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Centre for Agrobiological Research

Department of Theoretical Production Ecology, Agricultural University

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SIMULATION OF BARLEY PRODUCTION IN THE NORTHWESTERN COASTAL ZONE OF EGYPT

G.W.J. van de Ven

Sim. Rep. CABO-TT No. 12
Second revised edition

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SUMMARY

The northwestern coastal zone of Egypt extends from Alexandria to the Lybian border over a length of about 500 km and a width of 15 to 30 km. The main agricultural activities at present are animal husbandry on natural rangeland, rainfed barley cultivation and fruittree cultivation, mainly for the production of figs and olives. In the most eastern part irrigation is possible. This report deals with barley cultivation only.

Simulation runs were carried out to calculate barley production for different locations in the northwestern coastal zone, using the CWFS simulation model for annual crops. That model calculates in a hierarchical sequence potential production, water-limited production and nutrient-limited production, considering especially nitrogen and phosphorus, from basic data on crops, weather and soils.

The phenological development of an Egyptian barley cultivar before and after anthesis was calculated from available data. The other crop parameters are default values as used in the original barley data set. Most of the parameters are rather crop than cultivar-specific.
The climatic data were derived from climatic normals for meteorological stations along the coast. The mean annual rainfall is 150 mm.

The soil data file of the simulation model contains 15 "standard" soil types according to Rijtema (1969). For two soil types in the region, measured soil moisture characteristics were available from literature, which were used to replace the standard ones. For each soil type natural soil fertility and agricultural potentiality were derived from own measurements and literature.

Simulation runs were carried out for each soil type in each part of the region to which a climatic data set applies. The water regimes used are rainfed with complete and homogeneous infiltration, assuming availability of the amount of water needed for maximum production without fertilizer application, 450 mm infiltration annually and optimum water availability. The rainfed situation includes surface run-off and wadi flow, if any.

The simulation results show that rainfed barley cultivation is only possible at locations where considerable amounts of surface run-off and wadi flow are concentrated, the depressions. The total area that is suitable for barley cultivation, on the basis of soil characteristics, is ca. 160 000 ha. The average cultivable area at present is determined by water availability and is limited to the depressions, comprising ca. 40 000 ha or 25%. Barley production is estimated at 32 000 ton grain and 144 000 ton straw when all cultivable land is in use. If water is concentrated on part of the depression surface to a maximum water availability without the need for fertilizer

application, the cultivable area is reduced to 29 000 ha or 18% of the suitable area, producing 36 000 ton grain and 131 000 ton straw. Under a water availability of 450 mm annually the cultivable area decreases to 16 000 ha or 10% and the production becomes 66 000 ton grain and 77 000 ton straw. In the latter situation 1 100 ton N and 600 ton P fertilizer have to be applied.

In the Burg el Arab region ca. 25 000 ha can be irrigated. If irrigation water is applied to a level that the maximum yield without fertilizer application can be achieved, the total barley production is 26 000 ton grain and 33 000 ton straw, requiring 17 million m^3 water. At an irrigation level comparable to the 450 mm water regime under rainfed conditions, the grain yield becomes 77 000 ton and straw yield 90 000 ton, requiring 1 180 ton N and 690 ton P fertilizer and 31 million m^3 water. However, when sufficient irrigation water is available other crops will be more profitable than barley.

It should be noted that yield reducing factors, such as pests and diseases, weeds and harvest losses, have not been taken into account so far. Grain yield reduction due to the presence of weeds is estimated at 25% and post harvest losses at 10%. For straw the total losses are estimated at 20%. Data on actual water availability and natural soil fertility are scarce and incomplete, so a considerable part of the analysis is based on estimates.

To construct input/output tables, that can be used for Multiple Goal Linear Programming (MGLP), not only the yield levels have to be specified, but also the inputs required to achieve them. Therefore, various systems for barley cultivation have been defined. In this study ten agricultural operations are distinguished, some of which are obligatory, like sowing and harvesting and others are optional, like harrowing and weeding. Those operations can be carried out in hand labour, by using animal traction or by using mechanical equipment. Not all three modes of operation are applicable to all operations in the Egyptian situation and only the relevant combinations are considered. For each combination all inputs, mainly labour, are quantified. The ten operations, the three levels of mechanization and the three production levels are combined into seventeen barley cultivation systems, which can be applied in the Mariut region.

This set of cultivation systems is used in an MGLP module to assess which cultivation systems are selected under various socio-economic conditions.

1. INTRODUCTION

This report on barley production in the northwestern coastal zone of Egypt is part of the Mariut-project, a joint activity of the University of Alexandria, CABO and the Department of Theoretical Production Ecology of the Agricultural University aiming at assessing the potentials of different agricultural systems for land use planning. The Egyptian government is interested in developing the northwestern coastal zone to alleviate population pressure on the old land and to contribute to the food security of the country (Project proposal, 1981).

The northwestern coastal zone extends from Alexandria ca. 500 km west, to the Lybian border, over a width of 15-30 km (Figure 1). The main agricultural activities at present are animal husbandry on natural rangeland, rainfed barley culivation and fruittree cultivation, mainly for the production of figs and olives. In the most eastern part irrigation is possible and other crops are grown too. This report deals with barley production in the region only.

FAO carried out an extensive project in this region in the sixties. They defined 5 pilot areas along the coast, where elaborate observations were performed and research on a small scale was carried out and these results were extrapolated along the whole coast (FAO-1, 1970). A soil map was prepared based on photo-analysis and data of a soil map by the UAR High Dam Soil Survey. The analyses by FAO, embodied in 6 reports and several maps, are intensively used for basic information needed in the present project. Other important sources of information are the SAMDENE and REMDENE Progress Reports (S.P.R. and R.P.R., 1975-1982).

1.1 Present methods of barley cultivation

Various strategies for barley cultivation are practiced by farmers in the region. Some Bedouin sow barley before the first rains in autumn (beginning of October). It is then left to germinate and grow. If shortly after germination a drought period occurs for more than about 5 days, the young plants will be damaged or they may even die. As rainfall is very erratic, most Bedouin sow barley after the first 2 or 3 "heavy" rain showers. Usually the available amount of water is then sufficient for germination, but for actual plant growth continued rain is required (Abou El Enein, 1983). In that case germination usually takes place in December (Bedouin, pers.comm.). Seeding after January 8, the end of one of the rainfall periods distinguished by the Bedouin is extremely rare. The seeds are broadcast by hand and then the soil is ploughed. The crop is harvested in April. After that, the grain and the straw are stored or used. Harvesting is usually done by hired labour. As the agricultural labour force drastically declined during the last 15 years due to emigration and the availability of more rewarding jobs, the barley is sometimes left to be grazed. The barley stubble is grazed after the spring pasture is exhausted. Subsequently, the stored straw and grain are fed during the summer as supplements (Wilder, 1984).

1.2 Method of analysis

A simulation model calculating the growth of annual crops is used to estimate the potentials for barley production in the Mariut region. This simulation model, developed by the Centre for World Food Studies (CWFS), calculates in a hierarchical sequence potential production, water-limited production and nutrient-limited production, from basic data on crop, weather and soils. For the soil and crop characteristics a standard data file is available, that can be used in case local data are lacking. Weather data or climatic data are needed from the region itself.

A detailed description of the simulation model is given in Van Keulen and Wolf (1986) and Rappoldt (1986) and it is not discussed here any further.

Combining the simulated barley yields with agricultural operations, various barley cultivation systems are defined in terms of inputs and outputs. Those systems are used in a Multiple Goal linear programme, to assess the best suitable barley cultivation systems under various socio-economic conditions, but that part of the analysis described elsewhere (Mariut team, 1987).

2. INPUT DATA FOR THE SIMULATION MODEL

2.1 Crop characteristics

A plant data set containing parameters for barley was available at the CWFS. In the Mariut region a local desert cultivar is grown, so the value of some parameters, especially with respect to phenological development, differs from the originally defined value.

The values of the maximum development rates before and after anthesis, used in the simulation model to calculate the actual development rate, had to be adapted for the Egyptian barley cultivar. The model assumes a linear relationship between average temperature and development rate up to 35 °C. At 35 °C the development rate reaches a maximum. The optimum length of the pre-anthesis growing period for desert cultivars under the prevailing conditions is 75 days. The length of the grain filling period is about 35 days, which adds up to a growing season of 110 days. From these data and the temperature sum during the growing period, the maximum development rates at 35 °C were calculated. This resulted in a value of 0.034 d^{-1} for the pre-anthesis period and of 0.058 d^{-1} for the post-anthesis period. The development stage is defined in such a way, that it has the value 0 at emergence, 1.0 at anthesis and 2.0 at maturity.

2.2 Climate

To obtain an average crop production for a region two methods can be applied. One is to use actual weather data, calculate crop production for each year over the period that weather data are available, and then calculate the average production for that period. As rainfall is very erratic, daily rainfall data are the minimum required to calculate crop production for each year accurately.

Another method is to calculate crop production using climatic data, i.e. long term averages for the various weather variables. As for the Mariut region no daily rainfall data are available over a longer period, the latter method had to be used.

The climatic data needed in the simulation model were calculated according to Frère et al. (1975) from Climatic Normals for five stations along the coast: Dekheila, Dabaa, Mersa Matruh, Sidi Barrani and Salloum Meteorological Authority (1975). The main difference between the stations is the average annual rainfall.

Rainfall decreases rapidly with increasing distance from the sea. No accurate data on rainfall patterns are available, as there are no meteorological stations in the inland area. To estimate rainfall further inland, a map with lines of equal rainfall is used (Euroconsult, 1976). Rainfall distribution over the year was calculated as the average distribution of the five coastal stations, i.e. the average monthly rainfall and the average number of rainy days per month. For the inland area three rainfall zones were distinguished with annual averages of 75-100 mm; 100-125 mm; 125-150 mm, respectively. For these zones, artificial climatic data sets were calculated for an annual rainfall of 87, 112 and 137 mm, respectively.

In the simulation model rain is distributed over each month according to a mathematical algorithm (Rappoldt, 1986), which calculates the size of individual showers in dependence of the number of rainy days and the total monthly rainfall. The showers are distributed 'at random' over the days of a month. The 'random' distribution of rain and the barley production are calculated twenty times. The mean of the 20 simulation runs is considered the average barley production for a specific climate and soil type.

The other climatic data needed for simulation, i.e. average air temperature, radiation, air humidity and wind speed, were calculated as the mean of the data for the five coastal stations.

The Mariut region is subdivided into 5 regions, with a meteorological station in the centre of each region (Figure 2). The climatic data sets for each of the five stations and one example of a "mean climate", as used in the simulation runs, are presented in Table 1.

2.3 Soils

a. Physical classification

Soil data from the FAO reports on the northwestern coastal region of Egypt were used for simulation of barley production. FAO prepared both a soil map and a potentiality map for agriculture.

Four main soil groups are distinguished:
- windblown soils
- soils of the former beach plains and dune depressions
- soils of the alluvial fans and outwash plains
- rock land

These soil groups are subdivided into soil types according to depth of the profile and soil texture. For each soil type a representative set of soil physical and soil chemical characteristics is tabulated in the FAO reports. For the present purpose, however, it is more realistic to classify the soils according to soil moisture characteristics and/or hydraulic conductivity. The FAO reports do not provide enough data for that purpose.

Harga et al. (1973) determined soil moisture characteristics for the following five geomorphological units, distinguished in the northwestern desert:
- oolitic sand dunes
- coastal plain
- lagoon area
- frontal plain
- Mariut tableland

For that purpose a transect was sampled in the Burg el Arab area. The soil moisture content at different soil moisture suction values is reported as a fraction by weight. In the simulation model a volume fraction is needed. Harga et al. (op.cit.) did not measure bulk density, needed for the transformation from weight to volume fraction. Therefore, bulk densities measured by Gomaa et al. (1978) were used. They sampled in the Burg el Arab and Omayed areas and determined both bulk density and particle size distribution. Harga et al. (1973) also determined particle size distribution.

In the soil data file of the simulation model, data for 14 different "standard" soil types, characterized by particle size distribution are tabulated, following the classification by Rijtema (1969). In literature on Egypt many soils are classified as sandy loam. This texture class was not included in the standard soil data set and was added to the soil data file (Rijtema, 1969).

The measured soil moisture characteristics, given in Table 2, were added to the soil data file as separate soil types except those for the oolitic sand dunes and the lagoon area, because these areas are not suitable for field crops. The additional parameters needed for simulation (e.g. hydraulic conductivity) were taken from a similar soil texture class, according to particle size distribution and soil moisture characteristic.

A short description of the soil types, as distinguished by FAO (1970), is given in Appendix I.

The potentiality map for agriculture was used to determine which soil types and which areas are suitable for barley cultivation. Only these areas are considered in the simulation study.

b. Chemical classification

Most of the soils in the area are calcareous and the average $CaCO_3$ content of soils suitable for barley cultivation is 30%, but ranges between 10 and 60%. The most appropriate way of taking this into consideration in the simulation model is through its effect on the soil moisture characteristics. Unfortunately only very few measured ones are available.

Another problem in the region is soil salinity. For all soil types, part of the area is reported to be saline and therefore unsuitable for agriculture. FAO (Report 2, 1970) estimated the fraction of saline soils within each potentiality class. These fractions are presented when calculating the cultivable area for the various regions. If enough water is available with adequate drainage facilities, the salts can be leached beyond the rooted zone into deeper layers until they finally reach the groundwater.

The uptake of nitrogen and phosphorus by barley is estimated from chemical analysis of samples from 8 barley fields, sampled in spring 1985 in Egypt. Six of the barley fields were situated on a sandy loam soil, one on a loam and one on a loamy sand soil. One of the six barley fields on a sandy loam was an exceptional field, so it was discarded. The averages of available N and P for plant growth on sandy loam soils are 32 kg ha^{-1} and 2.8 kg ha^{-1}, respectively (P/N-ratio = 0.09). For loamy sand the values are 28 and 3.9 kg ha^{-1} (P/N-ratio = 0.14) and for loam 15 and 1.1 kg ha^{-1} (P/N-ratio = 0.07). Bakr Salem (1985) measured values of 33 and 3.6 kg ha^{-1} on a fine sandy soil (P/N-ratio = 0.11). These values are all for unfertilized situations in the growing season 1984-1985. From the P/N-ratios it may be concluded that P uptake is not limited by a minimum supply of N or visa versa, although on loamy soils P is in relatively short supply and on loamy sand soils N.

