered	Explanation % By Step	Explanation % Total	R adj.for df	F	SEE of Yield adj.for df
1	R.July	57.8	57.8	0.76	15.1	2.34
2	R.Apr(fa) L	16.1	73.9	0.86	14.2	2.02
*3	R.Jan	8.9	82.8	0.89	14.5	1.81
*4	R.S/May Q	3.8	86.6	0.91	13.0	1.78

F(calc: 4 & 8 df) = 12.96
F(0.5%: 4 & 8 df) = 8.81

$$Y = a + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4^2$$

Regression Coefficients

	b-coef(x 10^4)	SEE(x 10^4)	t-value
b_1	-6942.3	1471.6	4.7
b_2	-461.9	189.5	2.4
b_3	489.1	190.6	2.6
b_4	0.		1.5

a = 12.804

* of possible indicative value only

Table 85. Centre 02. Soft Wheat.
Relationship Between Climate and Wheat Yields.

Yield Statistics 1948/49 to 1960/61

Mean: 12.2 ql/ha. S.D.: 4.0 C.V.: 33.0
Min.: 5.1 ql/ha.(1961)
Max.: 20.0 ql/ha.(1959)

Multiple Regression

Step	Variable Entered	Explanation % By Step	Explanation % Total	R adj.for df	F	SEE of Yield adj.for df
1	T.mid-May	36.4	36.4	0.60	6.3	3.34
2	T.25 May Q	12.3	48.7	0.66	4.8	3.28
3	R.May	16.0	64.7	0.76	5.5	3.01
4	T.25 May L	6.5	71.2	0.78	4.9	3.00
5	R.A/May Q	8.9	80.0	0.84	5.6	2.87

F(calc: 5 & 7 df) = 5.61
F(2.5%: 5 & 7 df) = 5.29

$$Y = a + b_1X_1 + b_2X_2^2 + b_3X_3 + b_4X_2 + b_5X_4^2$$

Regression Coefficients

	b-coef(x 10^4)	SEE(x 10^4)	t-value
b_1	-2848.1	1319.9	2.2
b_2	4637.2	2109.2	2.2
b_3	1097.2	438.6	2.5
b_4	-31888.2	17883.3	1.8
b_5	-2.9	1.7	1.8

a = 18.892

is also low as only the south-westerly parts are on steeply sloping ground; the region being a shallow synclinal basin along which the el Bathan to Furna road runs.

South of el Bathan is found a stratum of pliocene/quarternary gravels. Elsewhere there are pliocene alluviums, marls and sandstones. The French farm evaluations of the early 1960's show that the flatter parts have a deeper soil with a higher concentration of humus and clay - generally favourable for cereals. However most of the land where it is inclined to strongly sloping is described as light, perhaps chalky, sandy or even stony, with outcrops of tuff; medium to poor quality soils for cereals.

One farm of 147 ha. at el Mahrine with a mixture of these two types of soil had high yields which, according to the farm evaluations, were due to the; 'quality of the property, claimed amongst the best of the sector and to the methods of cultivation with rational use of fertiliser'. The evaluation added that; 'the variety of soils appeared to ensure a certain regularity of yields; in wet years good harvests from the rich, deep areas whilst in dry years the light parts assured in their turn a worthwhile harvest'. Nevertheless most of the comments speak of yields being 'medium' or even 'poor'.

The yields 1948/49 to 1960/61 were below average and considerably below those of Centre 02 which was in a rather drier area. It was a region of medium-sized farms noted neither for the quality of their land nor their productivity.

The explanation of yield variation is very high for both soft and hard wheat, Tables 86 and 87, with levels of signif-

Table 86. Centre 03. Hard Wheat.
Relationship Between Climate and Wheat Yields.

Yield Statistics 1948/49 to 1960/61

Mean: 9.1 ql/ha. S.D.: 3.3 C.V.: 36.6
Min.: 2.5 ql/ha.(1961)
Max.: 15.6 ql/ha.(1950)

Multiple Regression

Step	Variable Entered	Explanation % By Step	Explanation % Total	R adj.for df	F	SEE of Yield adj.for df
1	T.mid-May	53.3	53.3	0.73	12.6	2.38
2	R.Jan	15.9	69.2	0.82	11.2	2.12
*3	R.F/apr L	5.5	74.7	0.83	8.8	2.12
*4	R.May	9.0	83.6	0.88	10.2	1.91
*5	R.S/May L	6.8	90.4	0.93	13.2	1.66
*6	T.25 May L	6.7	97.1	0.98	34.0	1.04

F(calc: 6 & 6 df) = 34.0
F(0.1%: 6 & 6 df) = 20.0

Regression Coefficients

	b-coef(x 10^4)	SEE(x 10^4)	t-value
b_1	-2777.3	599.3	4.6
b_2	168.0	103.7	1.6
b_3	505.9	73.7	6.9
b_4	768.4	147.0	5.2
b_5	-138.7	32.8	4.2
b_6	671.4	178.4	3.8

a = 7.555

* of possible indicative value only.

Table 87. Centre 03. Soft Wheat.
Relationship Between Climate and Wheat Yields.

Yield Statistics 1948/49 to 1960/61

Mean: 9.3 ql/ha. S.D.: 4.0 C.V.: 43.1
Min.: 2.1 ql/ha.(1961)
Max.: 16.6 ql/ha.(1950)

Multiple Regression

Step	Variable Entered	Explanation % By Step	Explanation % Total	R adj.for df	F	SEE of Yield adj.for df
1	R.Jan	51.3	51.3	0.72	11.6	2.92
2	R.A/May L	28.0	79.3	0.88	19.2	2.09
*3	R.A/May Q	8.6	87.9	0.93	21.9	1.76
*4	R.D/Mar(fa) Q	5.6	93.5	0.96	28.9	1.44
*5	R.Apr(fa) Q	3.4	97.0	0.97	44.5	1.12

F(calc: 5 & 7 df) = 44.52
F(0.1%: 5 & 7 df) = 16.2

$$Y = a + b_1X_1 + b_2X_2 + b_3X_2^2 + b_4X_3^2 + b_5X_4^2$$

Regression Coefficients

	b-coef(x 10^4)	SEE(x 10^4)	t-value
b_1	918.3	90.2	10.2
b_2	2463.2	337.4	7.3
b_3	-12.8	2.4	5.4
b_4	-0.5	0.1	4.3
b_5	-2.4	0.8	2.8

a = -2.909

* of possible indicative value only

The principal difference between the two crops is that hard wheat appears here to be very dependent on the climate of the growth season with the rainfall and temperatures of May both being important. But the soft wheat yield is determined less by the end of the crop year, though it is still important, and more by the climate of the fallow year. This is more what one would expect with the soft wheat needing more nitrogen and escaping the full effect of May temperatures because it matures earlier.

Centre 04. Centre 04 consisted of only one farm of 650 ha. (Fig. 26, p. 314), all but 50 ha. of which were used for growing wheat. The farm's most northerly point adjoins the wadi Chafrou but the boundary south from this point rises steeply following the successive crests of the djebel Djerifel (120 m.). These hills together with their counterpart, the djebel Mergueb, on the right bank of the Chafrou form the narrow gateway dividing the plain of Furna/Mornaghia from the Chafrou High Plain.

The Centre is rather higher than Centre 03 - 79.2 m. - and its mean gradient is much greater. Water is locally available, collecting in aquifers from the djebel Djerifel, and two large wells provided water to irrigate 15 ha. of the farm.

The soils are formed from pliocene or quarternary alluvium; lenses of limestone, marls and sandstone are found. The farm evaluation speaks of the plain soils (flat to gently inclined) as being silty alluvium; 'sensitive to a too small rainfall but also fearing locally an excess of moisture'. Shortly before 1960 this latter land was drained.

Off the plain the soils were of poorer quality, the worst 16 ha. being described as very shallow and mediocre with tuff outcrops. But overall the land was described as being; 'among the good soils of the region'.

In the southern part of the property 44 ha. had been levelled to form wide terraces; one indication why the farmer enjoyed the high reputation which he did. He was referred to as a standard in the farm studies done by the SBAT particularly, however, for soft wheat.

The hard wheat yields were high (mean 11.5 ql/ha.) but the standard deviation of 6.4 was the highest in the study area. It is unlikely that this is all due to the climate,particularly on a well managed farm. The crop may have suffered unduly in years when sowing or harvest conditions were bad, because it took second place after the needs of a very large area of soft wheat had been catered for.

At any rate, Table 88, only a 2.5% level of significance was attained with 82% of the total variation explained. The result is made even more suspect because of the very high contribution to yield of the July rainfall.

On the other hand the yields of soft wheat are perfectly explained in terms of the rainfall of the crop year, and its distribution, and the climate of May. The contribution of the total September/May rainfall variable plays a contrasting role in the hard and soft wheat analyses. In both cases the heaviest totals were detrimental to yield but the effect was much more pronounced for the soft wheat: Table 89.

It will be seen that in the exposed central-southern area of the LMV, which includes Centre 04, the Centres are all strongly affected by the May climate, especially the temperature maxima of mid-May. This effect is exaggerated where, as in

Table 88. Centre 04. Hard Wheat.
Relationship Between Climate and Wheat Yields.

Yield Statistics 1948/49 to 1960/61

Mean: 11.5 ql/ha. S.D.: 6.4 C.V.: 55.8
Min.: 2.3 ql/ha.(1961)
Max.: 26.3 ql/ha.(1950)

Multiple Regression

Step	Variable Entered	Explanation % By Step	Explanation % Total	R adj.for df	F	SEE of Yield adj.for df
1	R.July	43.9	43.9	0.66	8.6	5.03
2	T.mid May	16.5	60.4	0.75	7.6	4.63
3	R.May	5.3	65.7	0.77	5.7	4.77
4	R.S/May Q	5.0	70.7	0.78	4.8	4.93
5	R.F/Apr L	11.1	81.8	0.85	6.3	4.40

F(calc: 5 & 7 df) = 6.3
F(2.5%: 5 & 7 df) = 5.3

$$Y = a + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4^2 + b_5X_5$$

Regression Coefficients

	b-coef(x 10^4)	SEE(x 10^4)	t-value
b_1	4630.9	1514.8	3.1
b_2	-6351.9	2289.5	2.8
b_3	1110.0	495.0	2.2
b_4	-0.4	0.2	2.5
b_5	723.5	349.6	2.1

a = 11.986

Table 89. Centre 04. Soft Wheat.
Relationship Between Climate and Wheat Yields.

Yield Statistics 1948/49 to 1960/61

Mean: 13.4 ql/ha. S.D.: 5.3 C.V.: 39.6
Min.: 5.7 ql/ha.(1956)
Max.: 22.3 ql/ha.(1950)

Multiple Regression

Step	Variable Entered	Explanation % By Step	Explanation % Total	R adj.for df	F	SEE of Yield adj.for df
1	T.mid-May	43.7	43.7	0.66	8.5	4.17
2	R.S/May Q	43.2	86.8	0.93	33.0	2.21
*3	R.Jan	9.2	96.1	0.98	73.3	1.34
*4	R.May	1.7	97.7	0.99	85.7	0.98

F(calc: 4 & 8 df) = 85.7
F(0.1%: 4 & 8 df) = 14.4

$$Y = a + b_1X_1 + b_2X_2^2 + b_3X_3 + b_4X_4$$

Regression Coefficients

	b-coef(x 10^4)	SEE(x 10^4)	t-value
b_1	-8104.3	547.8	14.8
b_2	-0.4	0.	13.3
b_3	479.5	82.9	5.8
b_4	318.2	132.2	2.4

a = 32.069

* of possible indicative value only

Centre 04, the climate is on the dry side and the soils are sensitive to low rainfalls because they drain easily or dry quickly.