El Hadidy et al. (1971) measured an N-uptake by barley of 72.5 kg ha^{-1} in a phosphorus fertilized situation (application of 55.3 kg P ha^{-1}) on a sandy loam soil in Ras el Hekma. This value seems rather high, as no nitrogen fertilizer had been applied on that plot, but no satisfactory explanation could be found. From the same fertilizer experiment the N-recovery was calculated from plots where nitrogen fertilizer was applied. It was 0.44 for nitrate fertilizers and 0.3 for ammonium fertilizers. From experiments by Wassif et al. (1979) a recovery of N-fertilizers of 0.4 is estimated.
Sabet et al. (1968) carried out a fertilizer experiment using various nitrogen fertilizers. All treatments received 250 kg P ha^{-1}, including the control (i.e. no N application). In the control 10.4 kg N ha^{-1} was taken up from the soil by

the barley crop. The N-recovery was 0.65 for calcium nitrate and urea, 0.56 for ammonium sulphate and 0.74 for ammonium nitrate. It should be noted that this was a lysimeter trial and the plants had only grown for 56 days.

These are the only available soil chemical data at the moment. On the basis of these data the following natural soil fertility data are estimated:

loam : 10 kg N and 1 kg P per hectare
sandy loam: 32 kg N and 3 kg P per hectare
loamy sand: 28 kg N and 4 kg P per hectare
fine sand : 33 kg N and 4 kg P per hectare

The N-recovery is set at 0.4 and the P-recovery at 0.1, the latter estimated as an average for superphosphate.

2.4 Water supply

Two sources of water exist in addition to rainfall.

a. Surface run-off

Measured quantitative data about run-on/run-off in the area are very scarce. In the FAO project some estimates were made for the pilot areas. Surface run-off coefficients (= fraction of the rainfall that flows to other areas over the soil surface) are estimated and for some areas also the ratio catchment area to beneficiary area. The average run-off coefficient over distances of 50 to 100 m is 0.20 to 0.25 and over longer distances 0.05 to 0.10. Run-off is depending on rainfall intensity and infiltration capacity and is a function of soil type and soil surface conditions and topography (slope). If rainfall is low, the ratio catchment area to beneficiary area has to be high for a successful barley crop, as a total water supply of 200 mm is considered the minimum for barley cultivation (FAO, REMDENE).

b. Wadi flow

In part of the Mariut region additional water is supplied by wadi flow. East of Fuka no wadis exist and the barley crop depends on rainfall and surface run-off only. West of Fuka wadi flow is an important part of the total water supply to the crop. FAO has estimated the wadi flow and the beneficiary area for some wadis in the region. These data have been extrapolated to other wadis too, as these are the only data available.

2.5 Water regimes

Simulation runs have been carried out for various water regimes, i.e.:
- water regime with an even distribution and complete and homogeneous infiltration;
- 250 mm infiltration annually;
- 300 mm infiltration annually;
- 450 mm infiltration annually;
- potential situation with an optimal water supply.

The natural water regime comprises rainfall, surface run-off and, if present, wadi flow. In the first simulation runs the water regime with an even distribution resulted in very low yields and in some areas in no yield at all, which seemed unrealistic compared to the reported average yield levels of 500 to 700 kg grain ha^{-1}. From additional simulation runs it was concluded that the water regime, required to achieve the actual barley yields was about 250 mm. Therefore, simulation runs for a water regime of 250 mm were carried out for each soil type.

The 250 mm water regime can only be realized by collection of run-off and wadi flow in addition to rain. The area has an undulating relief and barley is grown mainly in the depressions. In this study it is assumed that on average 250 mm of water is available in the depressions and that the cultivable area consists of depressions only. For each soil type the cultivable area can now be calculated from the total amount of water available on that soil type (rainfall and wadi flow) and the run-off coefficient over short distances.

The 300 mm infiltration represents the amount of water needed for maximum use of the natural soil fertility. At higher water availability nutrient supply is limiting for crop production and fertilizers should be applied.

An infiltration of 450 mm annually is used to calculate the barley production in a fertilized situation. The amount of 450 mm is enough to realize a reasonable yield (3000-5000 kg grain ha^{-1}) and a higher water availability gives only a marginal increase, due to the erratic distribution of rainfall. The required amounts of N and P fertilizers are calculated in the model.

2.6 Standard input data

For execution of the simulation runs some data have to be introduced at the start. These were assumed identical for all simulation runs.

a. WAV: The amount of water available in the soil at emergence in excess of the amount of water at wilting point. This value is set to zero. The actual value is very difficult to assess and depends on unknown factors, such as the intensity and distribution of rain before emergence. In any case the amount available is very low. In the SAMDENE and REMDENE Progress Reports the soil moisture content for various soil types in different years in December/January is reported to be around wilting point, so the assumption WAV = 0 seems reasonable.

b. SSMAX: the maximum surface storage capacity for water. This is set to zero too. Very little is known about the surface storage capacity and in this case it is of minor importance, as infiltration is always complete, and no standing water occurs.

c. In the calculations no influence of a groundwater table is assumed. In most locations the depth of the groundwater is such, that it does not contribute at all to the water availability for plant growth. Only in a narrow belt along the coast groundwater may influence moisture availability to the crop, but as no quantitative data are available about areas and depth of the groundwater table it is difficult to estimate that influence. Moreover, if the groundwater is quantitatively of importance, fruit trees are grown.

2.7 Simulation runs

Simulation of barley production is carried out for four of the five regions distinguished. For the Salloum region no data on soils and water management were available, so barley production could not be estimated. In each region the soil types were described by FAO. Only the soil types suitable for barley cultivation are considered. For each soil type the simulation runs were carried out for the four water regimes described. Most soil types have two different natural water regimes because they occur in two rainfall zones.

As starting date for simulation and thus as date of emergence December 20 was taken.

The results of the simulation runs are presented in units of 100 kg dry matter per hectare, because, considering the reliability of the input data, the calculations are not more accurate. The fertilizers required to achieve the calculated dry matter production are presented in units of 5 kg ha^{-1}.

3. BARLEY PRODUCTION IN THE BURG EL ARAB REGION

The results presented in this chapter refer to the Burg el Arab region, defined as the region between Dekheila and El Alamein.

3.1 Introduction

For simulating barley production in the Burg El Arab region the climatic data set from Dekheila meteorological station is used (Table 1). The area is served by two irrigation canals: the Nasr Canal and the Mariut (Extension) Canal. From these canals part of the area between Alexandria and El Hammam can be irrigated.

For the simulation of barley production, the amount of irrigation water available for plant growth is added to the rainfall. The number of rainy days is reduced to 3 per month and the dates for irrigation are set at 5, 15 and 25 for each month. A farmer usually does not irrigate more than once a month, but rain may fall between two irrigation events. In this case rain is distributed together with the irrigation water, which means that between irrigations no water is added to the soil. To compensate partly for this effect, the monthly number of irrigations is set to 3 instead of 1.

"Irrigation" in this context refers to both run-on and irrigation from the canals, i.e. the total amount of water added to the soil surface in addition to rainfall. The efficiency of irrigation is not taken into account. "Infiltration" comprises both "irrigation" and rainfall added to the soil surface during the growth period of barley.

The simulated results for the potential, the nitrogen-limited and the phosphorus-limited production situations are specific for each climate and are discussed first. Subsequently, the results for each soil type are presented separately for the irrigated and the rainfed situation, in dependence of water and nutrient availability. No wadis are present in the Burg el Arab region.

3.2 The potential and the nutrient-limited situation

The potential yield amounts to 6 300 kg grain ha^{-1} and 4 900 kg straw ha^{-1} (Table 3). Depending on the natural soil fertility, which is either 32 kg N and 3 kg P ha^{-1} or 28 kg N and 4 kg P ha^{-1}, the required fertilizer amounts to attain that yield are either 125 kg N and 65 kg P ha^{-1} or 135 kg N and 55 kg P ha^{-1}. The nitrogen-limited yield, when 32 kg N is available is 2 400 kg grain ha^{-1} and for 3 kg available phosphorus the maximum yield is 2 000 kg grain ha^{-1}. For a natural soil fertility level of 28 kg N and 4 kg P ha^{-1}, the maximum yields are 2 100 and 2 700 kg grain ha^{-1}, respectively.

In the potential situation the value of the harvest index is about 0.55, depending on the exact lenght of the growth period. The harvest index is a result of the dry matter distribution, which is introduced in the model as a forcing function. As no data on the potential of Egyptian barley cultivars were available, it is unknown what the harvest index should be. Therefore, it is left unchanged. In the water-limited situation the simulated harvest index and the actual harvest index, as reported by Abo Elenein and Sultan (pers.comm.) vary within the same range (0.10-0.25). In the nutrient-limited situation an optimal water supply is assumed. The only constraint on crop production is the absolute amount of nitrogen or phosphorus available. The situation, where both nutrients and water may be limiting at times, is not considered here.

3.3 Barley yields for the various soil types under irrigation

The results of the simulation runs for the various soil types are presented in Table 4. The 250 mm water regime, as described in Section 2.5, is not considered for the irrigated area, because levelling of the surface has been carried out. Two irrigation levels are distinguished. Irrigation level one is equivalent to the 300 mm water regime in rainfed areas and represents the situation in which maximum production without fertilizer application can be achieved. Irrigation level two is equivalent to the 450 mm water regime in rainfed areas, as can be seen by comparing the annual infiltration during the growing season (I) in Table 4 and 5. Of course, higher irrigation rates can be applied, but then also other crops will be grown. Even at the second irrigation level farmers may prefer other crops, but this is not considered in this study. Only the potentials for barley cultivation are explored.

b. Soil type B1

- Soil type: deep sandy loam to loam or clay loam.
- Natural soil fertility: 32 kg N ha^{-1}; 3 kg P ha^{-1}.
- Agricultural potentiality: suitable for all crops.

This soil type is situated on the Frontal Plain and the Mariut Tableland. For both geomorphological units soil moisture characteristics are measured (Harga et al., 1973, Table 2), so two separate simulation runs were carried out.

- Frontal Plain

Irrigation water is available from the Mariut (Extension) Canal. The soil type is situated in two rainfall zones. From the simulation results it may be concluded that growing barley under rainfed conditions assuming an even distribution and homogeneous infiltration of water, without any additional water is not feasible. Grain yield is only 300 kg ha^{-1} in the highest rainfall zone (184 mm), while straw yield is 3 300 kg ha^{-1}. If crop performance is poor and expected grain yields are low like this, the barley is usually grazed.

Without any nitrogen and/or phosphorus fertilizer application, i.e. irrigation level one, the maximum yield is about 1 550 kg grain and 4 400 kg straw ha^{-1}. If more irrigation water is available and fertilizers are applied higher yields are possible. The magnitude of the increment depends on the degree to which the constraints are removed by additional water and nutrients. If irrigation level two is reached, both the grain and the straw yield increase to 4 600 kg ha^{-1}. Fertilizer requirements are 80 kg N and 45 kg P ha^{-1}.

- Mariut Tableland

Irrigation water is available from the Nasr Canal for part of the Tableland region with soil type B1. This soil type is situated in two rainfall zones. Under rainfed conditions grain yield is 50 kg ha^{-1} and straw yield 1 400 kg ha^{-1}. For the rainfall zone with an average precipitation of 112 mm no simulation runs have been carried out.

At irrigation level one a yield of 1 300 kg grain and 4 050 kg straw ha^{-1} can be achieved, without fertilizer application. At irrigation level two the yield is 3 500 kg grain and 4 500 kg straw ha^{-1}. Fertilizer requirements are 50 kg N and 30 kg P ha^{-1}.

b. Soil type C2

In part of the area another variation of soil type B1 is found, i.e. as a complex with rock (C2). The soil present is suitable for all crops, but it does not cover the whole area, as in part rock surfaces. No data are available on the part of the surface covered by soil, so a ratio of 1:1 for soil area to rock area is assumed. C2 occurs both in the Frontal Plain and on the Mariut Tableland. The soil moisture characteristics are the same as for B1, so the yields presented in Table 4 have to be divided by two to obtain the average yields for the C2 soil type, in both areas, since only half of the area can be cultivated.

3.4 Barley yields for the various soil types in the rainfed situation

In part of the Burg el Arab region only rainfed barley cultivation is possible. The simulation results for the various soil types are presented in Table 5.

a. Soil type B1

The physical and chemical characteristics of this soil type are similar to those described in the previous section and so are the simulation results for the rainfed situation with an even distribution of water over the surface of B1. As described in Section 2.5, the prevailing average water regime is 250 mm (in the depressions).

- Frontal Plain

The yield for the rainfed situation with barley cultivation in the depressions only, is 600 kg grain and 3 350 kg straw ha^{-1}. Under the 300 mm water regime the yield increases to 1 050 kg grain and 4 350 kg straw ha^{-1} and under 450 mm to 4 550 and 4 850 kg ha^{-1}, respectively, the latter situation requiring 80 kg N and 45 kg P ha^{-1}.

- Mariut Tableland

Under 250 mm infiltration annually, the grain yield is 400 kg ha^{-1} and the straw yield is 2 700 kg ha^{-1}. This increases to 900 and 4 000 kg ha^{-1}, respectively, under 300 mm and to 3 200 and 4 550 kg ha^{-1} under 450 mm. In the latter situation 45 kg N and 25 kg P ha^{-1} have to be applied.

b. Soil type B4d

- Soil type: deep loamy sand to slightly loamy sand, with locally a loamy subsoil, sloping and gullied.
- Soil moisture characteristic: Coastal Plain.
- Natural soil fertility: 28 kg N ha^{-1}; 4 kg P ha^{-1}.
- Agricultural potentiality: suitable for all crops.

Under rainfed conditions in the 125-150 mm rainfall zone grain yield is 50 kg ha^{-1} and straw yield 1 200 kg ha^{-1}. Receiving 184 mm rain annually, the yield is 500 kg grain and 3 350 kg straw ha^{-1}. Cultivating barley in the depressions, yields 1 100 kg grain and 4 050 kg straw ha^{-1}. Concentrating the water on part of the depression surface to an availability of 300 mm, increases the production to 1 800 kg grain and 4 800 kg straw ha^{-1}. Under a water regime of 450 mm the yields are 4 500 kg grain and 4 900 kg straw ha^{-1}. The amounts of fertilizer required to obtain these latter yields are 90 kg N and 35 kg P ha^{-1}.

c. Soil type C2

Soil type C2 is also present in the area, depending on rainfall only. The characteristics of this soil type and the remarks as presented in the previous section, apply to this section too.

3.5 Discussion on the simulation results

Under the regimes with a limited water availability the harvest indices are very unfavourable due to the rainfall distribution. Most of the rain falls during the pre-anthesis phase of the crop and only 10% of the annual precipitation is available during grain filling. Water stress is thus much more severe after anthesis than before. Reported harvest indices vary from 0.1 in dry years to 0.25 in wet years. For the simulation runs climatic averages are used. For the 250 mm water regime the harvest index is about 0.15 and for the 300 mm water regime it is 0.20 to 0.25. Thus the simulated harvest indices correspond with the reported values.

From the simulated results it may be concluded, that growing barley under rainfed conditions, assuming an even distribution of rainfall over the surface and a homogeneous infiltration, is not a feasible nor a realistic activity. Cultivating the depressions only, which is assumed to be equivalent to a water availability of 250 mm, gives the yields that are achieved at present.

In part of the Burg el Arab region irrigation is possible from the existing canals. Irrigation with 110 mm water, evenly distributed over the growing season and using additional fertilizers, gives reasonable to good yields. That also applies to barley cultivation under an annual water availability of 450 mm in rainfed areas, which can be achieved by concentrating water on part of the depressions. Considering an equal water availability the harvest index under irrigation is more favourable than under water harvesting, due to the more regular distribution of available water.

Simulation runs for rainfall zones below 125-150 mm have not been carried out, because the yields would be too low, compared to reported yields.

3.6 Cultivable area

The area per soil type is estimated using the soil map and data from FAO reports 2 and 5 (1970) and REMDENE Progress Report 2 III (1981). All land suitable for field crops is situated east of el Hammam. The whole area to which the climatic data set of Dekheila is applied, roughly situated between Burg el Arab and el Alamein, covers an area of 171 670 ha of which 35% is suitable for barley cultivation. The area per soil type and the distribution over the rainfed and irrigated area are given in Table 6.

Part of these areas cannot be cultivated, because the soil is too saline. The area suitable for barley cultivation, i.e. the total area minus the saline area, is distributed over four rainfall zones (Table 7), by combining a soil map with an isohyet map.

Under irrigation all land can be cultivated, because additional water is supplied by canals. It is assumed, that 20% of the surface is occupied by roads, dykes, canals etc. (FAO-1 and -5, 1970). This estimate applies to floodirrigation systems, which is the main irrigation method in the northwestern coastal zone. Under rainfed conditions, however, the depressions, i.e. the actually cultivable area, comprise only part of the suitable area. The cultivable area, as given in Table 2, differs for the various water regimes, depending on the degree of concentration of the available water. The total amount of water available on a soil type is equal for all three calculated water regimes; only the degree of concentration varies. Soil type B4d is described as being sloping and gullied. Therefore, a reduction of 25% is imposed on the cultivable area of B4d. To avoid this 25% reduction, erosion controll measures are necessary. As for the complex soil type C2, half of the area is assumed to be covered by rock and half by soil. The run-off coefficient of rocks is estimated at twice that of soil, i.e. 0.50, so half of the area of C2 receives 1.5 times the amount of rainfall.

The efficiency of water concentration is assumed to be equal to the run-off coefficient over short distances, i.e. 0.25 for the Burg el Arab region. This applies to all water regimes. As the situation with 250 mm in the depressions is assumed to be the existing situation, a special effort has to be made to concentrate the water on smaller areas with an availability of 300 or 450 mm. This can be done, for instance, by constructing dykes. At the same time measures can be taken to increase the run-off coefficient, resulting in a larger cultivable area. These latter measures are not considered at this stage in this study.

The area under irrigation in the Burg el Arab region is estimated at about 25 000 ha (Table 7). This estimate is based on a combination of various maps (U.A.R. High Dam Soil Survey Project, 1963; FAO-2, 1970; ULG consultants, 1976; Kamal, in prep.). Subtracting 20% for dykes, roads, canals etc., the net area becomes about 20 000 ha. The rainfed area, suitable for barley cultivation is 33 000 ha. Under natural conditions (250 mm water regime) roughly 7 000 ha can be cultivated. If water is concentrated to such an extent that 300 mm is available annually, the cultivable area is reduced to 5 000 ha. Increasing concentration of water to an availability of 450 mm, reduces the cultivable area to roughly 3 000 ha or 9% of the total suitable area.

On the remaining part of a soil type, where no barley is cultivated due to water shortage, 75% of the rainfall is available for the natural vegetation, 25% being run-off. This area can be grazed by sheep and goats and the higher the water regime for barley cultivation, the larger the area to be grazed.

3.7 Regional barley production

From the calculated barley yields and the estimates of the cultivable area for the various soil types, the regional barley production is calculated. Table 8 presents the production of the irrigated area. If no fertilizers are applied, the maximum production is 27 000 ton grain and 83 000 ton straw yr^{-1}. If irrigation level 2 is applied the maximum yield is 77 000 ton grain and 90 000 ton straw yr^{-1}. In the latter case fertilizers have to be applied at a rate of 1 200 ton N and 700 ton P yr^{-1}.

The water requirements to achieve irrigation level 1 and 2 are presented in Table 9. Infiltration during the growing season is calculated by the simulation model and this is given in Table 4 for each of the production levels. The difference in infiltration between two production levels is the amount of water that should be supplied by irrigation. Of course that amount varies with rainfall zone. That means for instance that 60 mm irrigation is required in the 150-200 mm rainfall zone to reach irrigation level one and 130 mm to reach irrigation level two (Table 4). The amounts of water required are calculated for all three rainfall zones in which irrigation is possible and for both irrigation levels. To achieve irrigation level one on all irrigated land, 17 million m^3 water is required. To achieve irrigation level two 31 million m^3 water is required.

Irrigation efficiency, i.e. the ratio between the amount of water applied in the field and the amount of water delivered at the head of the main canal, is not considered in these calculations. Cabellero (1984) estimates the irrigation efficiency at present at 25% and it can be increased to 40-63% by shortening the length of the irrigation runs and postponing the subsequent irrigation until the soil moisture content is below field capacity. FAO (Report 2, 1970) expects that an efficiency of 60% can be achieved. It should be noted that not the whole area is under irrigation yet. In part of the area reclamation is still going on. Furthermore, other crops are probably more profitable than barley when enough water is available, but this will not be considered in this study.

Barley production in the rainfed part of the Burg el Arab region for the 3 distinguished water regimes is given in Table 10. At present, with barley cultivation in the depressions only, the total production is 3 800 ton grain and 20 900 ton straw. No fertilizers have to be applied in that situation. If water is concentrated on part of the depression surface to an availability of 300 mm annually, the production increases to 5 500 ton grain and 21 500 ton straw. The reduction in cultivable area is more than compensated by the yield increase, both for grain and straw. A further concentration to the 450 mm water regime increases total grain yield to 10 200 ton, but reduces straw production to 12 800 ton. In that situation 163 ton N and 86 ton P have to be applied annually. The reduction in cultivable area can still be compensated by the yield increase as far as the grain is concerned, but for straw the production decreases by 40%. The overall harvest index increases with increasing water availability from 0.15 to 0.44.

4. BARLEY PRODUCTION IN THE DABAA REGION

4.1 Introduction

The procedure followed is the same as in the preceding chapter. The climatic data set from Dabaa meteorological station is used and the region extends from el Alamein westwards to Fuka. The most important difference with the Burg el Arab region is that in this region no irrigation canals exist. Plans exist to extend the Nasr Canal up to Dabaa, but it is doubtful whether these plans will ever be implemented due to the limited suitability of the region for irrigated agriculture. At this moment the canal extends till Hammam, where water is available. In this study only the present situation is considered and future plans are not taken into account.

"Infiltration" in this situation refers to run-on and rainfall added to the soil surface during the growing period of barley. The catchment area for run-off consists of rocky ridges, surrounding the soils suitable for barley cultivation. The ridges are 3 to 10 m higher than the cultivated soils. In most places rock surfaces, but locally less than 30 cm loamy sand to sandy loam may overly the rock (FAO-2, 1970). Considering this nature of the surface the run-off coefficient for long courses of water flow is estimated at 0.10. From the soil map of the pilot areas Fuka and Dabaa it is derived, that the ratio catchment area to beneficiary area is about 1. Therefore, the soils in the 125-150 mm rainfall zone receive about 150 mm water annually, and the soils in the 100-125 mm rainfall zone receive 125 mm annually. This latter amount is below the 137 mm rainfall, and yields at this water regime are very low, so no separate simulation runs have been carried out.

4.2 The potential and the nutrient-limited situation

Potential production amounts to 6 700 kg grains ha^{-1} and 5 600 kg straw ha^{-1} (Table 11). Depending on natural soil fertility, which is either 32 kg N and 3 kg P ha^{-1} or 28 kg N and 4 kg P ha^{-1}, the required fertilizer amounts are 145 kg N and 70 kg P ha^{-1} or 155 kg N and 60 kg P ha^{-1}, respectively.

The N-limited production with 32 kg ha^{-1} of available N is 2 400 kg grains and 2 000 kg straw ha^{-1} and for 3 kg ha^{-1} of available P the yields are 2 000 and 1 700 kg ha^{-1}, respectively. The N-limited production with 28 kg ha^{-1} of available N is 2 100 kg grains and 1 800 kg straw ha^{-1} and for 4 kg ha^{-1} available P the yields are 2 600 and 2 200 kg ha^{-1}, respectively.

4.3 Barley yields for the various soil types

The results of the simulation runs are presented in Table 12. For the 250, 300 and 450 mm water regime the calculated yields are identical to those for the rainfed part of the Burg el Arab region, because a mean climatic data set is used for these water regimes. The results are presented again in Table 12 to complete the picture for each region, because the results will be used per region later on.

a. Soil type B1

- Soil type: deep sandy loam to loam or clay loam.
- Soil moisture characteristic: Frontal Plain.
- Natural soil fertility: 32 kg N ha^{-1}; 3 kg P ha^{-1}.
- Agricultural potentiality: suitable for all crops.

The simulation results for this soil type show that under rainfed conditions in the 100-125 mm rainfall zone no grains are produced at all and only 1 250 kg straw ha^{-1} can be harvested. Under a water regime of 150 mm grain yield is 50 kg ha^{-1} and straw yield is 1 500 kg ha^{-1}. This is still not profitable, considering the sowing rate of 60-100 kg ha^{-1}. Under the mean climate with 250 mm annual infiltration the grain yield is 600 kg ha^{-1}. Under the 300 mm water regime grain yield is 1 050 and straw yield 4 350 kg ha^{-1}. Under the mean climate with 450 mm annual infiltration both grain and straw production are 4 600 kg ha^{-1}. To achieve this yield, application of 80 kg N ha^{-1} and 45 kg P ha^{-1} is required.

b. Soil type B3

- Soil type: limited (30-60 cm) and moderately deep (60-90 cm) sandy loam to loam over caliche or rock.
- Soil moisture characteristic and texture: fine sandy loam.
- Natural soil fertility: 32 kg N ha^{-1}; 3 kg P ha^{-1}.
- Agricultural potentiality: suitable for vegetables, field crops and moderately deep rooted crops, partly shallow rooted (30-60 cm) crops only.

Under rainfed conditions 100 kg grain is produced and 1 850 kg straw ha^{-1}. Assuming a water regime of 150 mm, grain yield is 150 kg ha^{-1} and straw yield 2 050 kg ha^{-1}. Under the mean climate with 250 mm infiltration annually, grain yield on the shallow soils of 30 to 60 cm depth is 850-950 kg ha^{-1}, with a mean of 900 kg ha^{-1} and straw yield is 3 800 kg ha^{-1}. No fertilizers are needed. On the deeper soils of 60 to 90 cm grain yield is also 900 kg ha^{-1} and straw yield is 3 700 kg ha^{-1}. Under the 300 mm water regime grain yield is 1 350 kg and straw yield 4 700 kg ha^{-1} on the shallow soils. On the deeper soils the yields are 1 400 and 4 600 kg grain and straw ha^{-1}, respectively. For the mean climate with 450 mm infiltration annually, the grain production on the shallow soils and the deeper soils is 3 850 and 4 950 kg ha^{-1}, respectively, and straw yield is 4 850 kg ha^{-1} for both soil depths. On the shallow soils application of 65 kg N ha^{-1} and 35 kg P ha^{-1} is required. On the deeper soils this is 90 kg N and 50 kg P ha^{-1}.

c. Soil type B4

- Soil type: limited and moderately deep (30-90 cm) loamy sand to slightly loamy sand over caliche or rock, sloping and gullied.
- Soil moisture characteristic: Coastal Plain.
- Natural soil fertility: 28 kg N ha^{-1}; 4 kg P ha^{-1}.
- Agricultural potentiality: suitable for vegetables, field crops and moderately deep rooted crops, partly shallow rooted crops only.

Under rainfed conditions with homogeneous infiltration 50 kg grain is produced and 1 400 kg straw ha^{-1}. Under a water regime of 150 mm 100 kg grain ha^{-1} and 1 700 kg straw ha^{-1} are produced. Under the 250 mm water regime the yield increases to 600 kg grain and 3 200 kg straw ha^{-1}. The yield increases with increasing water availability to 950-1 050 kg grain ha^{-1}, depending on soil depth, under the 300 mm water regime. As it is unknown what proportion of this soil type is shallow and produces 950 kg grain ha^{-1} and what proportion is deeper and produces 1 050 kg ha^{-1}, an average of 1 000 kg grain ha^{-1} is assumed to be representative for this soil type. The same procedure is followed for the straw, which yields 4 100 kg ha^{-1}. Under the 450 mm water regime a yield of 3 200 kg grain and 4 450 kg straw ha^{-1} is achieved, requiring 50 kg N and 20 kg P ha^{-1}.

d. Soil type DS5

- Soil type: dune depressions, predominantly less than 60 cm weathered oolitic sand over caliche.
- ~~Soil moisture characteristic and texture: loamy fine sand.~~
- Natural soil fertility: 28 kg N ha^{-1}; 4 kg P ha^{-1}.
- Agricultural potentiality: only suitable for shallow rooted crops.

The inland dunes have a moderate infiltration capacity and are only slightly sloping, so a relatively low run-off coefficient seems appropriate for these soils. It is estimated at 0.05 for long courses of water flow. Dune depressions (soil type DS5) are situated at several places in the inland dunes. The area of the dune depressions that receives run-off, is relatively small compared to the surrounding dunes that supply the run-off. These dune depressions occur mainly in the 100-125 mm rainfall zone. The depressions receive enough run-off in favourable rainfall years to cultivate a good barley crop (FAO-2, 1970). Considering this and the soil map, it is assumed that for the dune depressions the ratio catchment area to beneficiary area is 5. This amounts to 140 mm infiltration annually, comparable to the rainfall in the 125-150 mm zone.