<u>Centre 05</u>. There was one Farm Group in Centre 05, Bordj el Khalsi, incorporating nine farms with a total of 957 ha. Just over 150 ha. were planted and practically all the rest was ploughed for cereals. The mean height of the Centre - 66 m. - is the same as for Centre 03 which is adjacent to it. However the mean gradient is considerably greater because the Centre is on the top of rolling hills, including several low summits divided by <u>wadis</u>, overlooking the plain of Furna/Mornaghia and the lower Chafrou valley. Unlike all the other Centres considered so far, no part of Centre 05 lies on a plain or shallow syncline.

The soils are similar to those of Centre 03 in origin but because of the hilly terrain they are less deep or even strongly eroded. The farm evaluations mention that some are siliceous or have tuff outcrops but Centre 05 does contain some good soil.

Not surprisingly the land is very short of water. The evaluations mention only one well between all the farms and that yielding brackish water.

For hard wheat the variables which give the best explanation of yield variation do not include mid-May temperature, although individually it is very important. The emphasis is on rainfall of January and spring of the crop year, high in the former and moderate in the latter, and the distribution of rainfall in the spring and summer of the fallow year: Table 90.

For soft wheat again the emphasis is on the crop year but in addition to January rainfall it is the mid-May temperature which plays the critical role: Table 91.

Table 90. Centre 05. Hard Wheat.
Relationship Between Climate and Wheat Yields.

Yield Statistics 1948/49 to 1960/61

Mean: 7.6 ql/ha. S.D.: 3.4 C.V.: 45.1
Min.: 2.8 ql/ha.(1961)
Max.: 13.1 ql/ha.(1950)

Multiple Regression

Step	Variable Entered	Explanation % By Step	Explanation % Total	R adj.for df	F	SEE of Yield adj.for df
1	R.Jan	52.2	52.2	0.72	12.0	2.47
2	R.F/Apr L	16.3	68.4	0.81	10.8	2.20
*3	R.July	8.1	76.6	0.88	9.8	2.09
*4	R.F/Apr Q	5.3	81.9	0.87	9.0	2.06
*5	R.Apr(fa) Q	11.4	93.2	0.95	19.3	1.43

F(calc: 5 & 7 df) = 19.3
F(0.1%: 5 & 7 df) = 16.2

$$Y = a + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4^2 + b_5X_5^2$$

Regression Coefficients

	b-coef(x 10^4)	SEE(x 10^4)	t-value
b_1	255.3	146.0	1.8
b_2	1751.9	385.9	4.5
b_3	1362.5	807.7	1.7
b_4	-5.1	1.4	3.7
b_5	-3.4	1.0	3.4

a = -6.043

* of possible indicative value only

Table 91. Centre 05. Soft Wheat.
Relationship Between Climate and Wheat Yields.

Yield Statistics 1948/49 to 1960/61

Mean: 8.3 ql/ha. S.D.: 3.7 C.V.: 44.1
Min.: 3.3 ql/ha.(1961)
Max.: 15.6 ql/ha.(1950)

Multiple Regression

Step	Variable Entered	Explanation % By Step	Explanation % Total	R adj.for df	F	SEE of Yield adj.for df
1	R.Jan	48.8	48.8	0.70	10.5	2.73
2	T.mid-May	21.8	70.6	0.82	12.0	2.27
*3	R.July	9.1	79.7	0.87	11.8	2.08
*4	R.D/Mar(fa) Q	7.8	87.5	0.91	14.0	1.83

F(calc: 4 & 8 df) = 14.02
F(0.5%: 4 & 8 df) = 8.81

$$Y = a + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4^2$$

Regression Coefficients

	b-coef(x 10^4)	SEE(x 10^4)	t-value
b_1	227.8	190.6	1.2
b_2	-3518.1	845.8	4.2
b_3	3398.0	1095.9	3.1
b_4	-0.4	0.2	2.2

a = 14.441

* of possible indicative value only

Centre 06. The Centre 06 is situated on the flood plain of the Medjerda (Fig.26, p. 314), only a short distance from the river itself. It includes two Farm Groups, Chaouat I and Chaouat II, with partially different features: Pte. 3, p. 73.

Chaouat II comprised 14 farms totalling 1,390 ha. practically all of which were used for growing cereals. The farms lay entirely on the flood plain of the river where they were, to the naked eye, on entirely level ground. The soils are alluvial of very recent deposition. The water table is high, especially in winter when it can rise to the surface in a wet year, and both water and soil are saline.

The farm evaluations speak of the soil as being flat, deep and usually containing a highish clay content which though normally good for cereals makes the soils difficult to work when they are too dry or too wet. Very high yields are also prevented by the salinity of the soil. A good 'washing' with an occasional rainstorm (CRUESI, 1969) is thought good for such soils. Heavy rain may tend to increase yield by washing salt from the soil but decrease yield by leaching nitrogen, and water-logging the land.

Many of the farms had wells which gave a lot of brackish to saline water.

The dominant feature of Chaouat I is the djebel Chaouat (114 m.). The upper slopes, about 180 ha., were mostly planted with olives and vines or uncultivated, leaving 575 ha. under cereals. The lower slopes of the hill had thin, calcareous, hamri soils often eroded to expose tuff outcrops. Yields were not very good. The flatter low-lying land had the same characteristics as Chaouat II.

The controlling importance of the climate is mentioned several times in the farm evaluations of Centre 06. The general position is established by one comment which reads; 'the yields of wheat are very irregular - harvest nil in a drought year (1951 & 1955) because of the very clayey nature of the plain - poor harvest in years of excessive rain (1954): flooding'. In 1953/54 the area sown on many of the farms was considerably reduced because the ground became inundated after the heavy rain of autumn. The land remained saturated for months. But that year a major drainage canal prevented a similar occurrence in future years. However in 1958/59 pressure on the Medjerda dam was relieved by suddenly opening the sluices which caused temporary flooding of some land that had already been sown.

The effect of mid-May temperatures was here less strong than in the more southerly Centres. For both hard wheat and soft wheat the variables which best explain variation in yield, Tables 92 and 93, are measures of the quantity and distribution of the rainfall of the crop year. There is one important difference between the responses of the two wheats. The yield of soft wheat is less strongly helped by high rainfall of January and of May and is limited more severely by very large September/May rainfall totals. Again this is expected of soft wheats which require less rainfall and more nitrogen.

Centre 07. This Centre includes only one Farm Group, Ain Ghelal; two farms totalling 650 ha. The Centre lies at the western extremity of the plain of Mabtouha. It is mostly on flat, alluvial land but does extend into the hills bordering the plain, following the middle course of the small, temporary wadi, el Mellaha. This wadi does not flow into the Medjerda but drains its saline

Table 92. Centre 06. Hard Wheat.
Relationship Between Climate and Wheat Yields.

Yield Statistics 1948/49 to 1960/61

Mean: 11.0 ql/ha. S.D.: 4.2 C.V.: 38.4
Min.: 4.4 ql/ha.(1961)
Max.: 16.9 ql/ha.(1950)

Multiple Regression

Step	Variable Entered	Explanation % By Step	Explanation % Total	R adj.for df	F	SEE of Yield adj.for df
1	R.May	47.1	47.1	0.69	9.8	3.20
2	R.Jan	20.7	67.8	0.81	10.5	2.73
*3	R.S/May L	3.3	71.0	0.81	7.4	2.86
*4	R.S/May Q	15.8	86.8	0.91	13.3	2.16

F(calc: 4 & 8 df) = 13.2
F(0.5%: 4 & 8 df) = 8.8

$$Y = a + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_3^2$$

Regression Coefficients

	b-coef(x 10^4)	SEE(x 10^4)	t-value
b_1	1030.0	359.8	2.9
b_2	444.8	143.8	3.1
b_3	690.8	209.1	3.3
b_4	-9.7	0.2	3.1

a = -11.532

* of possible indicative value only

Table 93. Centre 06. Soft Wheat.
Relationship Between Climate and Wheat Yields.

Yield Statistics 1948/49 to 1960/61

Mean: 10.7 ql/ha. S.D.: 4.4 C.V.: 41.5
Min.: 2.2 ql/ha.(1961)
Max.: 16.4 ql/ha.(1957)

Multiple Regression

Step	Variable Entered	Explanation % By Step	Explanation % Total	R adj.for df	F	SEE of Yield adj.for df
1	R.May	42.6	42.6	0.65	8.2	3.52
2	R.Jan	13.4	56.1	0.72	6.4	3.37
3	R.S/May L	2.6	58.7	0.71	4.3	3.61
4	R.S/May Q	30.4	89.1	0.92	16.3	2.08

F(calc: 4 & 8 df) = 16.33
F(0.1%: 4 & 8 df) = 14.4

$$Y = a + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_3^2$$

Regression Coefficients

	b-coef(x 10^4)	SEE(x 10^4)	t-value
b_1	901.6	346.1	2.6
b_2	373.3	138.3	2.7
b_3	984.1	201.1	4.9
b_4	-1.0	0.2	4.7

a = -17.251

waters to a marsh within the Centre itself. In the winter of very wet years the marsh area expands and the cultivable area contracts.

The flat land adjoining the marsh is also saline and of poorish quality; coarse, calcareous alluvium. On the other hand the hill soils though mostly deep enough are light and red (hamri). A poor cereal area.

The one strong point of the region was its situation - well sheltered, by hills to the south and east (Fig. 26 , p. 314) and by its northerly location - which protects it from the hot Saharan winds of May.

In these strongly saline conditions it is difficult to say whether a period of heavy rain would do more good by leaching salt and providing a reserve of water, or harm by leaching nitrogen and water-logging the soil. As the Centre is wetter than those discussed so far, with the exception of Centre 01, the soil of poor quality and the May temperatures not severe, it is likely that moderate rainfalls and factors promoting nitrification would be required for high yields. In fact the yields were rarely high. The means of both soft and hard wheat yields were the lowest of all the Centres.

With these unique features it is not surprising that the correlation of yield with individual variables is extremely atypical.

For both hard and soft wheat a high January rainfall and a moderate rainfall in the crop year are shown in the analyses, Tables 94 and 95, to be important. In addition, for hard wheat, high rainfall in April and July of the fallow year are beneficial but for soft wheat a moderate spring rainfall of the

Table 94. Centre 07. Hard Wheat.
Relationship Between Climate and Wheat Yields.