Under rainfed conditions with homogeneous infiltration the yield is 100 kg grain ha^{-1} and 1 500 kg straw ha^{-1}. The production on soils of 30 cm deep and 60 cm deep does not differ under these conditions. The production increases to 950 kg grain and 3 050-4 050 kg straw ha^{-1}, if infiltration is 250 mm. Again the arithmetic average of the different values for straw production (3 550 kg) is assumed to be representative for this soil type. Under the 300 mm water regime grain yield is 1 250 kg ha^{-1} and straw yield 4 200 kg ha. This increases to 2 400 and 4 500 kg ha^{-1}, respectively, under the 450 mm water regime. In the latter situation 35 kg N and 10 kg P ha^{-1} are required.

e. Soil type F1

- Soil type: limited deep sandy loam to loam over caliche or rock (30-60 cm).
- Soil moisture characteristic and texture: fine sandy loam.
- Natural soil fertility: 32 kg N ha^{-1}; 3 kg P ha^{-1}.
- Agricultural potentiality: only suitable for shallow rooted crops.

The simulation results for this soil type are identical to those for soil type B3, depth 30-60 cm. Soil type F1 has been distinguished because of its different origin, but barley production on both soil types is identical.

f. Soil type F3

- Soil type: deep sandy loam to loam or clay loam.
- Soil moisture characteristic and texture: sandy loam.
- Natural soil fertility: 32 kg N ha^{-1}; 3 kg P ha^{-1}.
- Agricultural potentiality: suitable for all crops.

Under rainfed conditions in the 100-125 mm rainfall zone 50 kg grain ha^{-1} is produced and 1 350 kg straw ha^{-1}. In the 125-150 mm rainfall zone 200 kg grain and 2 150 kg straw ha^{-1} are produced. Under the mean climate with 250 mm infiltration annually, 1 000 kg grain ha^{-1} and 3 850 kg straw ha^{-1} are produced. This increases to only 1 450 kg grain and 4 700 kg straw ha^{-1} under a mean climate with 300 mm infiltration annually. Under the 450 mm water regime grain yield is 5 350 kg ha^{-1} and straw yield 4 900 kg.ha^{-1}. Fertilizer requirements in that case are 105 kg N and 50 kg P ha^{-1}.

g. Soil type C1

- Soil type: complex of rock and shallow to moderately deep sandy loam to loam over caliche or rock.

This is a complex of rock and soil type B3, mainly with soil depth 30-60 cm. Rock is assumed to cover half the surface area and soil the other half. The surface run-off coefficient for rock is estimated at about 0.5, so the natural water regime is 210 mm (1.5 * 140 mm). Grain yield is 500 kg ha^{-1} and straw yield 3200 kg ha^{-1} in that situation. The other simulation results are identical to those for soil type B3, but only half of the area can be cultivated.

4.4 Discussion on the simulation results

From the simulated results it may be concluded that barley cultivation under rainfed conditions is not a feasible nor a realistic activity. In the Dabaa region, irrigation is not possible. The water from cisterns and galleries is mainly used for human and animal consumption. The amount available for supplemental irrigation is not sufficient for irrigation of barley fields, the cisterns can only serve on a small scale vegetable fields and young fruit trees.

Barley is the most important field crop in the area, but it gives a satisfactory yield only once every five years (FAO-5, 1970). Only at places where substantial amounts of run-off water concentrate, continuous barley cultivation is a feasible activity.

4.5 Cultivable area

The total area covered by the various soil types in the region is 47 470 ha (Table 13). As irrigation on a large scale is not possible, all water available to plants in addition to rain must originate from run-off/run-on. For each soil type part of the area is reported to be saline and therefore unsuitable for agriculture. FAO gives a rough estimate of the percentage saline soils for each potentiality class. The soils suitable for barley cultivation are concentrated close to the coast and comprise 44 230 ha totally. From areas more inland, only a limited amount of water runs off to the coastal zone, because the land is only slightly sloping (FAO-2, 1970), so all water in addition to rain originates from redistribution on a restricted scale.

The suitable soils are situated in two rainfall zones. In the 100-125 mm rainfall zone 29 790 ha is suitable for barley cultivation. The cultivable area, however, which is restricted to the depressions, is 5 310 ha. If water is concentrated to an availability of 300 mm annually, the cultivable area is reduced to 3 830 ha. Increasing water concentration to the 450 mm water regime, results in a further reduction of the cultivable area to 2 260 ha. The rainfall zone 125-150 mm comprises 14 440 ha, of which 4 320 ha is situated in depressions. On soil type B4 barley can be grown on only 75% of the area, because the surface is sloping and gullied. On the other hand, the water table is close to the surface (FAO-2, 1970), so it is assumed that barley can use the groundwater. Therefore 75% of the area can be cultivated for all water regimes. Concentrating water to an availability of 300 or 450 mm, results in a total cultivable area of 3 380 and 2 180 ha, respectively.

Under the present conditions with barley cultivation in the depressions only, 9 630 ha or 22% of the suitable area can be used annually.

4.6 Regional barley production

From the calculated barley yields and the estimated cultivable area, the total barley production in the Dabaa region is calculated for the three distinguished water regimes (Table 14). At present, with barley cultivation in the depressions only, the total production is 6 600 ton grain and 33 300 ton straw from 9 630 ha. Under the 300 mm water regime a total production of 8 100 ton grain and 31 400 ton straw can be achieved on 7 210 ha. The reduction in cultivable area results in an increase in the total grain production and a decrease in the total straw production. A further concentration of water to an availability of 450 mm annually, increases grain yield considerably to 18 300 ton, but due to the reduction of the cultivable area to 4 440 ha the total straw production decreases by 35% to 20 400 ton. To achieve the latter production level 314 ton N and 167 ton P are required annually. It depends on the relative scarcity of both grain and straw and therefore on their price ratio, which water regime is the most favourable. Other factors influencing this choice are labour requirements and the costs, but these factors are considered elsewhere.

5. BARLEY PRODUCTION IN THE MATRUH REGION

5.1 Introduction

The results presented in this chapter refer to the Matruh region, defined as the region between Fuka and Negeila.

The climatic data set for Mersa Matruh meteorological station is used for the Matruh region. An important feature of this region is the availability of water supplied by wadi flow. In the regions east of Fuka, hardly any wadi flow occurs, but west of Fuka it can be a substantial part of the total water available for plant growth.

"Infiltration" in this situation refers to rainfall, surface run-on and water from wadi flow added to the soil surface during the growing period of barley.

Data on run-off coefficients, wadi flow, etc. for the whole region, are available from 3 pilot areas, as described by FAO (Report 5, 1970). By combining these data with the soil map and the rainfall zones, average values for the total annual water supply for the various soil types are calculated. These calculated water regimes may differ per soil type, because the soil types are situated at different locations in the region. A short description of the water regime applied in the simulation runs is given for each soil type in the relevant subsection.

In the FAO reports (Reports 2 and 5, 1970) the wadi flow that is utilized in average years is estimated. That fraction is usually only 20 to 30% of the total wadi flow, the remainder flowing to the sea. For simulation, only the fraction utilized is taken into account for estimating the amount annually available for plant growth. The amount of water lost is discarded. The amount of water annually available is calculated, assuming that run-off is evenly distributed over the whole area. Then redistribution is calculated in such a way that the depressions receive 250 mm.

5.2 The potential and nutrient-limited situation

Under optimum conditions barley yield is 6 500 kg grain and 5 300 kg straw ha^{-1} (Table 15). Depending on natural soil fertility, either 32 kg N and 3 kg P ha^{-1}, 28 kg N and 4 kg P ha^{-1} or 15 kg N and 1 kg P ha^{-1}, the fertilizer requirements for these yields are 135 kg N and 65 kg P ha^{-1}, 145 kg N and 55 kg P ha^{-1} or 175 kg N and 85 kg P ha^{-1}, respectively.

The N-limited production on soils with a natural fertility of 32 kg N ha^{-1} is 2 400 kg grain and 2 000 kg straw ha^{-1}. On soils with 28 kg ha^{-1} available N the production is 2 100 and 1 700 kg ha^{-1}, respectively, and on soils with 15 kg N ha^{-1} it is 1 100 and 900 kg ha^{-1}. The P-limited production on soils with 3 kg available P ha^{-1} is 2 000 kg grain and 1 600 kg straw ha^{-1}, on soils with a P supply of 4 kg ha^{-1} it is 2 700 and 2 200 kg ha^{-1} and on soils with 1 kg P ha^{-1} it is 700 and 500 kg ha^{-1}, respectively. It should be noted that in the nutrient-limited situation an optimal water supply is assumed.

5.3 Barley yields for the various soil types

The results of the simulations for the various soil types are presented in Table 16.

a. Soil type B1

- Soil type: deep sandy loam to loam or clay loam.
- Soil moisture characteristic: Frontal Plain.
- Natural soil fertility: 32 kg N ha^{-1}; 3 kg P ha^{-1}.
- Agricultural potentiality: suitable for all crops.

A total of 120 mm of water is added to the soil surface annually in the 100-125 mm rainfall zone between Fuka and Mersa Matruh. That amount is based on 112 mm rainfall, a surface run-off coefficient over long distances of 0.075 and a ratio of beneficiary area to catchment area of 1:1 ($(1 + 0.075) * 112 = 120$ mm). No simulation runs have been carried out for this water regime, as it will give almost no yield.

A total of 180 mm is added to the soil surface in the 125-150 mm rainfall zone west of Mersa Matruh. This amount is based on 137 mm rainfall, an average wadi flow of 33 mm, an average run-off coefficient over long distances of 0.075 and a ratio of beneficiary area to catchment area of 1:1.

If the available water is distributed evenly over the soil surface, i.e. a water regime of 180 mm annually west of Mersa Matruh, the yield is 100 kg grain and 1 900 kg straw ha^{-1}. Assuming water redistribution to obtain a water availability of 250 mm in the depressions, the production increases to 600 kg grain and 3 350 kg straw ha^{-1}. Concentrating the water on part of the depression surface to an availability of 300 mm, increases the production to 1 050 kg grain and 4 350 kg straw ha^{-1}. Under a water regime of 450 mm the yields are 4 550 kg grain and 4 850 kg straw ha^{-1}. The amount of fertilizer required to obtain these relatively high yields is 80 kg N and 45 kg P ha^{-1}.

b. Soil type B2

- Soil type: deep loamy sand to slightly loamy sand.
- Soil moisture characteristic and texture: loamy fine sand.
- Natural soil fertility: 28 kg N ha^{-1}; 4 kg P ha^{-1}.
- Agricultural potentiality: suitable for all crops.

This soil type only occurs in the northern plain at El Qasr. Under the dunes a large aquifer exists, of which the water is suitable for irrigation. At present, the water is only used for human and animal consumption and for irrigating young fruit trees and vegetables, but it can easily supply the northern plain with irrigation water, according to FAO estimates (Report 5, 1970). In the present situation excess water seeps through the dunes and is lost to the sea.

Under rainfed conditions no grain and 1 200 kg straw ha^{-1} is produced (Table 16). Under 250 mm annual infiltration 1 100 kg grain and 4 050 kg straw are produced. This increases to 1 800 kg grain and 4 800 kg straw ha^{-1} under 300 mm and to 4 500 kg grain and 4 900 kg straw ha^{-1} under 450 mm. In the latter situation 90 kg N and 35 kg P fertilizer ha^{-1} have to be applied.

c. Soil type F1

- Soil type: limited deep (30-60 cm) sandy loam to loam over caliche or rock.
- Soil moisture characteristic and texture: fine sandy loam.
- Natural soil fertility: 32 kg N ha^{-1}; 3 kg P ha^{-1}.
- Agricultural potentiality: only suitable for shallow rooted crops.

The mean climate with 130 mm annual infiltration is based on 112 mm rainfall (100-125 mm zone), an average surface run-off coefficient over long distances of 0.075 and a ratio of beneficiary area to catchment area of 1:2 ((1 + 0.075 * 2) * 112 = 130 mm). This value closely approaches the rainfall of 137 mm, so this water regime is used for calculations for the 100-125 mm rainfall zone. In the 125-150 mm rainfall zone the amount of water added annually to the soil is 150 mm, the parameter values being identical. In general, no wadi flow reaches these local inland depressions in the plateau land. The wadis transport the water further to the coast. Occasionally, small areas may receive some wadi flow, either because they are situated close to the coast or because a wadi passes through the depression, but the areas involved are of minor importance.

In the lower rainfall zone of 100-125 mm with an even water distribution, the calculated yield is 100 kg grain and 1 300 kg straw ha^{-1} (Table 16). In the rainfall zone 125-150 mm the yield is 150 kg grain and 2 050 kg straw ha^{-1}.

When growing barley in the depressions only, the yield could increase to 900 kg grain and 3 800 kg straw ha^{-1}. Under 300 mm moisture availability the yield is 1 350 kg grain and 4 700 kg straw ha^{-1} and under 450 mm it is 3 850 kg grain and 4 850 kg straw ha^{-1}. In the latter situation fertilizer at a rate of 65 kg N and 35 kg P ha^{-1} has to be applied.

d. Soil type F2

- Soil type: moderately deep (60-90 cm) sandy loam to loam, locally clay loam over caliche or rock.
- Soil moisture characteristic and texture: fine sandy loam.
- Natural soil fertility: 32 kg N ha^{-1}; 3 kg P ha^{-1}.
- Agricultural potentiality: suitable for vegetables, field crops and moderately deep rooted crops only.

Soil type F2 is situated mainly in the 100-125 mm rainfall zone. Assuming an average surface run-off coefficient over long distances of 0.075 and a ratio of beneficiary area to catchment area of 1:2, the annual amount of water received is 140 mm. That is comparable with the 137 mm rain received on average in Mersa Matruh, so the data set of that station is used.

Assuming an even water distribution, the calculated yield is 100 kg grain and 1 300 kg straw ha^{-1}. Limiting barley production to the depressions only, the yield is 900 kg grain and 3 700 kg straw ha^{-1}. This increases to 1 400 kg grain and 4 600 kg straw ha^{-1} under 300 mm and to 4 950 kg grain and 4 850 kg straw ha^{-1} under 450 mm water availability. In the latter situation fertilizer at a rate of 90 kg N and 50 kg P ha^{-1} has to be applied.

e. Soil type F3

- Soil type: deep sandy loam to loam or clay loam.
- Soil moisture characteristic and texture: sandy loam.
- Natural soil fertility: 32 kg N ha^{-1}; 3 kg P ha^{-1}.
- Agricultural potentiality: suitable for all crops.

The water regimes assumed for soil type F3 are identical to those for soil type B1. The parameters and coefficients have identical values, so the mean climate with 120 mm water supply is applied for the lower rainfall zone and the one with 180 mm for the higher rainfall zone. The yields are not calculated for the lower rainfall zones separately.

Assuming an even distribution of the available water results in a production of 300 kg grain and 2 600 kg straw ha^{-1}. Limiting barley growth to the depressions yields 1 000 kg grain and 3 850 kg straw ha^{-1}. Under 300 mm water availability the yield increases to 1 450 kg grain and 4 700 kg straw ha^{-1} and under 450 mm to 5 350 kg grain and 4 900 kg straw ha^{-1}. In the latter situation fertilizer at a rate of 105 kg N and 50 kg P ha^{-1} has to be applied.

f. Soil type Wb

- Soil type: wadi bottom soils, deep sandy loam to loam with sand and gravel layers.
- Soil moisture characteristic and texture: sandy loam.
- Natural soil fertility: 32 kg N ha^{-1}; 3 kg P ha^{-1}.
- Agricultural potentiality: suitable for all crops.

The simulation results for this soil type are identical to those for soil type F3, the surface run-off and wadi flow received are the same, so the results are not discussed here any further.

g. Soil type Pl

- Soil type: deep loam to clay loam soils, overlain by 20-60 cm sand.
- Soil moisture characteristic and texture: loam.
- Natural soil fertility: 15 kg N ha^{-1}; 1 kg P ha^{-1}.
- Agricultural potentiality: suitable for all crops.

The area of soil type Pl in this region is limited and the average annual rainfall is about 125 mm. Assuming a surface run-off coefficient of 0.075 and a ratio of beneficiary area to catchment area of 1:2, the mean climate with 150 mm infiltration is the most appropriate climatic data set. Barley production under this water regime is limited to 100 kg grain and 1 500 kg straw ha^{-1}.

Without fertilizer application, but with some additional water (200 mm water regime) a maximum yield of 350 kg grain and 2 000 kg straw can be achieved. Soil fertility is a limiting factor on this soil type.

At the 250 mm water regime, fertilizer has to be applied, 15 kg N and 15 kg P ha^{-1}, to achieve the yield of 800 kg grain and 3 450 kg straw ha^{-1}. Under 300 mm the production is 1 500 kg grain and 4 000 kg straw ha^{-1}, requiring 40 kg N and 25 kg P ha^{-1}. Under 450 mm the yield is 4 500 kg grain and 4 900 kg straw, requiring 125 kg N and 65 kg P ha^{-1}.

h. Soil type C1

- Soil type: a complex of rock and shallow to moderately deep sandy loam to loam soils over caliche or rock.

The soils of this complex belong to soil types B3 or F1, depending on their origin. From the soil map it can be deduced that in the Matruh region, C1 is a complex of rock and F1. Rock is assumed to cover half the surface area and soil the other half. The run-off coefficient of the rocks is estimated at 0.5, so half of the area receives 1.5 times the amount of rainfall. The average wadi flow to this soil type is 26 mm, the surface run-off coefficient for long courses of water flow is 0.075 and the ratio of beneficiary area to catchment area is 1:1. This all results in a water regime of 250 mm ((1 + 0.5 + 0.075) * 140 + 26 = 250 mm). C1 only occurs in the 125-150 mm rainfall zone.

The simulation results are identical to those for F1, but only half the area can be cultivated with barley.

i. Soil type C2

- Soil type: complex of rock and deep sandy loam to loam or clay loam.

Deep sandy loam to loam or clay loam refers to soil types B1 or F3. From the soil map it can be deduced that in the Matruh region, C2 is a complex of rock and B1. Again, half the area is assumed to be covered by soil and half by rock. The run-off coefficient of the rocks is estimated at 0.5, so half of the area receives 1.5 times the amount of rainfall. The surface run-off coefficient for long courses of water flow is 0.075 and the ratio of beneficiary area to catchment area is 1:1. This results in a water regime of 180 mm. No wadi flow is received by this soil type. Soil type C2 only occurs in the 100-125 mm rainfall zone. The yields for C2 are the same as for B1 under the 180 mm water regime, but barley is cultivated on only half the area covered by C2.

5.4 Cultivable area

The total area per soil type, as presented in Table 17, is derived from FAO data (Report 2, 1970). Again part of the area cannot be cultivated, because the soil is too saline. The area suitable for barley cultivation is situated in two rainfall zones: 33 870 ha in the lowest rainfall zone of 100-125 mm and 12 450 ha in the 125-150 mm rainfall zone. The efficiency of water concentration is assumed to be equal to the run-off coefficient over short distances, i.e. 0.25 for the Matruh region. Additional water from wadi flow is also taken into account.

In the lowest rainfall zone about 20% of the cultivable area can be used at present and in the 125-150 mm rainfall zone 45% can be cultivated. That results in a total cultivable area of 12 710 ha. Under the 300 mm water regime 5 190 ha and 3 920 ha can be cultivated in the two rainfall zones or 15 and 30%, respectively. Concentrating the water to an availability of 450 mm annually decreases the cultivable area to 2 850 ha or 8% in the lowest rainfall zone and to 2 130 ha or 17% in the highest rainfall zone.

5.5 Regional barley production

Barley production in the Matruh region can now be calculated for various situations (Table 18). If all depressions of the suitable soil types would be cultivated under the present conditions, the maximum production would be 11 000 ton grain and 47 200 ton straw from 12 710 ha. Under a water regime of 300 mm the maximum production is 12 000 ton grain and 42 200 ton straw from 9 110 ha. Under a water regime of 450 mm the maximum production is 21 100 ton grain and 24 100 ton straw from 4 980 ha.

The differences in grain yield among the water regimes are high compared to that in straw yield. As at low moisture availability water stress is more severe during the post-anthesis phase, the grain filling period benefits more from a higher water availability than the pre-anthesis period.

6. BARLEY PRODUCTION IN THE BARRANI REGION

6.1 Introduction

The procedure followed is the same as in the preceding chapters. The climatic data set from Sidi Barrani meteorological station is used. Some data were not consistent: the climatic mean for rainfall in Sidi Barrani according to the Egyptian Meteorological Organization is 171 mm yr^{-1}, while according to the isohyet map it is 150 mm yr^{-1}. The data from the Meteorological Authority (1975) were used.

In this region no pilot areas from the FAO project were situated, hence little is known about the water regimes. A run-off coefficient over short distances of 0.075 is assumed. This value is derived as an average of the run-off coefficients for other parts of the northwestern coastal zone. The total annual wadi flow in the region is estimated at 2 220 000 m^3, but most of the wadis in the Barrani area are situated inland at a distance of 20-50 km from the coast (FAO-2, 1970). Only in the eastern part some wadi flow may reach the coast. Soil type B2, situated in that area, is the only soil type that receives wadi flow. For all other soil types wadi flow is assumed to be zero.

6.2 The potential and the nutrient-limited situation

The potential production is 6 600 kg grain and 5 300 kg straw ha^{-1} (Table 19). Depending on natural soil fertility, which is either 32 kg N and 3 kg P ha^{-1} or 28 kg N and 4 kg P ha^{-1}, the fertilizer requirements are 135 kg N and 70 kg P ha^{-1} or 145 kg N and 60 kg P ha^{-1}, respectively.

The N-limited production is 2 400 kg grain and 2 000 kg straw ha^{-1} when 32 kg N ha^{-1} is available and 2 100 kg grain and 1 700 kg straw ha^{-1} when 28 kg N ha^{-1} is available. The P-limited production is 2 000 kg grain and 1 600 kg straw ha^{-1} with 3 kg available P and 2 700 kg grain and 2 200 kg straw ha^{-1} when 4 kg P is available.

6.3 Barley yields for the various soil types

The simulation results for the Barrani region are given in Table 20. For the 250, 300 and 450 mm water regimes the results per soil type are identical to those for the previous regions. Therefore, the yields are not discussed again, but they are given in Table 20 to present a complete picture of the Barrani region.

a. Soil type B1

- Soil type: deep sandy loam to loam or clay loam.
- Soil moisture characteristic: Frontal Plain.
- Natural soil fertility: 32 kg N ha^{-1}; 3 kg P ha^{-1}.
- Agricultural potentiality: suitable for all crops.

Assuming a run-off coefficient of 0.075 and a ratio beneficiary area to catchment area of 1:1, which is deduced from the soil map, natural infiltration is 180 mm annually. From this 180 mm, 95 mm infiltrates during the growing period of barley when growth starts on December 20. The yield is 150 kg grain and 2 000 kg straw ha^{-1} in this case and no fertilizer application is required.

The results under water regimes of 250 mm, 300 mm and 450 mm water are not discussed here again. They are identical to the results for these water regimes in the other regions.

b. Soil type B2

- Soil type: deep loamy sand to slightly loamy sand.
- Soil moisture characteristic and texture: loamy fine sand.
- Natural soil fertility: 28 kg N ha^{-1}; 4 kg P ha^{-1}.
- Agricultural potentiality: suitable for all crops.

Also in this region it is assumed that B2 can be completely irrigated. Along the coast, where B2 is situated, many cisterns exist (about 40) and some wadi flow contributes water to this area too. The natural infiltration is 180 mm. Under these conditions the barley yield is 500 kg grain ha^{-1} and 3 350 kg straw ha^{-1}.

c. Soil type B3

- Soil type: limited and moderately deep sandy loam to loam over caliche or rock (30-90 cm).
- Soil moisture characteristic and texture: fine sandy loam.
- Natural soil fertility: 32 kg N ha^{-1}; 3 kg P ha^{-1}.
- Agricultural potentiality: suitable for vegetables, field crops and moderately deep rooted crops, partly shallow rooted crops only.

For this soil type two soil depth classes were distinguished in the other regions. Since no specific information is available for the Barrani region, the same subdivision has been applied for this region, i.e. soils with a depth of 30-60 cm occupying twice as much area as soils with a depth of 60-90 cm.

Soil type B3 is situated in the same area as B1, so the natural water regime is identical, i.e. 180 mm infiltration annually. Under this water regime crops on the shallow soils produce 300 kg grain and 2 600 kg straw ha^{-1}. On the deeper soils the production is 300 kg grain and 2 500 kg straw ha^{-1}. No fertilizer application is required.

d. Soil type F1

- Soil type: limited deep (30-60 cm) sandy loam over caliche or rock.
- Soil moisture characteristic and texture: fine sandy loam.
- Natural soil fertility: 32 kg N ha^{-1}; 3 kg P ha^{-1}.
- Agricultural potentiality: only suitable for shallow rooted crops.

In the 100-125 mm rainfall zone, where a quarter of the area with soil type F1 is situated, the ratio beneficiary area to catchment area is about 1:3. The natural water supply is therefore 140 mm per year, assuming a run-off coefficient of 0.075. Another quarter of this soil type is situated in the 125-150 mm rainfall zone. The ratio beneficiary area to catchment area is 1:1 and the surface run-off coefficient for long courses of water flow is 0.075. This results in 145 mm infiltration annually. This is close to 140 mm and thus half of the area with soil type F1 is considered to receive 140 mm infiltration annually. The other half of soil type F1 is situated close to the coast and will therefore receive about 170 mm as measured in the meteorological station.

Under the water regime of 170 mm grain production is 300 kg and straw production is 2 600 kg ha^{-1}. Under the water regime of 140 mm the yield is 100 kg grain and 1 700 kg straw ha^{-1}.

d. Soil type C1

- Soil type: complex of rock and shallow to moderately deep sandy loam to loam over caliche or rock.

From the soil map it can be deduced that this soil type is a combination of rock and soil type B3. As in other regions it is assumed, that C1 mainly exists of moderately deep soils of 30-60 cm and that it covers half the surface area. The run-off coefficient for rocks is estimated at 0.5, so the natural water regime for the area covered with soil is 250 mm annually (1.5 $\times$ 170 mm). The simulation results are identical to the ones presented in Table 20 for this water regime.

Although in the Barrani region the yields are somewhat higher than in the other regions, because of the higher rainfall, they are not high enough for succesful crop production. Only on soil type B2 a reasonable barley crop can be produced. Information about the amount of water available for plant growth is too limited to give reliable estimates of production possibilities. The natural water regimes have been estimated conservatively.

6.4 Cultivable area

The soil types considered suitable for barley cultivation in the Barrani region are situated in two rainfall zones, about one third in the 100-125 mm rainfall zone and two thirds in the 125-175 mm rainfall zone (Table 21). The area suitable for barley production is 31 700 ha, of which 11 330 ha or 35% can be used under the present conditions. If water is concentrated to an availability of 300 mm annually the cultivable area is reduced to 7 730 ha. Under the 450 mm water regime only 4 000 ha can be used for shallow rooted field crops.

6.5 Regional barley production

Regional barley production can now be calculated for the Barrani region under the various water regimes (Table 22). If all depressions of the suitable soil types would be cultivated, i.e. 11 330 ha, total grain production would be 10 100 ton and total straw production 42 600 ton. If water is concentrated on part of the depressions in such a way that the annual water availability is 300 mm, total production is 10 400 ton grain and 36 100 ton straw, produced on 7 730 ha. Total grain production remains at about the same level compared to the 250 mm water regime, but straw production decreases by 6 500 ton. Thus the decrease in cultivable area is not compensated by higher yields per ha. Under the 450 mm water regime total production is 16 000 ton grain and 19 400 ton straw, produced on 4 000 ha. In this situation grain production is increased by 5 900 ton and straw production is reduced by 55%, compared to the present situation. It depends on the prevailing socio-economic conditions which water regime is the most favourable.

7. COMMENTS ON THE SIMULATION RESULTS

7.1 Yield levels

The calculated barley production levels, as presented in this paper, are based on many assumptions. Most of these assumptions have been presented explicitly in the previous chapters. If reality, especially with respect to water and nutrient availability, is different from the assumptions, the simulated results may present a distorted picture.

The aggregated regional production for the three water regimes as calculated is a maximum value, as the total available area is assumed to be cultivated with barley and nothing is left for fruit trees. Moreover, no yield losses due to weeds, pests and diseases nor post-harvest losses have been taken into account.