Yield Statistics 1948/49 to 1960/61

Mean: 7.5 ql/ha. S.D.: 2.8 C.V.: 37.4
Min.: 3.4 ql/ha.(1959)
Max.: 14.1 ql/ha.(1950)

Multiple Regression

Step	Variable Entered	Explanation % By Step	Explanation % Total	R adj.for df	F	SEE of Yield adj.for df
1	R.July	50.1	50.1	0.71	11.0	2.07
2	R.S/May Q	16.3	66.4	0.80	9.9	1.86
3	R.Jan	13.0	79.5	0.87	11.6	1.61
*4	R.Apr(fa) L	15.1	94.5	0.96	34.5	0.93
*5	R.S/May L	1.5	96.0	0.97	33.9	0.90
*6	T.mid-May	1.4	97.5	0.98	38.6	0.83

F(calc: 6 & 6 df) = 38.6
F(0.1%: 6 & 6 df) = 20.0

$$Y = a + b_1X_1 + b_2X_2^2 + b_3X_3 + b_4X_4 + b_5X_2 + b_6X_5$$

Regression Coefficients

	b-coef(x 10^4)	SEE(x 10^4)	t-value
b_1	1008.4	627.0	1.6
b_2	-0.5	0.1	3.3
b_3	502.0	90.5	5.6
b_4	164.8	91.1	1.8
b_5	429.8	165.3	2.6
b_6	1529.3	824.2	1.9

a = -7.229

* of possible indicative value only

Table 95. Centre 07. Soft Wheat.
Relationship Between Climate and Wheat Yields.

Yield Statistics 1948/49 to 1960/61

Mean: 5.8 ql/ha. S.D.: 2.8 C.V.: 47.5
Min.: 2.5 ql/ha.(1951)
Max.: 11.1 ql/ha.(1957)

Multiple Regression

Step	Variable Entered	Explanation % By Step	Explanation % Total	R adj.for df	F	SEE of Yield adj.for df
*1	R.Jan	41.8	41.8	0.65	6.5	2.23
*2	R.S/May Q	11.9	53.8	0.73	4.7	2.22
*3	R.A/May Q	15.2	69.0	0.78	5.2	2.06
*4	R.S/May L	6.7	75.7	0.81	4.7	2.11
*5	R.May	8.4	84.0	0.86	5.3	2.02

F(calc: 5 & 5 df) = 5.27
F(5.0%: 5 & 5 df) = 5.05

$$Y = a + b_1X_1 + b_2X_2^2 + b_3X_3^2 + b_4X_2 + b_5X_4$$

Regression Coefficients

	b-coef(x 10^4)	SEE(x 10^4)	t-value
b_1	1340.5	355.1	3.8
b_2	-0.9	0.4	2.5
b_3	3.8	1.3	2.9
b_4	682.6	316.5	2.2
b_5	-841.7	519.6	1.6

a = -14.496

* of possible indicative value only

crop year is emphasised. Unfortunately the reduced number of observations for soft wheat, eleven, makes the analysis of indicative interest only.

Centre 08. Only one Farm Group, Kabouti/Ressas, comprising 2,025 ha. divided between four farms, is included in Centre 08.

The Centre is situated in the south-east corner of the LMV (Fig. 26, p. 314) astride the middle valley of the wadi el Hamma. In contrast with the previous Centre the wadi contains good quality water and, flowing along a well defined bed, empties its waters without danger of flooding into the river Miliane.

The Centre is the second highest in the study area and has one of the steepest gradients and highest rainfalls. In all three factors it is surpassed by Centre 11 which lies directly to the north of it. But although rainfall and its surrounding hills give it some protection from the sirocco it lies just north of the gap in the Dorsale through which the Saharan winds penetrate most easily (Fig. 27, p. 327) to the north of the country.

Of the 2,025 ha., 580 ha. were too mountainous to be cultivated and a further 385 ha. were planted with olives and vines leaving the rest for cereals. Some of the slopes had been terraced. The soils of these slopes were described as either 'mediocre' or 'better quality but not impressive' in the farm evaluations. The flatter land in the northern half of the Centre was more suited to growing cereals.

Although overall there was little available ground water, the water that was found was of good quality and locally plentiful; used to irrigate a few hectares. Salinity was not a problem.

For hard wheat no single rainfall variable correlated very strongly with yield. The strongest individual correlations were given by mid-May temperatures, reflecting the southerly position of the Centre, and by the mean temperature of January/April. However the best explanation of yield is given by mid-May temperatures, Table 96, in combination with six rainfall variables which cover the distribution of rainfall in the crop year and the latter part of the fallow year. The only periods when higher than average rainfall seem to be required in this wet region are January and February/April of the crop year. Although these variables together account for 92% of the total variation the explanation is spread over so many factors that the level of significance is reduced. In addition there is no group of two or three variables accounting for a high proportion of the variation between them. The result, therefore, is at best indicative throughout.

As far as soft wheat was concerned several combinations of variables explained up to 80% of the total variation but this was with complete loss of significance for both the correlation coefficient and the t-values for the regression coefficients.

Centre 09. Centre 09 again consists of one Farm Group, Sidi Bou Douib. Its five farms total 800 ha., mostly used for cereal cultivation or grazing.

Although the Centre is high - mean of 93.6 m. - it is at the lowest point of the southern border of the LMV, apart from the narrow Medjerda corridor: Figure 26, (p. 314). Its relatively slight gradient reflects the fact that it is exposed - not under the shelter of any hills - and forms a principal gateway through which the Saharan sirocco penetrate the LMV (Fig. 27, p. 327) after crossing the low and narrow eastern part of the Dorsale.

Table 96. Centre 08. Hard Wheat.
Relationship Between Climate and Wheat Yields.

Yield Statistics 1948/49 to 1960/61

Mean: 10.0 ql/ha. S.D.: 4.2 C.V.: 42.0
Min.: 3.5 ql/ha.(1960)
Max.: 15.4 ql/ha.(1953)

Multiple Regression

Step	Variable Entered	Explanation % By Step	Explanation % Total	R adj.for df	F	SEE of Yield adj.for df
1	T.mdi-May	33.5	33.5	0.58	5.6	3.56
2	R.May	11.3	44.8	0.63	4.1	3.55
3	R.F/Apr L	11.2	56.0	0.69	3.8	3.51
4	R.S/May L	8.1	64.2	0.72	3.6	3.54
5	R.Apr(fa) L	7.8	72.0	0.76	3.6	3.55
6	R.July	10.9	82.9	0.84	4.8	3.20
7	R.Jan	9.5	92.4	0.92	8.7	2.52

F(calc: 7 & 5 df) = 8.70
F(2.5%: 7 & 5 df) = 6.85

$$Y = a + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + b_5X_5 + b_6X_6 + b_7X_7$$

Regression Coefficients

	b-coef(x 10^4)	SEE(x 10^4)	t-value
b_1	-5649.6	1465.4	3.9
b_2	-1255.2	848.4	3.6
b_3	978.5	178.3	5.5
b_4	-484.8	115.0	4.2
b_5	-990.0	242.5	4.1
b_6	-3463.1	962.0	3.6
b_7	641.5	255.9	2.5

a = 30.041

The eastern border of the Centre is formed by the wadi Miliane. It is the river which has laid down the sandy, alluvial deposits from which the soils are formed. These soils are mostly light, hamri, calcareous or sandy. Land lying adjacent to the Miliane is described in the farm evaluations as; 'relief; plateau descending towards the wadi Miliane, cut by depressions and several deep ravines'.

The region was reputed by the farm evaluations to be; 'a cereal sector of very average reputation'. The best farm of the Centre, described as; 'of good quality for the sector', owed its quality not only to its heavier soils and flat land but also to the farming standards of the family who held it for 30 years. It was reported that: 'In normal period there was a double speculation; cereal cultivation and stock raising. The fields were regularly provided with fertiliser and manure from the livestock of the farm'.

On the light soil, fully exposed to high temperatures of May, and in one of the driest parts of the LMV, the Centre tended to be very short of water in the last half of the growing season.

The analysis shows that the crucial period of the growth season was the month of May. Low rainfall and high temperatures in May ensured a poor yield no matter what rainfall had fallen in the previous months.

The best explanation of yield variation of hard wheat, Table 97, is given by May temperature maxima (60% of total), July rainfall and the overall rainfall of the growing season, September/May. After taking out the explanation given by the mid-May temperatures the analysis indicates that lower than

Table 97. Centre 09. Hard Wheat.
Relationship Between Climate and Wheat Yields.

Yield Statistics 1948/49 to 1960/61

Mean: 6.6 ql/ha. S.D.: 3.2 C.V.: 49.0
Min.: 1.6 ql/ha.(1960)
Max.: 12.0 ql/ha.(1953)

Multiple Regression

Step	Variable Entered	Explanation % By Step	Explanation % Total	R adj.for df	F	SEE of Yield adj.for df
1	T.mid-May	59.8	59.8	0.77	16.3	2.13
2	R.July	25.0	84.7	0.91	27.7	1.44
*3	R.S/May L	8.3	93.0	0.96	40.0	1.07
*4	R.S/May Q	2.3	95.4	0.97	41.1	0.98

F(calc: 4 & 8 df) = 41.10
F(0.1%: 4 & 8 df) = 14.4

$$Y = a + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_3^2$$

Regression Coefficients

	b-coef(x 10^4)	SEE(x 10^4)	t-value
b_1	-8551.3	992.9	8.6
b_2	2939.7	497.3	5.9
b_3	-414.1	164.0	2.5
b_4	0.3	0.2	2.0

a = 22.710

* of possible indicative value only

Table 98. Centre 09. Soft Wheat.
Relationship Between Climate and Wheat Yields.

Yield Statistics 1948/49 to 1960/61

Mean: 6.7 ql/ha. S.D.: 3.4 C.V.: 50.8
Min.: 1.0 ql/ha.(1960)
Max.: 11.6 ql/ha.(1953)

Multiple Regression

Step	Variable Entered	Explanation % By Step	Explanation % Total	R adj.for df	F	SEE of Yield adj.for df
1	T.Jan/Apr	70.9	70.9	0.84	26.7	1.89
2	T.mid-May	15.6	86.5	0.92	31.9	1.41
*3	T.25 May	3.8	90.3	0.94	28.0	1.32
*4	R.July	3.2	93.5	0.96	28.9	1.20
*5	R.D/Mar(fa) Q	2.8	96.4	0.97	37.2	1.02

F(calc; 5 & 7 df) = 37.19
F(0.1%: 5 & 7 df) = 16.2

$$Y = a + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + b_5X_5^2$$

Regression Coefficients

	b-coef(x 10^4)	SEE(x 10^4)	t-value
b_1	-6104.1	1141.0	5.4
b_2	-3315.5	559.9	5.9
b_3	6016.3	1622.9	3.7
b_4	1511.6	528.2	2.9
b_5	-0.2	0.1	2.3

a = 43.523

* of possible indicative value only

average seasonal rainfall correlates with higher yields.

With soft wheat there is again a very high correlation between yield and mid-May temperature maxima - explaining 50% of the variation - but the correlation between yield and the mean January/April temperature, Table 98, is even higher. As explained above this is a general climatic measure, implying grey skies and higher than average rainfall from January to April. These factors account for 70.9% of the variation. In addition May temperatures also play an important role as, it is indicated, might the rainfall of the spring and summer of the fallow year. For both hard and soft wheat the level of explanation is well in excess of the 0.1% level.

Centre 10. Centre 10 consists of three Farm Groups; 14 farms totalling 2,100 ha. The Farm Groups - Attar, Bordj Chakir and Mohammedia - lie in the hilly country to the south and south-west of the sebkhet es Sedjoumi. They are rather higher and have a slightly steeper gradient than the average with little flat land although the southern part of Mohammedia does extend onto the northern edge of the Chafrou valley High Plain. Above 300 ha. were uncultivated hill crests - used for grazing - and 550 ha. were planted with fruit trees.

The farm evaluations indicate that the soils were average to good quality for wheat cultivation. The flatter fields had deep soils which contained sufficient clay to be retentive of the above average rainfall. The largest farm, 507 ha., which was also the best, was described as having; 'soils fairly rich in clay, especially in the valley, of good quality. Well cultivated and giving good yields particularly as a result of the rational rotation followed and the use of appropriate fertilisers

Here the correlation of yield with mid-May temperature is high but not so high as in the Centres to the south of it.

For hard wheat yield variation is best explained, Table 99, in terms of rainfall variables covering both fallow and crop years. The fallow retains useful water in winter but then requires a dry spring. In the crop year there is a strong linear response to higher September/May rainfall though this can be in excess. Moderate rainfall is needed in the spring of the growth year.

On the other hand it seems that soft wheat suffers as much from excess as from shortage of rain in the crop year, Table 100, and, it is indicated, seems actually to require low rainfall in May. As with Centre 09 the January/April period is best defined in terms of the mean temperature. Temperature maxima of mid-May enter strongly into the regression.

Centre 11. Centre 11 is the Farm Group of Creteville, named after the French family, Crete, who owned one of the two largest farms in the region; 725 ha. Members of the Crete family were known for their succes in selecting improved varieties of vines and developing methods of cultivating them. Creteville lies at the eastern end of the plain of Mornag, one of the most important vine growing regions in Tunisia.

Although the Centre is large, totalling 2,370 ha., roughly half of this total consisted of the south-eastern face of the djebel Bou Kournine which rises steeply to nearly 500 m. This mountainous area was uncultivated woodland or rough pasture. Another 1,000 ha. were planted with vines leaving some 340 ha. for cereal land.

The whole of the lower-lying flatter land is extremely

Table 99. Centre 10. Hard Wheat.
Relationship Between Climate and Wheat Yields.

Yield Statistics 1948/49 to 1960/61

Mean: 11.0 ql/ha. S.D.: 2.9 C.V.: 26.5
Min.: 7.1 ql/ha.(1959)
Max.: 15.5 ql/ha.(1950)

Multiple Regression

Step	Variable Entered	Explanation % By Step	Explanation % Total	R adj.for df	F	SEE of Yield adj.for df
1	R.Apr(fa) L	30.2	30.2	0.55	4.8	2.55
2	R.F/apr Q	18.2	48.4	0.66	4.7	2.40
3	R.S/May L	23.6	72.0	0.82	7.7	1.96
4	R.D/Feb(fa)Q	21.1	94.0	0.96	31.6	1.01
*5	R.S/May Q	3.1	97.2	0.98	47.9	0.79

F(calc: 5 & 7 df) = 47.85
F(0.1%: 5 & 7 df) = 16.2

$$Y = a + b_1X_1 + b_2X_2^2 + b_3X_3 + b_4X_4 + b_5X_3^2$$

Regression Coefficients

	b-coef(x 10^4)	SEE(x 10^4)	t-value
b_1	-232.4	47.9	4.9
b_2	-0.8	0.1	5.8
b_3	342.5	74.3	4.6
b_4	137.1	23.4	5.9
b_5	-0.2	0.1	2.8

a = 1.297

* of possible indicative value only

Table 100. Centre 10. Soft Wheat.
Relationship Between Climate and Wheat Yields.

Yield Statistics 1948/49 to 1960/61

Mean: 12.9 ql/ha. S.D.: 3.9 C.V.: 29.9
Min.: 6.5 ql/ha.(1959)
Max.: 18.4 ql/ha.(1952)

Multiple Regression

Step	Variable Entered	Explanation % By Step	Explanation % Total	R adj.for df	F	SEE of Yield adj.for df
1	T.Jan/Apr	44.3	44.3	0.67	8.8	3.00
2	R.S/May Q	17.4	61.7	0.76	8.1	2.61
3	T.mid-May	26.7	88.5	0.93	23.0	1.66
*4	R.May	6.6	95.0	0.97	38.4	1.21
*5	T.25 May Q	2.0	97.0	0.98	45.4	1.07
*6	R.S/May L	0.9	97.9	0.98	47.1	1.02

F(calc: 6 & 6 df) = 47.12
F(0.1%: 6 & 6 df) = 20.0

$$Y = a + b_1X_1 + b_2X_2^2 + b_3X_3 + b_4X_4 + b_5X_5^2 + b_6X_2$$

Regression Coefficients

	b-coef(x 10^4)	SEE(x 10^4)	t-value
b_1	-9245.0	1423.7	6.5
b_2	-0.3	0.1	2.9
b_3	-4717.3	593.9	7.9
b_4	-636.8	152.4	4.2
b_5	-363.8	138.5	2.6
b_6	207.3	127.8	1.6

a = 70.278

* of possible indicative value only

rich in water containing only a very low concentration of dissolved salts. It is this water which is the key explaining the succes of the Mornag/Creteville vineyards. In addition Creteville is in one of the wettest regions of the LMV.

The soils, as described in the evaluations, are of mixed quality. The upper plain, at the foot of the mountain, has fairly light, even stony, soils but in the plain proper the soils are much more compact; composed of fine silts.

The Centre has mountains to the north, east and south (the djebel Ressas - 795 m. - to the south, is the highest point of the LMV); the cultivable land slopes down to the west.

The wheat yields, Table 67 (p. 315), were the highest of all the Centres.

In this sheltered area it is not surprising that the correlation of yield with May temperatures is negligible. Although for both hard wheat and soft wheat high levels of explanation of yield variation are given by the rainfall variables in combination it is only with complete loss of significance.

Centre 12. Centre 12, the Farm Group, Sidi Fredj, includes 2,255 ha. All but 350 ha. were ploughed for cereal cultivation. The Centre lies just north of Centre 09 in the eastern half of the Chafrou High Plain whose characteristics were examined in chapter 3.3 (p. 83). But although it lies 56 m. above sea level it is almost completely flat, having the lowest gradient of all the Centres. The soil is 'grey', formed from quarternary alluviums; described as calcareous clay in the farm evaluations. The water table is high, especially in winter, and very saline. In wet years the water table could rise to the surface in the lowest parts of the Centre.

The High Plain is a wide shallow basin which heats rapidly and is as exposed as Centre 09 to the sirocco.

For both hard and soft wheat, Tables 101 and 102, nearly all the yield variation can be explained with the mid-May temperature maxima playing the dominant role. They are rather more important for the hard wheat, which is as expected following the climatic study in chapter 8 (F/A tending to mature before the mid-May sirocco).

Once again the other variables entered into the regression may indicate the susceptibility of soft wheat to the heaviest rains. As before the most likely explanation for this is leaching nitrogen salts; in this comparatively dry area the risk of water-logging soils is not very great except locally in the wettest of years.

Table 101. Centre 12. Hard Wheat.
Relationship Between Climate and Wheat Yields.

Yield Statistics 1948/49 to 1960/61

Mean: 9.4 ql/ha. S.D.: 4.3 C.V.: 45.7
Min.: 2.8 ql/ha.(1960)
Max.: 15.2 ql/ha.(1953)

Multiple Regression

Step	Variable Entered	Explanation % By Step	Explanation % Total	R adj.for df	F	SEE of Yield adj.for df
1	T.mid-May	74.2	74.2	0.86	28.7	2.28
2	R.May	6.0	80.1	0.88	18.1	2.21
*3	T.25 May Q	4.8	84.9	0.90	15.0	2.15
*4	R.Jan	8.6	93.5	0.95	25.1	1.61
*5	R.July	2.8	96.3	0.97	30.8	1.40

F(calc: 5 & 6 df) = 30.84
F(0.1%: 5 & 6 df) = 20.8

$$Y = a + b_1X_1 + b_2X_2 + b_3X_3^2 + b_4X_4 + b_5X_5$$

Regression Coefficients

	b-coef(x 10^4)	SEE(x 10^4)	t-value
b_1	-2419.6	846.7	2.9
b_2	1394.8	291.7	4.8
b_3	3008.7	617.4	4.9
b_4	840.2	196.9	4.3
b_5	-2257.6	1070.3	2.1

a = 2.417

* of possible indicative value only

Table 102. Centre 12. Soft Wheat.
Relationship Between Climate and Wheat Yields.

Yield Statistics 1948/49 to 1960/61

Mean: 10.0 ql/ha. S.D.: 5.1 C.V.: 51.3
Min.: 1.2 ql/ha.(1960)
Max.: 16.5 ql/ha.(1950)

Multiple Regression

Step	Variable Entered	Explanation % By Step	Explanation % Total	R adj.for df	F	SEE of Yield adj.for df
1	T.mid-May	69.3	69.3	0.83	24.8	2.97
2	T.Jan/Apr	13.1	82.3	0.90	23.3	2.47
*3	R.S/May Q	9.1	91.5	0.95	32.2	1.90
*4	T.25 May Q	4.0	95.4	0.97	41.7	1.55
*5	R.May	1.1	96.5	0.97	38.8	1.54
*6	R.A/May Q	1.8	98.3	0.99	58.1	1.24

F(calc: 6 & 6 df) = 58.12
F(0.1%: 6 & 6 df) = 20.0

$$Y = a + b_1X_1 + b_2X_2 + b_3X_3^2 + b_4X_4^2 + b_5X_5 + b_6X_6^2$$

Regression Coefficients

	b-coef(x 10^4)	SEE(x 10^4)	t-value
b_1	-5956.2	686.3	8.7
b_2	-6452.5	1309.4	4.9
b_3	-0.1	0.	1.6
b_4	645.6	155.0	4.2
b_5	565.4	183.8	3.1
b_6	-1.7	0.7	2.5

a = 54.817

* of possible indicative value only.

10.6 Conclusions.

Difference Between Years. The yields of both soft and hard wheat declined in the latter half of the 1950's and the early 1960's. Analysis of variance showed that the drop in yields was highly significant. However when the explanation of yield variation due to climatic factors was removed, a second analysis of variance showed that there was no longer any significant difference of yield between years. The decline could be explained entirely on climatic grounds.

This result, added to the conclusions drawn from chapter 7 (pp. 238-246), shows that there is no evidence to suggest that there was a deterioration of farming standards by the colonists in the post-war period. The result also underlines the importance of the climate in determining yields from year to year and stresses the dominant role played by the temperatures of mid-May

In an economic study of controllable factors and yield one could not dismiss variation due to climatic fluctuation into the 'error' column of the conclusions. Even over a longer period of time this would hold true because the volume and distribution of rainfall does not appear to fluctuate at random but in an irregular periodic manner (discussed in ch. 3.1, pp. 55-61). A gradual growth or decline in yields might be better explained in terms of climate than by changes in farming practice.

Differences Between Centres. The analysis of variance, after removing the explanation of yield given by climate, throws into strong relief the difference between Centres. For example the Centres with the highest yields included Centres 11 and 10, which were two of the wettest Centres, and Centres 04 and 02 which were in the driest parts of the LMV. On the other hand the lowest yielding Centres included 03, 05 and 09 which were among the driest, while the lowest of all yields were in Centre 07 which was wet but saline and marshy.

These differences show that climate is not the only factor to be taken into consideration. The other important factors might include the quality of the soil and the water, and the standard of farm management. But, on the side of climate, the role of temperature may have been obscured and diminished because of the nature of the data. A more complete temperature record would further contribute to the explanation of yield differences between Centres. These three factors - soil/water, management and temperature - are discussed below.