For barley in Egypt no data on post-harvest losses were found. From other literature it was derived that these losses are about 10% for barley grain. The post-harvest losses and losses in the field for straw are estimated at 20%, excluding the stubble, which is left for sheep and goats to graze.

The presence of weeds causes on average a yield reduction of 25% for barley (van Heemst, 1985). This agrees with the average of Egyptian data, although the variability in these data was very high: the yield loss reported varied between 3 and 66%. As no more accurate information is available, an average yield reduction of 25% is assumed to hold for barley in the Mariut region. For straw no yield reduction is taken into account, as the weeds will be harvested together with the straw and contribute to total dry matter yield.

Other effects of crop management will be considered when discussing the systems of barley cultivation.

7.2 Cultivable area

In literature several estimates for the area sown to barley are reported. According to FAO (Report 3, 1970) on average 250 000 feddan or 105 000 ha is under dry farming annually, of which 80 000-135 000 feddan (33 600-56 700 ha) is sown to barley. Not all barley sown is actually harvested. Usually, in some areas the crop fails due to drought periods and some barley is grazed if yield expectations are low. FAO (Report 3, 1970) estimates the harvested area to vary between 20 000 and 110 000 feddan (8 400-46 200 ha). Abo Elenein (1983) estimates the area sown to barley at 150 000-250 000 feddan (63 000-105 000 ha), but that again is not the area harvested. For acceptable yields seasonal rainfall should exceed 200 mm, so in average years yields are low and only part of the area is harvested. Soliman et al. (R.P.R., 1982) report the area under barley to vary between 54 800 and 200 000 ha in the period 1975-1981, with an average of 99 000 ha yr^{-1}. No estimate is given for the harvested area. Sultan (quoted by Chabbour, 1983) estimates the harvested area at 20 000-50 000 ha yr^{-1} and Euroconsult (1976) estimates it at 30 000-40 000 ha yr^{-1}.

In this study the total barley area that can be harvested annually, is estimated at 40 500 ha, representing the aggregated area of the depressions receiving 250 mm water annually. The present area under fruit trees, estimated at 10 500 ha (Mariut-team, 1987), has to be substracted from this area as fruit trees and barley compete partly for the same soil types. This means that at present 30 000 ha of barley can be harvested annually. Comparing this figure with the estimates reported above, shows that it is within all ranges, but the margins are wide. However, the assumption that the 250 mm water regime represents the present situation seems reasonable.

It should be noted that the area under fruit trees is expanding rapidly at the expense of good barley land. Barley cultivation is expanding at the expense of rangeland (Soliman et al., R.P.R., 1982). The latter lands are less suitable for barley than the areas that are being withdrawn from barley cultivation. Water availability is usually lower, so the incidence of crop failures will increase.

7.3 Water management

From the simulation results it may be concluded that barley can only be grown in depressions, which receive additional surface run-off and, if present, wadi flow. The Matruh region and the Barrani region receive a reasonable amount of wadi flow, which is, however, only partly used (25%) while the remainder flows off to the sea. The limiting factor for barley cultivation in this region is not the absolute amount of water, but the water management. To obtain high barley yields, dykes should be constructed and maintained and some areas would need terracing. Close to Mersa Matruh such constructions have been realized, but the beneficiary areas are not known. By improving the methods of water collection and water harvesting a larger part of the total amount of water could be used. The surface run-off coefficient could be increased and more of the wadi flow could be used.

It should be realized that the basic input data on water availability are all rough estimates, partly because FAO could not complete its hydrological research program. The measurements on wadi flow have been carried out in six wadis and their catchment areas. These results have been extrapolated along the whole northwestern coastal zone. Many of the data used were estimated on the basis of analogy and not measured.

7.4 Natural soil fertility

No data about soil fertility from plant analyses were available, except the ones mentioned in Section 2.3. The soil analysis data from the various sources were very variable and sometimes even contradictory. It would be worthwhile to pay more attention to this aspect in a possible second phase of the project.

The nutrients available for plant growth are estimated at 10-33 kg N and 3-4 kg P ha^{-1} yr^{-1}. If the system is considered in equilibrium, these amounts of N and P would have to be added to the pool of available nutrients in the soil each year. Nutrients become available for plants through various processes, such as weathering of minerals, mineralization of organic matter, activity of free living micro-organisms, addition by rain and urine and fixation by legumes. Janssen (1986) uses the rule of thumb that 1% organic matter yields 30 kg N ha^{-1} yr^{-1} through mineralization. Based on data by Harpaz (1975) addition by rain is estimated at 3 kg N ha^{-1} yr^{-1}. Sheep graze the barley stubble at a high stocking rate, but only during a limited period, so addition of N by urine is estimated at 1 kg ha^{-1}. Fixation of N by legumes will be limited, as only few legumes are present. The contribution of free living micro-organisms depends on wetness of the soil and will be negligible in this situation. Adding all of this the total quantity of N supplied to the nutrient pool of the soil is 19 to 34 kg ha^{-1} yr^{-1}. Mineralization contributes most to the available N and its availability thus depends mainly on soil organic matter content.

Considering this reasoning, the measured nitrogen uptake of 10 to 32 kg ha^{-1} yr^{-1} in the Mariut region seems reasonable. It should be noted that not all the land suitable for barley is actually cultivated each year, as amount and distribution of rainfall may not be favourable. If the soil is left fallow, a nitrogen store may build up during the fallow period and more N may be available the following year. If that would have been the case in the sampled barley fields, the annual N availability may have been overestimated. The exact history of the sampled barley fields, however, is not known. For the simulation results a change in natural soil fertility will have consequences only for the fertilizer requirements as long as water is the major constraint for plant growth. If soil fertility is limiting, the yield in the natural situation, i.e. 250 mm infiltration annually, will decrease.

8. SYSTEMS FOR BARLEY CULTIVATION

To construct input/output tables the yield estimates have to be supplemented by the inputs required to achieve them. Therefore, various systems for barley cultivation have been defined.

8.1 Agricultural operations

To obtain yield from a barley crop some operations are obligatory and others are optional, depending on the cultivation system choosen. In this study ten operations are distinguished. Table 23 summarizes the various operations necessary for cultivation under the three water regimes described. It is assumed that under high water availability, which takes considerable effort to achieve, more attention is paid to the cultivation techniques than under low water availability.

Sowing is assumed to take place in November for all water regimes. Immediately after sowing, also in November, the soil is ploughed. Ploughing in rainfed agriculture in the Mariut region is rather shallow (0-10 cm), comparable to seedbed preparation, and it is also considered a weed control measure. In this study shallow ploughing is required for the water regimes of 250 mm and 300 mm and deep ploughing for the 450 mm water regime.

Harrowing is not practiced in rainfed agriculture at present. In irrigated agriculture it serves as crushing of soil clods by pulling a thick wooden beam over the field. Clod crushing, after ploughing in November, is assumed a standard operation if cultivation practices are improved (300 and 450 mm water regime). It is done after ploughing in November and will be referred to as harrowing from now on.

Apart from ploughing no special weed control measurements are taken in rainfed agriculture. In irrigated agriculture herbicides are used sometimes and some hand weeding is carried out, but neither of these practices is standard. Weeding is not considered worthwhile for the 250 mm water regime, because the yield increase is small. For the improved water management systems weeding is optional. Weed control is carried out in January/February, whenever time permits.

As explained before, fertilizers are only used under the 450 mm water regime and they are applied in January/February. Promoting run-off by construction of dykes is necessary to achieve the 300 and the 450 mm water regime. For the present purpose, only the maintenance of the structures is considered, as that has to be repeated annually and construction is a one-time effort. Harvesting, threshing, winnowing and transporting operations have to be carried out for all three water regimes. The crop is harvested in April and threshed and winnowed in May and June.

8.2 Mechanization level and labour input

Three levels of mechanization have been distinguished: hand labour, animal power and mechanized equipment. Not all three levels of mechanization are applicable for all operations in the Egyptian situation and only the relevant combinations are considered here. The inputs required for each combination are defined and are used as such in a linear programming matrix.

All values for labour requirements are derived from Egyptian data, the FAO reports (1970) and Van Heemst et al. (1981). The latter paper presents estimates for labour requirements in agriculture in the Netherlands and in developing countries. The data for Dutch agriculture are rather reliable, but for developing countries they are not very accurate, due to lack of information. The FAO data are based on interviews with 24 farmers in the sixties. The information specific for Egypt is collected from various sources, but it is mainly based on interviews in 1985/86 with four Egyptians: two farmers, one regional planner for agriculture and one scientist specialized in barley research. The variability in the estimates of these four people was often considerable.

For estimating the parameter values it is not a matter of course to use the mathematical mean of the four data sets. Sometimes information seemed very unlikely and was discarded. Sometimes a combination was used with emphasis on one data set and if no data were available at all the value of a parameter was guesstimated.

The labour requirements are expressed in h ha^{-1} or h ton^{-1}. They comprise all actions required for a smooth continuation of the job, including minor repairs, installation and maintenance, if machines are used. It is assumed that a skilled healthy labourer carries out the operation under standard conditions, at normal working pace, with standard equipment and with maximum efficiency (Van Heemst et al., 1981). As most available data are not well specified, it is difficult to judge for which values these conditions are satisfied.

As the four data sets mentioned before, are the only ones available at the moment, they are used as such. A summary of these data and the ones actually used is given in Table 24 and is discussed in the following paragraphs.

a. Sowing

The Bedouin in the northwestern coastal zone usually broadcast the seeds by hand. Under rainfed conditions they broadcast about 60 kg ha^{-1} and under irrigated conditions about 100 kg ha^{-1}. For the present rainfed situation (a water regime of 250 mm) an amount of 60 kg ha^{-1} is applied and for the improved rainfed situation (water regimes of 300 and 450 mm) 100 kg ha^{-1} is applied. It is assumed that in the improved situation more attention is paid to the cultivation techniques than is the case at present. The difference between the two sowing rates has no consequences for the labour input, because the available information is not accurate enough to make a distinction between both.

The Egyptian estimate for sowing seems very low (Table 24). It only refers to the actual walking over the land and does not include all other actions required. The FAO estimate, on the other hand, seems rather high. As an intelligent guess, a human labour input of 4 h ha^{-1} seems reasonable.

b. Ploughing

In Egypt, ploughing is considered not only soil tillage, but also a method of weed control. Turning the soil with a hoe in hand labour is an unusual practice at present. Ploughing is carried out using animal traction or mechanized equipment and only once a year at the beginning of the rainy season. Depending on the expected yield and on the level of land reclamation, ploughing is either shallow (0-10 cm) or deep (15-20 cm). It is assumed that, using animal traction and an indigenous plough, shallow ploughing takes 18 h ha^{-1} and deep ploughing 28 h ha^{-1} (Table 24). Using a tractor and a chisel plough for shallow ploughing or a tractor and a mouldboard plough for deep ploughing, the operation takes 3 or 11 h ha^{-1}, respectively. Fuel requirements for shallow ploughing are estimated at 27 l ha^{-1} and for deep ploughing at 95 l ha^{-1} (Appendix II).

c. Harrowing

Harrowing, as carried out at present, is more or less crushing of soil clods. A thick wooden beam is pulled over the field by a donkey or a tractor. For harrowing the Egyptian data are applied. Harrowing takes 6 h ha^{-1} using animal traction and 2 h ha^{-1} using a tractor (Table 24). The data for the developing countries (Van Heemst et al., 1981) seem too high for the Egyptian situation, as here only clod crushing is involved. The fuel requirements are estimated at 9 l ha^{-1} (Appendix II).

d. Weed control

The two methods of weeding considered in the present study are hand weeding and the use of herbicides. A big discrepancy exists between the estimates of labour involved in hand spraying for the Netherlands and for developing countries (Table 24). The latter value is assumed to apply to Egypt, hence spraying against weeds takes 25 h ha^{-1}. For hand weeding the Egyptian data are used, i.e. 120 h ha^{-1}. Weeding is assumed to be carried out only once during the growing season.

e. Fertilizer application

At present, fertilizers are only applied in irrigated areas and they are broadcast by hand. The Egyptian estimate of the labour requirements includes only the actual spreading of the fertilizer over the land and is therefore an underestimate of the total time requirement. The labour input for developing countries (Van Heemst et al., 1981) probably refers to placement of the fertilizer and therefore seems too high. To estimate a labour requirement from these data, they are compared to the data for sowing. Because the quantity of fertilizers applied is usually higher than the quantity of seeds applied, it is assumed that broadcasting fertilizer takes one hour more than sowing, i.e. 5 h ha^{-1}.

f. Irrigation

In the irrigated part of the Mariut region about 5 h ha^{-1} are spent on each irrigation event. At present barley is irrigated two to four times a year, depending on the water supply. As the water supply from the canals is increasingly regular and dependable, the number of irrigations is increasing. When the supply is dependable enough, farmers start growing other crops like berseem, broad beans, grapes etc., with a higher net revenue.

For the irrigated area, situated between Burg el Arab and el Hammam, production calculations for barley have been carried out for two irrigation levels. For the low irrigation level it was assumed that barley is irrigated once a month, i.e. four times during the growing season, and for the high irrigation level it was assumed to be once every three weeks, i.e. six times during the growing season. Maintenance of the irrigation canals is assumed to take about 20 h ha^{-1} yr^{-1}. In areas with an undependable water supply hardly any summer crops are grown, so the labour requirements for maintenance are on account of barley only. In areas where water supply is more dependable summer crops are grown, but that activity is not considered separately at this stage. For the low irrigation level labour requirements are estimated at 40 h ha^{-1} yr^{-1} and for the high irrigation level at 50 h ha^{-1} yr^{-1}.

In rainfed areas dykes have to be constructed to concentrate the water from surface run-off and wadi flow on the cultivated land. Cost and labour associated with construction of dykes are one-time investments and are not taken into account here. Once the dykes have been constructed, however, they have to be maintained. According to FAO estimates (Report 2, 1970) maintenance takes 10% of the construction time, so the latter had to be estimated too. The surface run-off coefficient (FAO-2, 1970) holds for distances of 50 to 100 m, the average being 75 m. The distance between two parallel dykes should thus be 75 m. That implies 133 m of dyke length ha^{-1}. FAO developed several pilot areas using dykes to concentrate water. The average dimensions of those dykes were 0.5 m height, 0.5 m width at the top and 1.5 m width at the bottom, i.e. a volume of 0.5 m^3 m-1, or a volume of 66.5 m^3 ha^{-1}. The labour costs for construction were estimated at LE 0.15 m^{-3} and the wages at LE 0.44 person-day^{-1} (FAO-2 and -4, 1970). This means that 2.9 m^3 dyke can be constructed per day. According to Egyptian standards one person-day of agricultural labour is 7 h (Sultan, pers. comm.). The construction of dykes thus requires 160 h ha^{-1} yr^{-1} and maintenance 16 h ha^{-1}. This is assumed to hold for the low irrigation level. For the high irrigation level more dykes will have to be constructed to concentrate the water from a larger catchment area. Construction and maintenance are assumed to be 1.5 times that for the low irrigation level, i.e. 24 h ha^{-1} yr^{-1} for maintenance.

g. Harvesting

Harvesting is done by hand, using a selfbinder or using a combine. It is unknown whether selfbinders are actually used in the region. The difference in mechanization level between harvesting by hand and harvesting by combine is so large, that it is likely that there is room for an intermediate for which, rather arbitrarily, a selfbinder is choosen. According to Sultan (pers. comm.) a reaper is not used, so that option is not considered.

The labour requirement for harvesting by hand depends on yield and not on the area harvested. In this study the labour requirement is related to the total yield of both grain and straw, because the time requirement depends not only on grain yield and the harvest index is not identical for the various yield levels. The labour requirements for mechanized operations are expressed on an area basis.

The Egyptian estimate for harvesting in hand labour of 13 h ton^{-1} is applied for the barley systems (Table 24), even though it is low compared to other sources, except the Dutch estimate, but that refers to grain yield only. The Egyptian estimate is applied nevertheless, because all four people interviewed independently reported the same value. For harvesting by mechanized equipment the data from Van Heemst et al. (1981) for developing countries are applied, i.e. 5 h ha^{-1} to harvest by selfbinder and 4 h ha^{-1} to harvest by combine. The latter activity also includes threshing and winnowing. It is assumed that about one third of the straw remains in the field as stubble and as harvest losses.

Fuel requirements for mechanized operations are estimated at 36 l ha^{-1} for the combine and 30 l ha^{-1} for the selfbinder (Appendix II).

h. Threshing and winnowing

Threshing is carried out either using animal traction or a stationary threshing machine. In the first case animals pull a beam with discs in circles over the barley. The discs cut the material into small pieces and part of the straw is blown away by the wind. The remaining part is winnowed by using a flat basket and throwing the barley in the air. When using a threshing machine no separate winnowing has to be carried out. For both methods the time requirement depends on the total yield of grain and straw.

The Egyptian estimate of 19 h ton^{-1} (Table 24) includes interruptions, during which the animals are used for other activities. On the other hand, it is not known, whether the normal non-operative time is included. When the time requirement for winnowing is added to the 19 h ton^{-1} the total time requirement is comparable to the FAO estimate of 30 h ton^{-1} including both threshing and winnowing. The time required for winnowing will be closer to 5 than to 1 h ton^{-1} and it could even be higher, as the harvest index is low (0.25). Based on these data the total time required for threshing and winnowing is set at 30 h ton^{-1}, threshing taking 20 h ton^{-1} and winnowing 10 h ton^{-1}. Animal traction is only needed for threshing and not for winnowing. The value for threshing only agrees with the estimate for developing countries (Van Heemst et al., op. cit.), if the total yield is over 15 ton ha^{-1}. That seems a rather high value, but it depends on reclamation level and cultivation practices.

The Egyptian sources estimate that, when using a threshing machine, the time involved is 3 h ton^{-1}. Under Dutch conditions, with high yields, mechanized threshing requires 11 to 25 h ha^{-1}. For developing countries mechanized threshing requires 10 h ha^{-1} (Van Heemst et al., 1981), which agrees with the Egyptian estimate if the yield is 3.3 ton ha^{-1}. For mechanical threshing the Egyptian estimate is used. Two people are needed to operate the threshing machine. As part of the straw is lost during harvest and part is left in the field as stubble, the labour requirements are estimated by multiplying the straw yield by 2/3 and adding the grain yield.

The fuel requirements for the threshing machine are estimated at 11 l ton^{-1} (Appendix II).

i. Transport

It is difficult to estimate the labour requirements for transport from the field to the farmhouse, as no data are available on the average distance between. Own observations suggest that it varies between 0 and 10 km.

Barley can be transported using animal traction or mechanical traction. All available data refer to animal traction. The FAO estimate is three times higher than the estimate for developing countries from Van Heemst et al. (1981) (Table 24). It is not clear whether loading and unloading are included, but it is assumed to be the case.

The following assumptions were made to arrive at the final estimate. The average distance from the field to the farm is 5 km. A donkey can cover a distance of 2.8 km in one hour, drawing a cart loaded with 500 kg barley. When the cart is empty, the speed is about 4 km h^{-1}. The total time needed for the actual transport of 500 kg from field to farmhouse is thus 3 h. If loading and unloading and other time consuming activities are assumed to take 8 h ton^{-1}, the total time requirement for transport is 7 h per 500 kg, i.e 14 h ton^{-1}.

For mechanized transport no data are available and a similar reasoning is followed. It is assumed that the tractor has an average speed of 16 km h^{-1}, so the actual driving takes 0.6 h. The capacity of the cart is estimated at 5 ton. Loading and unloading of one cartload takes 40 h, at the same pace as for the small cart. Thus the labour requirements are 40.6 h for 5 ton, i.e. about 8 h ton^{-1}. For transport the same applies as for threshing and winnowing, i.e. the total labour requirements are obtained by taking into account 2/3 of the straw yield plus the grain yield. The fuel requirements are estimated at 2 l ton^{-1} (Appendix II).

8.3 Barley systems

The three water regimes, the ten operations, and the three levels of mechanization, are combined into seventeen cultivation systems (Figure 3). The first criterion distinguishes between the systems using animal traction and those using mechanized equipment. Systems using only hand labour for all operations have not been defined. The second criterion is the water regime: 250 mm, 300 mm, or 450 mm water annually available. The third criterion relates to weed control measures that are applied or not and in the first case in two ways: hand weeding or using a herbicide. As mentioned before, that only applies to the 300 and 450 mm water regimes. For the mechanized activities hand weeding is not considered an option. For mechanized activities the next and final criterion relates to harvesting either by selfbinder or by combine. It depends on the size of the plot whether a combine can be used or not, but it is assumed that plot size is not a constraint.

8.4 Assumptions

In defining the seventeen systems described above a number of implicit assumptions have been made that require attention.

The effects of pests and diseases have not been taken into account, due to lack of information.

Clearance of the land is not considered. That happens only once if at all, before a field is cultivated for the first time. Sometimes the land is not cleared and barley is sown directly between the existing vegetation of shrubs and subshrubs. That is considered a non-weeded system, although yield reduction due to weeds could be somewhat higher than 25% in that situation.

It is assumed that if a farmer uses animal traction, animals are available for all operations to be carried out and power equipment is not available. If a farmer uses power equipment, that applies to all operations. Thus, in this concept a rather sharp transition exists between mechanized and non-mechanized farms.

The additional feed input for animals to supply draught power is estimated at 0.11 Feed Unit per hour effective working time (Van Duivenbooden, 1985). For the barley systems 1 to 5 less than 25 kg barley grain would be needed to cover that requirement, hence that is neglected. For the systems 6 and 7 the additional feed requirement is just over 25 kg ha^{-1} and that has been included at 50 kg. That amount has been subtracted from the barley yield in the two systems concerned and is not introduced separately in the input/output tables.

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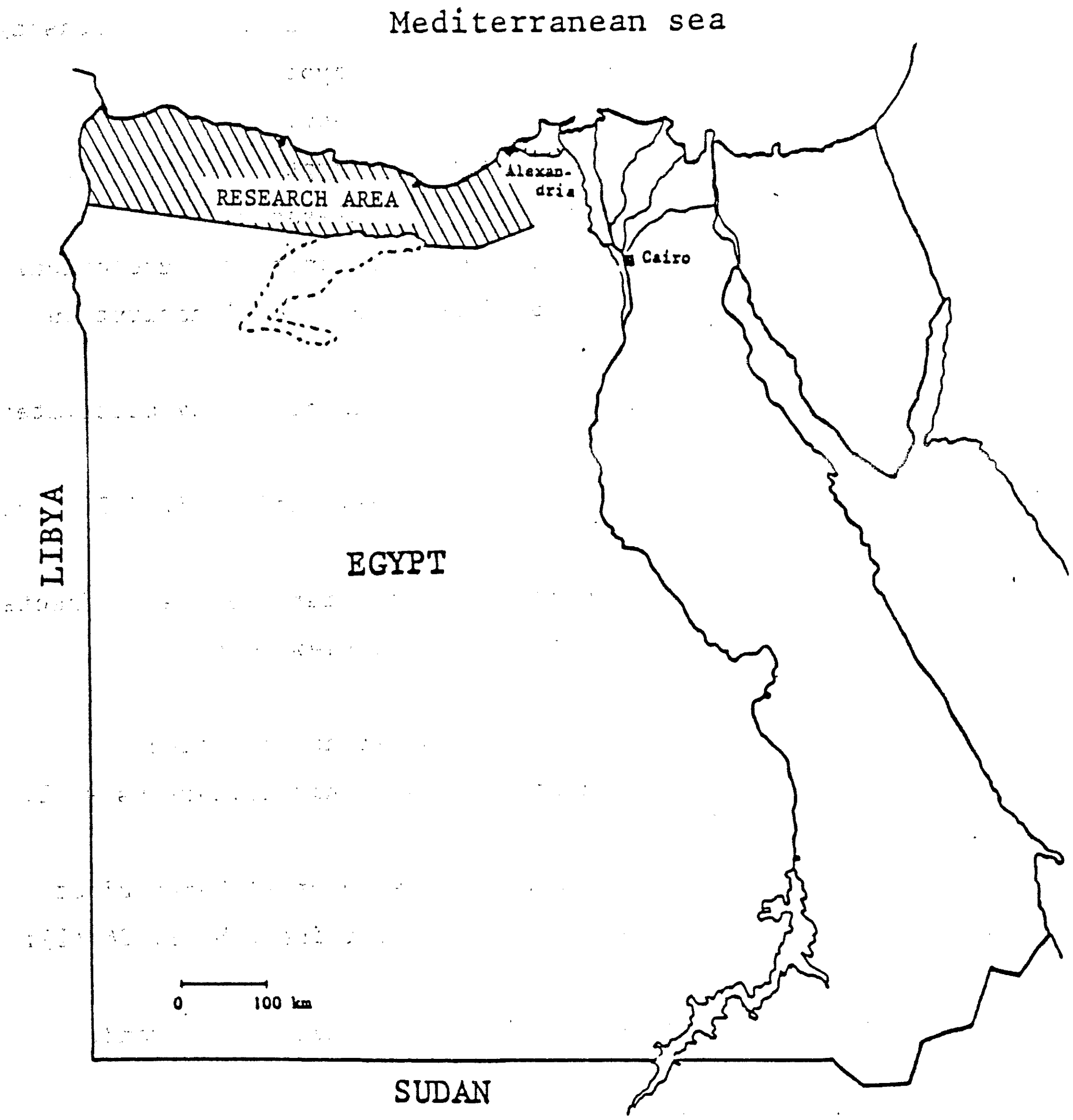

Figure 1. Map of Egypt and location of the research area.

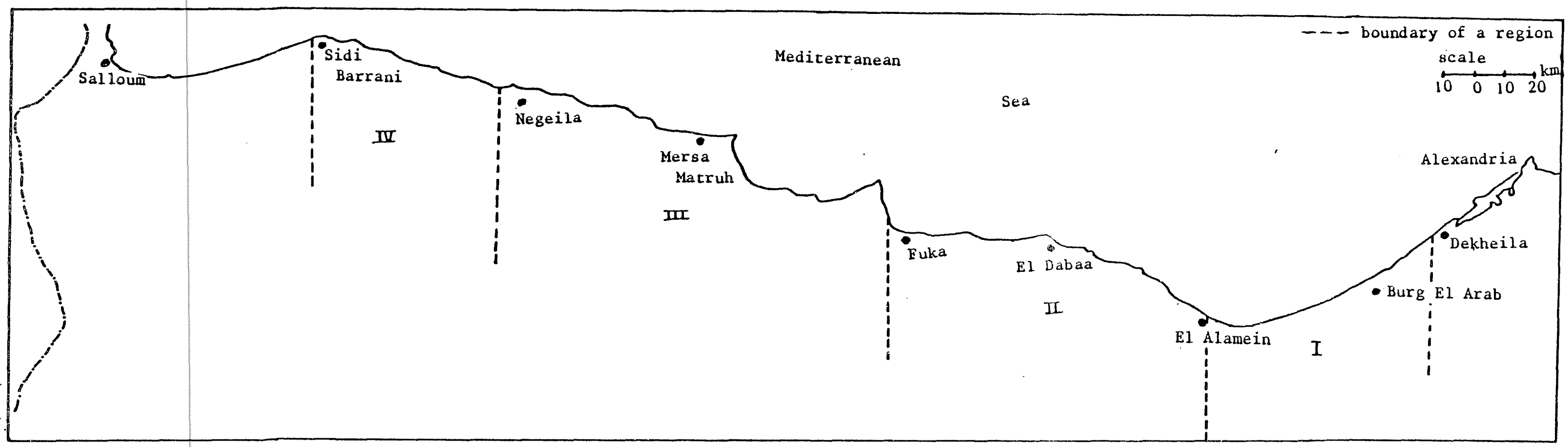

Figure 2. Map of the North-western Coastal Zone of Egypt, with the four regions for which simulations have been carried out.