For soil, the farm evaluations and the topographical maps of the LMV indicate that its quality is important. One example is the difference in yield between the adjacent Centres 03 and 05. Broadly speaking Centre 03 occupies a long shallow syncline with some deep soil of average to good quality while Centre 05 is astride a series of eroded hills. The yields from the two Centres clearly reflect this difference in soil quality.

Centre 07, which had the worst yields, included a saline marsh in its midst; a marsh whose borders expanded onto the cereal land in wet years. The soil on the land next to the marsh was also saline.

On the other hand Centre 11, which had the highest mean yields, contained much good, silty soil with a water table which was both high (but without danger of water-logging the soil) and completely free of salt. The Centre is in a region famous for its vines, which is an indication of the quality of the soil and water.

Management may have played an important role in obtaining the high yields of Centre 02. In terms of soil quality one would expect the yields of the Centre 02 to be higher than those of Centre 03, although the former lies in a slightly drier and more exposed region. But the difference is perhaps too great to be explained by soil quality alone especially as Centre 02 had one of the highest mean yields of all the Centres.

The two largest farms of Centre 02, which together formed the Farm Group of Montarnaud, had the largest area of wheat and the best yields. Both farms had established very good reputations in Tunisia for the quality of their farming, particularly the farm of Montarnaud itself.

In this case it may well be that the relatively low level of significance of yield explanation by climate (0.5% level for hard wheat and 2.5% level for soft wheat) indicates that the skilled and rigorous use of the most suitable methods of cereal cultivation on these farms made them relatively independent of the climate's control.

It is likely that May temperature maxima explain more of the sub-regional yield differences than has been revealed in the analysis. Only one temperature record was available for the whole of the LMV. But although it was argued that this should be sufficient it is clear from the dominant role of mid-May temperature maxima and from the strong sub-regional patterning of correlation between yield and temperature that one record is inadequate.

There is an apparent lack of response, or a low response, to May temperature in Centres 01, 07 and 12 which are all in very sheltered areas. This does not indicate that management skill prevented the May temperature maxima having their normal effect but that these Centres did not experience critically high temperatures. So part of the high yield of Centre 12, as well as the low yield of the exposed Centre 09, might be explained by a more detailed temperature record. Nevertheless, the low yields of Centre 07, also in a very sheltered area, and the yield difference between Centre 02 and Centre 03 cannot be explained in these terms.

May Temperature Maxima. Although the study of the effects of mid-May temperature maxima on the maturing grain (see ch. 8.2, pp. 269-273) showed that a sirocco in May could affect yield, the dominant controlling role of the temperature maxima of a few days in mid-May had not been anticipated. After two years' labour and investment spent to obtain the best conditions for a high yield, the harvest can be decimated in a few days. If this is true in the northern part of Tunisia it must be even more true of central Tunisia, south of the Dorsale which shields the north from the full force of the sirocco. If varieties were introduced which matured a fortnight earlier the average yield might be greatly enhanced.

The study of the 12 Centres shows that there is a strong sub-regional pattern of response to the May temperature maxima. The sirocco penetrate to the north of Tunisia most easily across the lowest and narrowest part of the Dorsale (Fig. 27, p. 327), in the east, north of Kairouan. The principal 'gateway' into the LMV is along the Miliane and Chafrou valleys where Centres 09 and 12 lie directly in their path. The other southern Centres are not so markedly affected whilst in the north and the sheltered areas the effect of the sirocco dies away to nothing.

Although some Centres appear to show a different degree of response to mid-May temperatures by hard and soft wheat no clear pattern emerges. Indeed it appears that soft wheats did not have a significant advantage over the hard wheat although they mature rather earlier. They still do not mature early enough to be effectively protected.

Excess Rainfall. In most of the Centres the variables entered into the multiple regression include at least one which suggests that moderate, rather than maximum, rains are required to obtain the best yields. This is as true for the fallow year - when low spring rainfalls are advantageous - as for the crop year. In the crop year the analysis using the sum of the LMV observations shows that the total rainfall of September to May can be too high although the highest rainfalls of January and May are normally advantageous. This pattern is reflected in most of the studies of individual Centres. This strongly suggests the desirability of low rainfall in autumn and December. Very heavy rainfall at this time is rarely needed to make the ground wet enough; such conditions are ensured in years of average rainfall where the Fallow-Wheat rotation is practised. Very heavy rainfall in autumn has the effect of bringing nitrification to an abrupt end (see ch. 6.6, pp. 195-196) and causes the essential reserves of nitrogen to be leached below the level at which the roots of the plant can absorb it during tillering and later stages of growth.

In the wetter Centres, particularly with soft wheat, there is an indication that rainfall must be moderate in spring also. Excess rain during this season both causes leaching and creates ideal conditions for pests and diseases. The mechanism by which excess rainfall acts directly and indirectly on yield is fully discussed in chapter 9.1 (pp. 297-302).

The analysis also indicates that soft wheat is, as expected, definitely more susceptible to excess rainfall than hard wheat. Again this is connected with nitrogen requirements which are greater for the soft wheats, particularly F/A.

In the wettest of the Centres, where the soil is free from salinity and the plough land sheltered from the sirocco, the correlation between yield and the climatic variables selected was not significant. This was true for hard wheat in Centre 11 and soft wheat in Centres 01, 08 and 11. Another choice of climatic variables might have obtained better results in these Centres but it may be that in these wetter Centres rain water - ground water - is rarely critically short. This would have the effect of reducing the strength of linear correlations between yield and the rainfall range and also allow yield to be controlled by a more subtle balance of climatic conditions. In addition, as noted above, the yields of these three Centres are not controlled by critically high May temperatures.

Problems Posed by the Analysis. According to the multiple regression analyses each of the Centres has a different response to climate, not only in the slope of the regression lines but in the variables which are entered into the regression equations. Many of these differences are not significant; no doubt if all 126 farms were analysed individually there would be 126 different regression equations.

However some of the differences are marked and have a sub-regional pattern which corresponds with known features of the climate or soil/ground water conditions. These, including the response to mid-May temperatures and excess rainfall, have been commented on either in the discussion of each Centre or, above, in the conclusions.

Other differences are on the border line. They are probably not significant, or at any rate must be assumed not significant, because the number of observations is not great enough to confirm them. For example the varying effect on the yield of hard and soft wheats played by the May climate in different Centres. In Centre 03, to take one case, it appears that mid-May temperature maxima are important in explaining variation in hard wheat yields but not in soft wheat yields; Tables 86 and 87 (pp. 358/359). Is this difference significant ? It is certainly a difference one would expect to find given that soft wheat matures before hard wheat. However the finding is not supported by Centre 05 where the reverse is true. Whether the difference between these two Centres is real - dependent on differing reactions between the climate and two distinctive qualitites of soil - or illusory would need a longer period of observations to tell.

Further problems are the apparent correlations existing between yield and July rainfall and the temperature maxima of 25 May. Both of these correlations are plausible and explanations of their possible mechanisms have been given. But in both cases the variables contain many zero values and the correlation may be coincidental.

The difficulty of accepting July rainfall as important is not only that the values concerned are small - often zero - but that heavy July rainfall appears to have an opposite effect in different Centres. As explained before, these effects exhibit a distinct regional pattern and, it must not be forgotten, the correlation of July rainfall with yield is often very strong. For these reasons the correlation between yield and July rainfall cannot be set aside, but further analysis of the correlation will be needed to prove whether it is significant or not.

If July rainfall does increase yield this could be an economically important fact. The quantity of rainfall involved is small and it might be secured by irrigation in certain areas, such as the LMV, where water is available for irrigation.

As for the temperature maxima of 25 May it must first be remembered that this day offered the best late May correlation with yield but that the days of the fourth week of May - singly and in combination - all showed some degree of positive correlation with yield. High temperatures at this time would also mean low, or probably no, rainfall. Séguéla (1959B) showed that in the final period of grain maturation up to harvest heavy rain can make the grain flowery and reduce its specific weight. The final phase of grain maturation would include the last part of May and the first half of June up to the time when the harvest is nearing completion.

A closer examination of the effects of the distribution of rainfall within the months of May and June is required. The ideal rainfall distribution might be high in the first two or three weeks of May and low in the last part of May and the first part of June.

But at any rate the part played by late May temperature maxima in the analysis was only small.

<u>Extrapolation</u>. The analysis emphasises the danger of extra-

polating the correlations found in the LMV to other areas of Tunisia. If in such a relatively small area the interaction between climate and yield can vary so much from Centre to Centre then the relationships would cover an even greater range in the different major wheat growing areas of northern Tunisia. The pattern may be completely different south of the Dorsale, with April/May temperatures playing a dominant role and the danger of excess rainfall very unlikely.

What can be taken to these areas is the method of analysis so that a clear regional understanding of the way climate affects yield might be obtained.

The other important point is whether the same Centres of the LMV would show a close relationship between yield and climate, based on the equations suggested by the above analyses, in a different period of years. Only further work will show if this is so. One reason making it likely is that the range of climate in the study years was as great as in the whole period since 1900. The years 1948/49 to 1960/61 included both the wettest year (1959) and the driest year (1961) of the century and years in which the late spring temperatures were cool (1950) and very hot (1960 and 1961). However the decade 1950/1960 was unusual in being overall the wettest of the century. It would be wrong to assume the same climate/yield relationship in the dry 1940's. Although the middle years of the 1940's did not have a greater range of climate they were a unique series of dry years which might have had a cumulative effect on yield over several years. To test this it might be necessary to consider a longer time span than the two years of the Fallow-Wheat rotation tested here.

In general if analyses were made over a much longer period of years than examined in this study one would expect, after taking out the variation explained by climate, to see an upward trend of yield, reflecting improved and more widely generalised use of good farming methods and better varieties of seed.

It is to be hoped that the new varieties of Mexican wheat now being introduced into Tunisia will further reinforce this trend.

CHAPTER 11

EXAMINATION OF THE ORIGINAL HYPOTHESES

As the conclusions at the end of each chapter have been drawn out at some length this chapter will be restricted to a brief re-examination of the original hypotheses in the light of the work completed.

1. The colonists clearly improved the fertility of their land. Yields increased markedly, particularly during the inter-war period. There is no evidence to suggest that soil fertility deteriorated during the final phase of colonisation, up to land nationalisation in 1964. Although yields declined during this period the lower yields of the late 1950's and the early 1960's are explained by a series of poor climatic years.

The extensive Fallow-Wheat rotation left the ground unproductive every second year. There seems little doubt that the rigorous application of the Fallow-Wheat rotation was not necessary in many areas of northern Tunisia, including parts of the LMV. On the other hand some fallow will remain necessary to keep the ground weed and pest free and to build up a reserve of water and nitrogen in the soil as a protection against dry years.

The use of fallow exposed the soil to erosion and undue erosion undoubtedly occurred on the lighter hill slopes; some of these slopes were better suited to rough grazing. However the colonists often terraced land for cereal cultivation on the flat, contoured fields that they thus created. Most erosion damage was done by the peasants who were pushed by the pressure of population back into the hills where they ploughed land which should have been left with a permanent protective cover of vegetation.

It was only in the 1950's that experiments conducted at the SBAT showed that the use of fallow combined with regular 16-month ploughing not only created conditions favourable to rapid nitrification but unfortunately led to the loss of soil nitrogen by leaching, especially in the wetter years. Yankovitch estimated a theoretical limit of 200 years before the soil became devoid of nitrogen. The loss of nitrogen could have been contained by ploughing in the early autumn before sowing and by reducing the number of fallow years in order to 'sponge' the soil of surplus moisture and provide an extra reserve of humus. The use of nitrogen fertiliser was advocated. But further intensification of the dry-farming regime would have come up against the related problems of which additional crops to fit into the rotation and the control of weeds and pests. Crops which would have had a value in cleaning the ground - such as sugar-beet and potatoes - would have been quite uneconomic. But on the other hand secondary cereals or a beans/oats mixture were dirty crops and always ran the risk of leaving the ground too dry in a year of low rainfall.

The farmers did respond to advice from the SBAT during the 1950's by increasing their useage of nitrates and slightly reducing the area of fallow. But the response, coming in the troubled period between independence and land nationalisation, was perhaps not as strong as the situation demanded.

2. The methods of cereal farming evolved by the colonists did take the climate into consideration. The fallow stored the winter rains which formed a reservoir for the crop year. In the summer at the end of the fallow year the moist soil and the hot

sunshine combined to form ideal conditions for soil nitrification. The fallow, by acting as a store for water and a factory for nitrogen, protected the farmer against the worst effects of the dry years. Even in the driest years a worthwhile harvest was obtained.

The use of heavy machinery allowed the farmers to work the land during a much greater range of climatic conditions and soil moisture content. Tillage was begun early in autumn so that the land was effectively cleared of weeds which, in most years, allowed sowing to take place at or near the optimal time.

But by concentrating on the danger of aridity the farming methods did expose the land to damage in the wettest years. The principal danger lay in leaching of the essential nitrogen salts. In some places heavy autumn rain falling on the finely prepared soils in early autumn caused undue erosion. A coarser soil preparation would have minimised this danger, as well as reducing risk of leaching.

3. In spite of the fact that the colonists overcame some of the worst effects of drought the climate still retained a strong and significant controlling effect on yields.

In particular the climatic defect which the French never overcame was the damage done by the sirocco of mid-May. The quantitative analysis revealed that where farms lay exposed to the sirocco the damage done by mid-May temperatures over 29°C. could severely reduce the yield.

In addition yields might be limited by a shortage, or an excess, of rainfall in all seasons of the growth year and during the winter and spring of the fallow year. Moreover the climate, or rather the available water, determined the choice of crop. Where water additional to the rainfall was available for irrigation it was, and had long been, effectively exploited for the intensive production of fruit and vegetables. In areas of the LMV which had most good quality ground water the colonists planted a high percentage of their arable land with vines and fruit trees. In places where the OMVVM increased the area reached by irrigation water so cereal crops began to be replaced by fodder and market garden crops. Where the land had, however, to rely solely on the natural rainfall extensive farming was the rule. On most of this land neither vines nor root crops were practicable alternatives to cereals.

4. The gulf between the productivity of the Tunisian farms and the colonial farms was not nearly as great as has been commonly supposed. The yields of the Tunisian farmers in the north of Tunisia were up to twice the yields published by the STONIC. This fact undermines deductions commonly made about the poverty of Tunisian farming.

The presence of the French led to an increase in the Tunisian population of the southern and western cheikhat of the LMV in which they settled although the extensive nature of the farming - determined by the climate - meant that the increace in population was not as rapid as the increase in land brought into permanent cultivation. In the newly irrigated areas, La Manouba for example, the growth in population has been most rapid.

The temporary labour force - used primarily to harvest cereal crops in the LMV - grew with colonisation but has subsequently declined because harvesting of cereals has become fully mechanised. The social consequences of the use of the combine harvester in Tunisia have yet to be fully evaluated.

Appendix 1. Yields of Hard Wheat in the Study Area by Year and Centre. (ql/ha.).

Centre	49	50	51	52	53	54	55	56	57	58	59	60	61	Mean
01	12.0	20.8	3.5	14.1	15.0	13.5	7.9	9.7	11.8	7.0	8.9	7.4	3.7	10.4
02	15.2	17.5	9.3	13.6	11.5	13.4	12.3	12.1	12.8	10.0	10.9	8.4	3.4	11.6
03	11.4	15.6	6.4	9.9	12.8	10.9	8.7	9.1	7.9	6.7	10.3	6.3	2.5	9.1
04	11.4	26.3	7.7	18.8	16.1	11.9	8.4	2.7	8.3	10.5	11.3	14.0	2.3	11.5
05	10.3	13.1	3.2	8.4	11.7	11.1	7.8	8.8	4.7	5.6	7.7	3.5	2.8	7.6
06	12.1	16.9	5.1	15.2	15.7	11.1	8.0	11.4	15.8	10.2	5.9	10.7	4.4	11.0
07	7.1	14.1	6.4	5.7	9.0	3.5	8.1	9.0	8.0	5.6	3.4	8.8	8.8	7.5
08	7.6	9.2	3.8	14.7	15.4	15.3	13.2	11.4	12.1	10.2	8.3	3.5	5.0	10.0
09	6.7	9.1	6.2	10.9	12.0	7.0	5.3	3.3	9.0	6.8	5.9	1.6	1.6	6.6
10	14.0	15.5	10.7	11.6	13.9	11.5	8.2	8.0	14.1	12.9	7.1	8.3	7.6	11.0
11	19.1	22.7	13.3	19.4	20.5	14.2	10.4	12.2	10.8	11.9	13.3	6.3	14.3	14.5
12	14.4		8.1	11.2	15.2	12.0	4.0	8.9	10.6	13.2	8.8	2.8	2.9	9.4

Appendix 2. Yields of Soft Wheat in the Study Area by Centre and Year. (ql/ha.).

Centre	49	50	51	52	53	54	55	56	57	58	59	60	61	Mean
01	16.9	21.8	4.6	12.3	11.0	11.8	6.6	8.5	8.7	5.9	16.7	12.6	7.2	11.1
02	13.1	20.0	9.6	15.7	19.0	11.8	11.4	10.5	11.1	10.1	10.5	10.2	5.1	12.2
03	9.4	16.6	4.3	12.9	14.4	11.5	9.7	9.8	8.3	7.9	8.5	5.5	2.1	9.3
04	14.1	22.3	16.3	19.3	16.8	14.4	15.4	5.7	17.8	11.2	7.3	7.3	6.9	13.4
05	11.0	15.6	5.6	12.1	12.3	10.4	7.5	6.7	6.0	6.5	6.6	4.1	3.3	8.3
06	10.1	16.2	6.7	15.7	15.3	7.7	7.3	12.5	16.4	12.3	7.2	9.8	2.2	10.7
07	3.3		2.5	5.0	10.7	4.5	6.2	4.5	11.1	5.1		4.4	7.0	5.8
08	7.8	10.4	11.0	11.3	14.0	10.3	8.0	8.1	7.5	8.4	4.1			9.2
09	9.3	9.6	5.8	8.6	11.6	9.3	1.5	6.3	5.9	9.0	6.4	1.0	2.4	6.7
10	12.1	14.7	12.8	18.4	15.9	14.1	11.9	15.9	15.7	15.4	6.5	7.4	6.7	12.9
11	10.1	16.5	11.5	19.0	19.5	10.8	14.9	11.3	16.0	14.3	10.6	11.1	15.1	13.9
12	13.6	16.5	8.9	14.5	16.4	12.7	6.0	7.1	12.1	12.4	7.2	1.2	1.5	10.0

BIBLIOGRAPHY

AOUANI, M.D. el, (1965), 'Structure agraire dans un village côtier du nord-est de la Tunisie: Galaat el-Andleuss', R. Tunis. des Sci. Soc., no. 3, 1965, pp. 71-108.

ASANA, R.D. and WILLIAMS, R.F., (1965), 'The effect of temperature stress on grain development in wheat', Aust. J. of Agric. Res., Vol. 16, Jan. 1965, pp. 1-13.

ATTIA, H., (1966), 'L'évolution des structures agraires on Tunisie depuis 1962', R. Tunis. des Sci. Soc., Nov. 1966.

BELING, W.A., (1965), Modernisation and African Labour. A Tunisian Case Study. New York, 1965. p. 259.

BERGE, A., (1955), 'L'aspect humain des problèmes de restauration des sols en Afriques du Nord', L'Afrique et L'Asie, no. 29, pp. 29-36.

BIGOURDAN, R., (1947), 'La production des céréales au cours des 40 dernières années et ses perspectives d'avenir en Tunisie', La Tun. Agric., Jan. 1947, pp. 2-14.

BIGOURDAN, R., (1951), 'Examen quantitatif et qualitatif de la récolte de céréales de 1951 en Tunisie', La Tun. Agric., Dec. 1951, pp. 145-156.

BIRH, (1951/1955), 'La régime de la Medjerda', Arch. du BIRH., Tunis, 1951 to 1955.

BOEUF, F., (1932), Le Blé en Tunisie. Vol.I. La Plante. Le Milieu Physico-chimique. Tunis, 1932, p.454.

BOEUF, F., (1946), 'Blés tendres et blés durs en Tunisie; un peu d'histoire', Ann. du SBAT de Tunisie, Vol. 19, pp. 97-109.

BOEUF, F., (1951), 'Blé tendre ou blé dur', La Tun. Agric., June 1951, pp. 1-2.

BONNIARD, A., (1925), 'Bizerte et sa région', Ann. de Géog., 1925, pp. 133-145.

BONNIARD, A., (1934), La Tunisie du Nord. Le Tell Septentrional. Etude Géographique. Paris, 1934, p. 534.

BUCK, S.F., (1961), 'The use of rainfall, temperature and actual transpiration in some crop weather investigations', J. of Agric. Sci., Vol. 57, 1961, pp. 355-365.

BULLETIN, (1959), 'Les céréales en Tunisie', Bulletin de la Banque Centrale de Tunisie, no. 2, July 1959, pp. 3-8.

BULLETIN, (1968), 'L'irrigation du blé tendre en Tunisie', Bulletin Trimestrial de la Division de Vulgarisation Agricole, 1er. et 2ème tri., 1968, pp. 23-26.

CENSUS, (1956), Recensement Général de la Population de la Tunisie du 1er. Février 1956 - Repartition Géographique de la Population. Service des Stat., Présid. du Conseil, Royaume de Tunisie, 1956, p. 191.

CENSUS, (1969), Recensement Général de la Population et des Logements - 3 Mai 1966 - Population par Division Administrative. Dir. Gén. du Plan, Section des Stat. Demog. Séc. d'E. au Plan et à l'Econ. Nat., Répub. Tunis., 1969, p. 103.

CHABROLIN, C., (1939), 'La culture des terres sèches', B. Service Agric., Dir. des Affaires Econ. de la Régence, Tunis, no. 177, XLIII, pp. 187-200.

CHABROLIN, C., (1942), 'Orientation à donner à la culture des céréales en Tunisie', La Tun. Agric,, Nov. 1942, pp. 122-128.

CHAMARY, D., (1969), 'Le blé dur, nouveau venu dans l'agriculture française', Science Progrès, La Nature, no. 3407, 1969, pp. 95-96.

CHARBONNIER, F., (1964), 'Les réformes agraires en Afrique du Nord. La Tunisie', Et. Maghrebines, no. 1, 1964, p. 37.

CHEVALIER, L., (1957), 'France et Tunisie', Population, no. 4, 1957, pp. 607-614.

CLARKE, J.I., (1955), 'Summer nomadism in Tunisia', Economic Geography, Vol. 31, no. 2, Apr. 1955, pp. 157-167.

COTE, M., (1964), 'La conservation des sols et des eaux en Tunisie', Méditerranée, no. 3, 1964, pp. 219-242.

CRUESI, (1969), Seminaire Sur l'Irrigation à l'Eau Saumatre: Rapport Technique (et Annexes). Tunis 24-29 Octobre, 1969. Centre de Recherches sur l'Utilisation de l'eau Salée en Irrigation, Tunis, Sep. 1969, p. 190 (plus vol. of annexes).

CUISENIER, J., (1961), 'Le sous-développement économique dans un groupement rural de Tunisie: le Djebel Lansarine'. C. Sociol. Econ., (Le Havre), no. 4, 1961, pp. 32-71.

DECKER-DAVID, M.P., (1911), L'Agriculture Indigène en Tunisie. Rapport Générale. Tunis, 1911, p. 777.

DESPOIS, J., (1961), La Tunisie. Paris, 1961,

DESPOIS, J. and RAYNAL, R., (1967), Géographie de l'Afrique du Nord-Ouest. Payot, p. 570.

DESTANNE DE BERNIS, G., (1958), 'Agriculture tunisienne. Problèmes et perspectives', Econ. et Humanisme, 1958, pp. 130-144.

DOCUMENTS, (1965), 'Effets de la colonisation dans un cheikhat rural tunisien: Le Djebel el Ansarin', Grands Documents de l'Imperialisme à la Décolonisation: Les Editions de Minuit, 1965, pp. 213-225.

DUPUY, A., (1955), 'La personalité du colon', R.d'Histoire Economique et Social, 1955, pp. 77-103 & 166-205.

DROGUE, C., (1966A), Cartes des Ressources en Eaux de la Tunisie. A l'Echelle du 1:200,000 - Feuille de Bizerte et Notice Explicative. BIRH, Séc. d'E. au Plan et à l'Econ. Nat., Sous-Sec. d'E. à l'Agric., Répub. Tunis., Apr. 1966.

DROGUE, C., (1966B), Cartes des Ressources en Eaux Souterraines de la Tunisie. A l'Echelle 1:200,000 - Feuille de La Goulette/Cap Bon et Notice Explicative. BIRH, Sec. d'E. au Plan et à l'Econ. Nat., Sous-Sec. d'E. à l'Agric., Répub. Tunis., Sep. 1966.

DROGUE, C., (1966C), Cartes des Ressources en Eaux Souterraines de la Tunisie. A l'Echelle 1:200,000 - Feuille de Tunis. BIRH, Sec. d'E. au Plan et à l'Econ. Nat., Sous-Sec. d'E. à l'Agric., Répub. Tunis., Oct. 1966.

DUMEIGE, A., (1953), 'Le logement des grains et la production céréalière en Tunisie', Bull. Econ. et Soc. de la Tun., no, 78, July 1953, pp. 76-83.

DUMONT, J., (1947), 'Le developpement de la motoculture en Tunisie', La Tun. Agric., Dec. 1947, pp. 129-145.

DUTTON, R.W., (1968), Problems of Large-Scale Water and Land Development in Tunisia - The Madjardah Valley Project. Unpublished M.A. dissertation, London, 1968, p. 73.

DUVDEVANI, S., (1957), 'Dew research for arid agriculture', Discovery, Vol. 18, no. 8, 1957, pp. 330-334.

ECK, H.V. and TUCKER, B.B., (1968), 'Winter wheat yield and response to nitrogen as affected by soil and climatic factors', Agronomy J., Vol. 60, no. 6, Nov/Dec. 1968, pp. 663-666.

ENJALBERT, H., (1947), 'A propos du dry-farming. Culture scientifique du blé et motorisation', B. Ass. G.F., no. 185/186, March/May 1947, pp. 61-68.

EROSION, (1958), La Lutte Contre l'Erosion. Terre de Tunise, no. 6, 1958, p. 108. (a collection of articles).

ESSAFI, A., (1962), La Fumure Azotée en Tunisie. Conférence à l'UNAT le 17 février 1962, Publication du Service de l'Enseign. de la Vulg. et de la Coop. Agric., Sec. d'E. à l'Agric., Répub. Tunis., p. 10.

ESSAFI, A., (1964), 'Quelques reflexions sur l'évolution de la fértilité des terres en zone semi-aride. Importance de l'assolement', Académie d'Agric. de France, Procès-verbal de la Séance du 8 Janvier 1964, pp. 77-83.

FERHAT, A., (1962), 'Contribution à l'étude de l'influence des régimes hydriques sur la tecnologie du blé, Ann. de l'INRAT, Vol. 35, 1962, pp. 111-160.

FINIELTZ, H., (1953), 'Conditions pedologiques et hydrologiques dans la vallée de la Medjerda', La Tun. Agric., March/April 1953, pp. 39-59.

FISHER, R.A., (1924), 'The influence of rainfall on the yield of wheat at Rothamsted', Phil. Trans. of the Royal Soc. of London, Vol. 213, 1924/25, pp. 89-142.

FLEURY DU SERT, (1902/1903), 'Le pont barrage du Bathan et les terres irrigables de Tebourba', Bull. Assoc. des Colons Français de la Région de Tebourba, 1902, pp. 145-154 and 1903, pp. 73-81.

GANGOPADHYANA, M. and SARKER, R.P., (1965), 'Influence of rainfall distribution on the yield of wheat crop', Agric. Meteorology, Vol. 2, Oct. 1965, pp. 331-350.

GENOUD, B., (1965), L'Evolution de l'Economie Tunisienne. Thèse de docteur es-sciences économiques, Genève, 1965, p. 404.

GESLIN, H., (1935), 'Les facteurs climatiques de la qualité', Ann. de la Sci. Agron., 1935, pp. 205-218.

GESLIN, H. and VERNET, A., (1952), 'Maturation du blé et climat', Ann. d'Amelioration des Plantes, no. 2(2), 1952, pp. 253-256.

GOSSELIN, M., (1950), 'La législation de l'hydraulique et la conservation des sols en Tunisie', Ann. des Ponts et Chaussées, (Paris), no. 6, pp. 733-774.

GRONTMIJ, (1961), Rapport Générale sur la Mise en Valeur de la Basse Vallée de la Medjerda. Grontmij (Tunis), 1961, p. 504.

HAFIZ, A., (1969), Report on Wheat and Barley Improvement and Production in Tunisia. FAO, Near East Regional Office, Cairo, June 1969, p. 5.

HARLE, P., (1958), 'Quelques principes d'aridoculture', La Tun. Agric., Oct. 1958, pp. 111-121.

HOOKER, R.H., (1922), 'The weather and crops in eastern England, 1885-1921', Quart. J. of the Met. Soc., Vol. 48, 1922, pp. 115-

HOPKINS, J.W., (1935), 'Weather and wheat yields in western Canada', Canadian J. of Res., no. 12, 1935, pp. 306-334.

HYSLOP, J.D. and DAHL, R.P., (1970), Wheat Production in Tunisia. Trends and Variables. (Unpublished paper), Minnesota Agricultural Mission to Tunisia, 1970. p. 5.

INRAT, (1964), Recommandation pour le Choix des Variétés de Céréales en Tunisie pour la Campagne 1964-1965. Documents techniques, no. 3, INRAT, Sep. 1964, p. 16.

ISNARD, H., (1952), 'La répartition saisonnière des pluies en Tunisie', Ann. de Géog., 1952, pp. 357-362.

JENKINS, J.E. and MORGAN, W., (1969), 'The effect of Septoria diseases on the yield of winter wheat', Plant Pathology, Vol. 18, no. 4, Dec. 1969, pp. 152-156.

KNIGHT, M.M., (1928/29), 'Water and the course of empire in North Africa', Quart. J. of Econ., Vol. 43, 1928/29, pp. 44-93.

KOOL, R.G.A., (1963), L'Agriculture Tunisienne - Analyse d'une Economie en Voie de Modernisation. Wageningen, 1963, p. 188.

LEE, J. and CONNAUGHTON, M.J., (1969), 'Effects of weather on wheat yields', Irish J. of Agric. Res., Vol. 8, no. 3, 1969, pp. 349-357.

LEPIDI, J., (1949), 'L'évolution récente de l'agriculture', Bull. Econ. et Soc. de la Tun., no. 31, Aug. 1949, pp. 25-32.

LEPIDI, J., (1955), L'Economie Tunisienne depuis la Fin de la Guerre. Tunis, 1955, p. 121.

LOTH, G., (1910), La Grande Colonisation Française en Tunisie: L'Enfida et Sidi Tabet. Tunis, 1910, p. 192.

MAKHLOUF, A., (1967), 'Nouveau dualisme de l'agriculture tunisienne: coopératives agricoles de production et grandes exploitations privées', R. Tunis. des Sci. Soc., no. 9, March 1967, pp. 27-56.

MARTHELOT, P., (1964), 'Les implications humaines de l'irrigation moderne en Afrique du Nord', In: Annuaire de l'Afrique du Nord, (Paris), 1962, pp. 127-154.

McKAY, D.V., (1945), 'The French in Tunisia', Geog. Rev., Vol. 35, July 1945, pp. 368-390.

MILLINGTON, R.J., (1961), 'Relations between yield of wheat, soil factors and rainfall', Aust. J. of Agric. Res., Vol. 12, May 1961, pp. 397-408.

MINANGOIN, N., (1908), 'La culture des céréales en Tunisie', Bull. Dir. Agric. Tun., 1908, pp. 81-103.

MITCHELL, P.K. and DEWDNEY, J.C., (1960), Climate. In: Malta. Background for Development. eds. Bowen-Jones, H., Dewdney, J.C. and Fisher, W.B., Durham, 1960, p. 356.

MONCHICOURT, C., (1904), 'La région de Tunis', Ann. de Géog., 1904, pp. 145-170.

MONCHICOURT, C., (1913), La Région du Haut Tell en Tunisie. Paris, 1913, p. 487.

MONTLAUR, L., (1941), Relations Entre les Elements Météorologiques et la Croissance d'une Lignée Pure d'un Blé. Extrait des Ann. du SBAT de Tunisie, Vol. 16-17, 1939/40, Tunis, 1941, p. 150.

MOTTES, V., (1925), La Colonisation Française et la Propriété Indigène dans le contrôle de Medjez-el-Bab. Tunis, 1925, p. 40.

MUSSET, R., (1933), 'La culture du blé en Tunisie', Ann. de Géog., vol. 42, 1933, pp. 540-543.

OMVVM, (1969), Plan Quadriennal 1969/72. Etude Technique et Economique. Bureau Technique, OMVVM, Répub. Tunis., June/Aug. 1969, p. 82.

OMVVM, (1970), Enquête Agricole Annuelle dans le Périmetre de l'OMVVM. Campagne 1968-1969. OMVVM, Répub. Tunis., Feb. 1970, p. 36.

PELLEGRIN, A., (1955), 'La Medjerda, aperçu géographique et historique', Bull. Econ. et Soc. de la Tun., no. 102, July 1955, pp. 34-48.

PERCIVAL, J., (1921), The Wheat Plant. London, 1921, p. 463.

PERRUSSET, M., (1950), 'La météorologie et l'agriculture', La Tun. Agric., Aug/Sep. 1950, pp. 71-75.

PERSON, J., (1955), 'Le developpement en Tunisie des traveux de défense et de restauration des sols cultivables', Bull. Econ. et Soc. de la Tun., no. 99, Apr. 1955, pp. 70-82.

PIMIENTA, J., (1953), 'Sur les emplacements de l'embouchure de la Medjerda et les charactères de son delta', C.R. des Séances Acad. des Sci., 15th. June 1953.

PIMIENTA, J., (1954), 'Répartition granulométrique instantanée du transport solide dans la Medjerda en crue', C.R. Acad. des Sci., Vol. 239, no. 5, 1954, pp. 441-443.

PISSALOUX, R., (1955), 'Production agricole et alimentation humaine', Les Cah. de Tun., no. 12, 1955, pp. 543-614.

PLAN, (1962), Structure des Exploitations Agricoles en Tunisie. Enquête de 1961 - 1962. Sec. d'E. au Plan et à l'Econ. Nat., Répub. Tunis., 1962, p. 90.

PLAN, (1968), Bassin Versant de la Medjerdah. Exploitation des Ressources Hydrauliques. Sec. d'E. à l'Agric., Répub. Tunis., 1968.

POCTHIER, M., (1943), 'Les céréales en Tunisie', Congres de la Mutualité Agricole d'Alger, 1943, pp. 5-10.

POLETAEF, N., (1946), 'Contribution à l'étude de l'influence du travail du sol sur la fertilité', Ann. du SBAT de Tunisie, Vol. 19, 1946, pp. 3-19.

POLETAEF, N., (1953), 'Action du travail profond du sol sur la fertilité et sur les rendements des céréales', Ann. du SBAT de Tunisie, Vol. 26, 1953, pp. 1-100.

POLETAEF, N., (1954), 'Role des labours profonds dans l'amelioration des rendements', La Tun. Agric., May 1954, pp. 1-9.

PONCET, J., (1956), 'La mise en valeur de la basse ballée de la Medjerda et ses perspectives humaines', Ann. de Géog., 1956, pp. 199-222.

PONCET, J., (1959), 'L'évolution géographique du peuplement tunisien à l'époque récente', Ann. de Géog., 1959 pp. 247-253.

PONCET, J., (1961A), La Colonisation et l'Agriculture Européene en Tunisie depuis 1881. Paris, 1961, p. 702.

PONCET, J., (1961B), Les Rapports Entre les Modes d'Exploitation Agricole et l'Evolution des Sols en Tunisie. Publications du Sec. d'E. à l'Agric., Etudes et Mémoires, no. 2, Tunis, 1961, p. 169.

PONCET, J., (1962), 'Les champs et l'évolution du paysage agraire en Tunisie', Ann. de Géog., 1962, pp. 620-629.

PONCET, J., (1963), Paysages et Problèmes Ruraux de Tunisie. Paris, 1963, p. 374.

PREJEAN, J., (1957), 'Le problème agraire en Tunisie', Economie et Politique, 1957, pp. 367-382.

RAYMOND, A., (1961), La Tunisie. Paris, 1961, p. 110.

RINGWALD, H., (1954), 'Acroissement de la production céréalière de Tunisie', Bull. Econ. et Soc. de la Tun., no. 91, Aug. 1954, pp. 44-50.

RINGWALD, H., (1955), 'La récolte des céréales de l'année 1954 pour la Tunisie', Bull. Econ. et Soc. de la Tun., no. 97, Feb. 1955, pp. 34-37.

ROUXEVILLE, P., (1957), 'Le port de Tunis-La Goulette', Encyclop. Mens. d'Outre-Mer, no. 79, 1957, pp. 99-103.

SCHOELLER, H., (1937), 'La protection des sols contre l'érosion', La Tun. Agric., Oct. 1937, pp. 177-191.

SEGUELA, J.M., (1958), 'Enseignements techniques à tirer de la campagne de céréales 1956-57', La Tun. Agric., Jan. 1958, pp. 1-15.

SEGUELA, J.M., (1959A), 'Enseignements à tirer de la campagne de céréales 1957/58', La Tun. Agric., Feb/Mar. 1959, pp. 13-32.

SEGUELA, J.M., (1959B), 'Enseignements techniques à tirer de la campagne de céréales 1958-59', La Tun. Agric., Dec. 1959, pp. 139-158.

SEGUELA, J.M., (1960), 'Enseignements techniques à tirer de la campagne de céréales 1959-60', La Tun. Agric., Oct. 1960, pp. 113-133.

SEGUELA, J.M. and JACQUARD, P., (1953), 'Importance du facteur variétal dans la céréaliculture', Bull. Econ. et Soc. de la Tun., no. 83, Dec. 1953, pp. 32-49.

SEGUELA, J.M. and JACQUARD, P., (1955), 'Les variétés de céréales cultivées en Tunisie', Almanach Agricole Tunisien, 1955, pp. 214-227.

SETHOM, H., (1963), 'Les rapports entre les modes d'exploitation agricole et l'érosion des sols en Tunisie', Les Cah. de Tun., 1963, pp. 85-95.

SILVERA, V., (1962), 'En marge des événements de Bizerte: reflexions sur la crise des rapports Franco-Tunisiens', R. de Déf. Nat., Apr. 1962, pp. 612-635.

SILVERA, V., (1964), 'L'évaluation de Bizerte et les rapports Franco-Tunisiens', R. de Déf. Nat., Jan. 1964, pp. 89-106.

STATISTIQUE, (1945-), Annuaire Statistique de la Tunisie. (published by various organisation), Tunis, consulted from 1945-.

STATISTIQUE, (1950-), Statistiques du Commerce Extérieur de la Tunisie. Institut National de la Statistique, Tunis, consulted from 1950-.

STATISTIQUE, (1968), La Consommation et les Dépenses des Ménages en Tunisie, 1965-68. Institut National de la Statistique, Premier Ministère, Répub. Tunis., Dec. 1968, p. 496.

TERRE, (1958), 'Pluviométrie et stabilité de la production - étude des rapports de la pluviométrie et des rendements en blé sur 20 ans dans une exploitation du Nord de la Tunisie', Terre de Tunisie, Bull. du Sec. d'E. à l'Agric., no. 4, Jan. 1958, pp. 59-63.

THIAULT, M., (1958), 'Les perspectives ouvertes à l'élèvage par les nouvelles méthodes de culture de l'herbe (2 partie)', La Tun. Agric., May 1958, pp. 65-70.

TINTHOIN, R., (1946), 'Tunisie 1945', L'Information Générale, Vol. 10, Nov/Dec. 1946, pp. 180-183.

TISSERON, J., (1957), 'Les cultures arbustives dans la mise en valeur de la Tunisie', Terre de Tun., no. 3, 1957, pp. 107-116.

TIXERONT, J., (1957), 'Le ruissellement en Tunisie', La Tun. Agric., Mar. 1957. (offprint).

TUNISIE, (1937), Dénombrement de la Population Civile Tunisienne (Musulmane et Israelite) en Tunisie au 12 Mars 1936. Direction de l'Intérieur, Régence de Tunis, 1937.

TUNISIE, (1950), Recensement Mondial de l'Agriculture 1949/50. (unpublished cheikhat summaries).

VALDEYRON, G., (1948), 'L'experimentation agricole en Tunisie au cours de l'année 1947-48; quelques résultats concernant la céréaliculture', La Tun. Agric., Nov. 1948. pp. 159-167.

VALDEYRON, G., (1949), 'Enseignements techniques à tirer de la campagne de céréales 1948-49 en Tunisie', La Tun. Agric., Oct. 1949, pp. 113-126.

VALDEYRON, G., (1950), 'Enseignements techniques à tirer de la campagne de céréales 1949-1950 en Tunisie', La Tun. Agric., Dec. 1950, pp. 91-101.

VALDEYRON, G., (1952), 'Enseignements techniques à tirer de la campagne de céréales 1951-52', La Tun. Agric., Aug/Sep/Oct. 1952, pp. 85-106.

VALDEYRON, G., (1953), 'Enseignements techniques à tirer de la campagne de céréales 1952-53 en Tunisie', La Tun. Agric., Oct. 1953, pp. 127-138.

VALDEYRON, G., (1954), 'Enseignements techniques à tirer de la campagnes de céréales 1953-54 en Tunisie', La Tun. Agric., Oct. 1954, pp. 97-113.

VALDEYRON, G., (1955), 'Enseignements techniques à tirer de la campagne de céréales 1954-55 en Tunisie', La Tun. Agric., Nov/Dec. 1955, pp. 143-163.

VALDEYRON, G., (1957), 'De quelques conclusions d'ensemble sur les dernières campagnes d'experimentation céréalicole', La Tun. Agric., Jan/Feb. 1957, pp. 1-13 & 15-23.

VALDEYRON, G. and SEGUELA, J., (1951), 'Enseignements techniques à tirer de la campagne de 1950-51 en Tunisie', La Tun. Agric., Nov. 1951, pp. 133-143.

VERNET, A., MOUSSET, P. and SAGLIO, P., (1968), 'Nutrition azotée et consommation en eau d'un blé irrigué sous le climat de Tunis', Bull. de l'ENSAT, no. 18 & 19, Jan/June, 1968, pp. 77-100.

VIOLARD, E., (1906), La Tunisie du Nord. Les Contrôles Civils de Souk el Arba, Béja, Tunis, Bizerte, Grombalia. Tunis, 1906.

WARDLAW, I.F., (1970), 'The early stages of grain development in wheat: response to light and temperature in a single variety', Aust. J. of Biological Sci., Vol. 23, no. 4, Aug. 1970, pp. 765-774.

WHEAT, (1969), 'Pour un meilleur rendement de Blé Mexicain en Tunisie', Horizons (publication of the American Cultural Centre, Tunis), 1969, pp. 2-7.

WHEAT, (1970), Rapport Annuel 1969-70: Projet pour L'Augmentation de la Production des Céréales. (unpublished report), Minist. de l'Agric., Répub. Tunis., 1970, p. 42.

WILLIMOTT, S.G., (1960), Soils of the Jefara. pp. 26-45 in: Field Studies in Libya. eds. Willimott, S.G. and Clarke, J.I., Res. Papers Series no. 4, Durham, 1960, p. 123.

WILSON, J.H., (1969), 'The influence of water on the yield components of wheat', Rhodesion J. of Agric. Res., Vol. 7, no. 2, 1969, pp. 129-133.

WOLKOWITSCH, M., (1959), 'L'émigration des Français de Tunisie', Ann. de Géog., 1959, pp. 253-257.

YANKOVITCH, L., (1947), 'L'assolement, le travail du sol et la fumure dans leurs rapports avec la culture des céréales', La Tun. Agric., Oct. 1947, pp. 110-117.

YANKOVITCH, L., (1953), Conservation de la Fertilité des Terres en Afrique du Nord. Le Colon Français, no. 2300, Supple. 1953.

YANKOVITCH, L., (1956), 'Résultats de 22 années d'experience dans les cases lysimétriques et cases de végétation du Service Botanique et Agronomique de Tunisie', Ann. du SBAT de Tunisie, Vol. 29, 1956, pp. 1-223.

ZARKA, C., (1957), 'L'éxperience du marché franco-tunisien des céréales', Rev. Economique, 1957, pp. 460-475.

ZGHAL, A., (1966), 'Cadres agricoles et ouvriers qualifiés dans le nouveau système agricole', R. Tunis. des Sci. Soc., Nov. 1966.

Also consulted:

SOGETHA, (1968). A chart defining soil types which was compiled in connection with a series of 'Cartes des Potentialitiés', produced by the Company SOGETHA and covering much of the agricultural area of northern Tunisia.