I. Region Burg El Arab-El Alamein

II. Region El Alamein-Fuka

III. Region Fuka-Negeila

IV. Region Negeila-Sidi Barrani

Figure 3. Barley systems

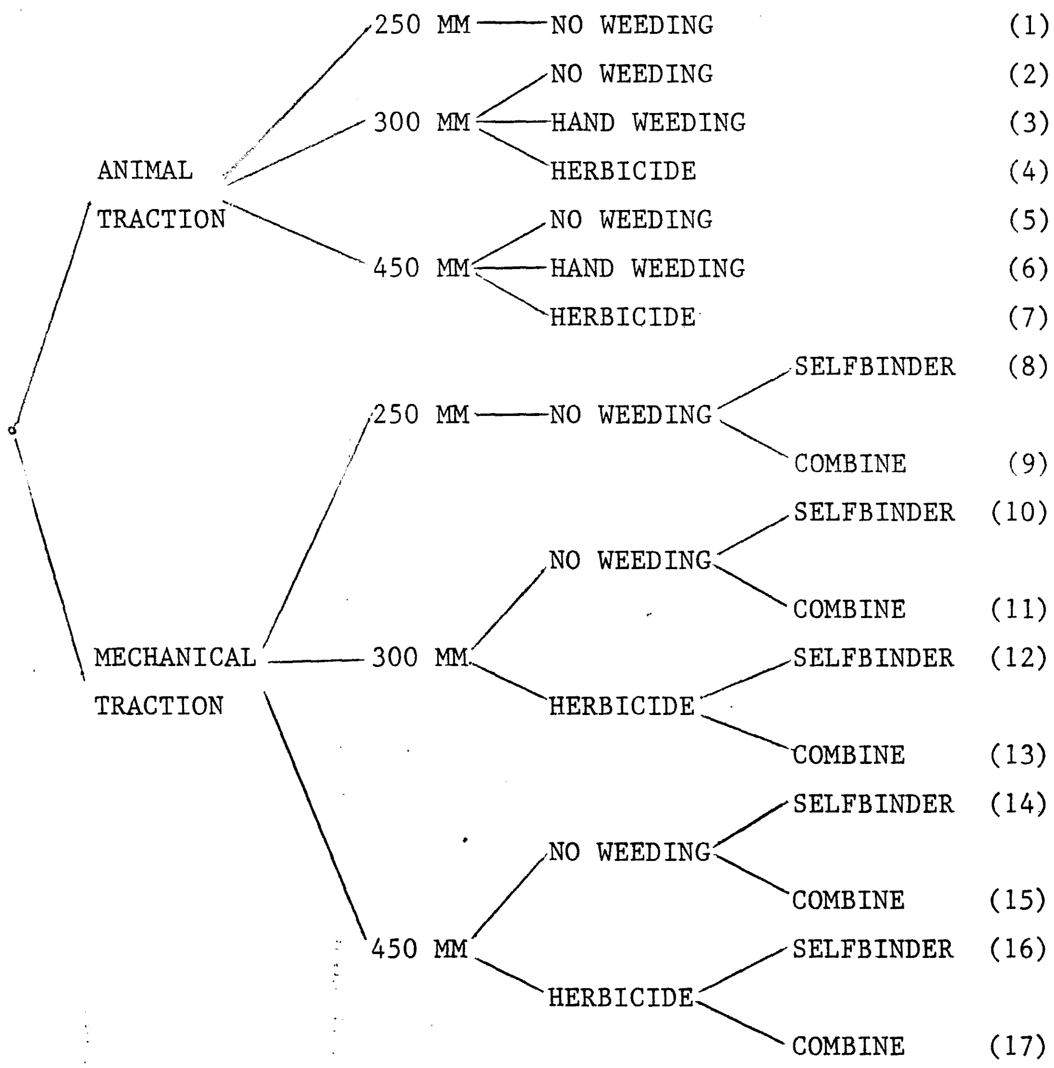

Table 1. Climatic data set for the 5 meteorological stations along the coast and for one calculated "mean climate". TEMP = monthly average of daily air temperature (°C), RAIN = monthly rainfall (cm), T = monthly average of daily potential transpiration rate (cm d^{-1}), ET = monthly average of daily potential evapotranspiration rate (cm d^{-1}), PGS4 (PGS3) = monthly average of daily gross CO_2 assimilation rate for a closed C4 (C3) canopy (kg ha^{-1} d^{-1}), RAIND = number of rainy days per month; the number following the name of a climatic data set indicates the geographical latitude.

TEMP	RAIN	T	ET	PGS4	PGS3	RAIND
DEKHEILA EGYPT					31.22	
13.7	5.92	.191	.222	445.	360.	11.
14.5	2.32	.250	.300	548.	438.	6.
16.4	1.18	.346	.408	652.	517.	4.
18.7	0.30	.438	.516	761.	601.	2.
21.0	0.11	.487	.605	861.	675.	1.
24.3	0.0	.566	.696	918.	716.	1.
25.4	0.0	.613	.726	920.	716.	1.
26.5	0.0	.588	.707	869.	677.	1.
25.5	0.14	.484	.581	761.	595.	1.
22.4	1.18	.377	.440	620.	491.	3.
19.4	2.47	.240	.289	503.	402.	5.
15.6	4.87	.188	.215	417.	339.	8.
DABAA EGYPT					30.56	
12.7	3.41	.211	.241	445.	360.	7.
13.4	1.38	.263	.312	548.	438.	4.
15.0	1.10	.385	.443	652.	517.	3.
17.6	0.15	.457	.533	761.	601.	1.
20.0	0.19	.509	.624	861.	675.	1.
23.2	0.00	.588	.716	918.	716.	1.
25.0	0.0	.620	.753	920.	716	1.
25.5	0.0	.579	.701	869.	677.	1.
24.2	0.11	.471	.569	761.	595.	1.
21.8	1.40	.334	.399	620.	491.	3.
18.2	2.50	.234	.279	503.	402.	5.
13.7	3.80	.216	.241	417.	339.	7.
MERSA MATRUH EGYPT					31.20	
13.2	3.32	.230	.260	445.	360.	9.
13.7	1.51	.282	.324	543.	435.	6.
15.3	1.20	.387	.446	640.	510.	5.
17.4	0.28	.450	.524	848.	592.	2.
20.1	0.26	.517	.619	854.	670.	1.
23.3	0.20	.577	.703	910.	711.	1.
24.8	0.00	.592	.724	920.	716.	1.
25.4	0.06	.553	.676	869.	677.	1.
24.2	0.11	.457	.554	761.	595.	1.
21.9	1.56	.344	.416	610.	484.	4.
18.3	2.25	.246	.284	503.	402.	6.
14.8	3.05	.229	.257	409.	334.	8.

Continuation Table 1.

TEMP	RAIN	T	ET	PGS4	PGS3	RAIND
SIDI BARRANI EGYPT					31.33	
13.2	4.58	.212	.242	441.	358.	10.
13.8	1.46	.298	.343	552.	438.	5.
15.3	1.56	.368	.435	652.	517.	5.
17.5	0.67	.436	.518	754.	597.	2.
19.9	0.34	.487	.593	854.	670.	2.
23.3	0.01	.560	.689	926.	721.	1.
24.9	0.00	.578	.712	920.	716.	1.
25.6	0.02	.546	.669	876.	682.	1.
24.4	0.08	.447	.545	761.	595.	1.
21.8	2.20	.334	.399	620.	491.	4.
18.4	2.22	.244	.280	503.	402.	5.
14.7	4.00	.223	.242	420.	342.	9.
SALLOUM EGYPT					31.24	
14.2	2.06	.255	.280	445.	349.	6.
15.0	0.96	.307	.348	548.	442.	4.
16.4	0.88	.396	.449	652.	533.	3.
18.7	0.37	.458	.529	761.	637.	2.
21.6	0.35	.523	.634	861.	738.	1.
24.8	0.04	.606	.725	918.	796.	1.
26.1	0.00	.659	.783	920.	796.	1.
26.4	0.00	.599	.715	869.	751.	1.
25.0	0.21	.474	.569	761.	641.	1.
22.8	1.59	.362	.422	620.	516.	3.
19.4	2.39	.270	.307	503.	397.	3.
15.6	1.72	.276	.296	417.	321.	5.
EGYPT MEAN 112 mm					31.	
13.4	2.92	.220	.249	443.	359.	9.
14.1	1.15	.280	.325	546.	437.	5.
15.7	0.88	.376	.436	648.	515.	4.
18.0	0.27	.448	.524	754.	597.	2.
20.5	0.19	.505	.615	856.	672.	1.
23.4	0.03	.579	.705	918.	716.	1.
25.2	0.00	.612	.740	920.	716.	1.
25.9	0.01	.573	.694	871.	679.	1.
24.6	0.09	.467	.564	761.	595.	1.
22.1	1.20	.350	.415	617.	488.	3.
18.7	1.79	.247	.288	503.	402.	5.
14.9	2.64	.226	.250	415.	339.	7.

Table 2. Soil moisture characteristics for 3 geomorphological units, derived from experiments by Harga et al. (1973). The soil moisture content (cm^3 cm^{-3}) for the Coastal Plain (C.Pl.), Frontal Plain (Fr.Pl.) and the Mariut Tableland (M.T.L.) at different tensions (P in mbar).

P	C.Pl.	Fr.Pl.	M.T.L.
0	0.312	0.575	0.360
2.5	0.310	0.550	0.359
10	0.285	0.520	0.357
31	0.260	0.450	0.355
100	0.210	0.375	0.353
200	0.184	0.325	0.330
500	0.150	0.225	0.235
2500	0.110	0.185	0.170
16000	0.076	0.156	0.122
10^6	0.010	0.090	0.050

Table 3. Simulation results for barley production. Potential and nutrient limited situation. Climate: Dekheila; grain and straw weight in kg dm ha^{-1}; N and P fertilizer requirements in kg ha^{-1} (N, P).

	Grain	Straw	N	P
Potential production 32 N + 3 P	6 300	4 900	125	65
Potential production 28 N + 4 P	6 300	4 900	135	55
N-limited production 32 N	2 400	2 000	-	5
N-limited production 28 N	2 100	1 700	-	0
P-limited production 3 P	2 000	1 600	0	-
P-limited production 4 P	2 700	2 100	10	-

Table 4. Simulation results for barley cultivation under a water regime with an even distribution and homogeneous infiltration of rainfall and under irrigation in the Burg el Arab region. Climate: Dekheila; grain and straw yields are in kg dm ha^{-1}; N and P fertilizer requirements in kg ha^{-1} (N, P); two soil moisture characteristics are used for B1 (fp = frontal plain, mtl = Mariut table land); I = infiltration during the growing season in mm.

Soil type	Water regime	Grain	Straw	N	P	I
B1-fp	rainfall 137 mm	50	1 100	0	0	75
	rainfall 184 mm	300	3 300	0	0	100
	irrigation level 1	1 500	4 400	0	0	160
	irrigation level 2	4 600	4 600	80	45	230
B1-mtl	rainfall 137 mm	50	1 400	0	0	75
	irrigation level 1	1 300	4 050	0	0	160
	irrigation level 2	3 500	4 500	50	30	230

Table 5. Simulation results for rainfed barley cultivation in the Burg el Arab region. Climate: Dekheila; grain and straw yields in kg dm ha^{-1}; N and P fertilizer requirements in kg ha^{-1} (N, P); I = infiltration during the growing season in mm.

Soil type	Water regime	Grain	Straw	N	P	I
B1-fp	rainfall 137 mm	50	1 100	0	0	75
	rainfall 184 mm	300	3 300	0	0	100
	250 mm	600	3 350	0	0	135
	300 mm	1 050	4 350	0	0	160
	450 mm	4 550	4 850	80	45	240
B1-mtl	rainfall 137 mm	50	1 400	0	0	75
	250 mm	400	2 700	0	0	135
	300 mm	900	4 000	0	0	160
	450 mm	3 200	4 550	45	25	240
B4d	rainfall 137 mm	50	1 200	0	0	75
	rainfall 184 mm	500	3 350	0	0	100
	250 mm	1 100	4 050	0	0	135
	300 mm	1 800	4 800	0	0	160
	450 mm	4 500	4 900	90	35	240

Table 6. The total area, the percentage of the area that is saline, the suitable area per soil type and the distribution of the soil types over the irrigated and the rainfed regions.

Soil type	total area ha	saline %	suitable ha	rainfed ha	irrigated ha
B1-fp	11 930	5	11 330	3 780	7 550
B1-mtl	23 860	5	22 670	5 670	17 000
B4d	4 000	10	3 600	3 600	-
C2-fp	1 500	5	1 420	710	710
C2-mtl	20 340	5	19 320	19 320	-
total	61 630	5	58 340	33 080	25 260

Table 7. Distribution of the area suitable for barley cultivation over the four rainfall zones and the cultivable area under various water regimes in the rainfed region, all figures are given in ha.

Rainfall zone	soil type	suitable area			cultivable area rainfed		
		total	irrigated	rainfed	250 mm	300 mm	450 mm
150-200 mm	B1-fp	3 780	2 520	1 260	600	420	200
	B4d	1 800	-	1 800	650	450	220
	C2-fp	480	480	-	-	-	-
125-150 mm	B1-fp	7 550	5 030	2 520	660	480	280
	B1-mtl	11 330	11 330	-	-	-	-
	B4d	1 800	-	1 800	470	340	200
	C2-fp	950	240	710	290	170	80
100-125 mm	B1-mtl	11 330	5 660	5 670	1 080	740	450
	C2-mtl	9 660	-	9 660	1 930	1 550	770
100 mm	C2-mtl	9 660	-	9 660	1 160	970	580
total		58 340	25 260	33 080	6 840	5 120	2 780

Table 8. Total barley production on irrigated land in the Burg el Arab region. All yields are in 10^6 kg. The required amount of fertilizer is given in 10^3 kg.

Soil type	area (ha)	irrigation level 1 Grain	irrigation level 1 Straw	irrigation level 2 Grain	irrigation level 2 Straw	N	P
B1-fp	6 040	9.1	26.6	27.8	27.8	480	270
B1-mt1	13 600	17.7	55.1	47.8	61.2	680	410
C2-fp*	350	0.5	1.3	1.3	1.3	20	10
total	20 210	27.3	83.0	76.9	90.3	1 180	690

* only half of the area can be cultivated

Table 9. The amount of water required per ha to achieve irrigation levels 1 and 2 in the three rainfall zones and the total amount.

Rainfall zone	nett area ha	irrigation level 1 $m^3\ ha^{-1}$	irrigation level 1 $10^3\ m^3$	irrigation level 2 $m^3\ ha^{-1}$	irrigation level 2 $10^3\ m^3$
150-200 mm	2 400	600	1 400	1 300	3 120
125-150 mm	13 280	850	11 290	1 550	20 580
100-125 mm	4 530	1 000	4 530	1 700	7 700
total	20 210		17 260		31 400

Table 10. Total barley production on rainfed land in the Burg el Arab region for the three distinguished water regimes.

Water regime	Soil type	area	Grain	Straw	N	P
		ha	10^6 kg	10^6 kg	10^3 kg	10^3 kg
250 mm	B1-fp	1 260	0.8	4.2	-	-
	B1-mtl	1 080	0.4	2.9	-	-
	B4d	1 120	1.2	4.5	-	-
	C2-fp	290	0.2	1.0	-	-
	C2-mtl	3 090	1.2	8.3	-	-
	total	6 840	3.8	20.9	-	-
300 mm	B1-fp	900	0.9	3.9	-	-
	B1-mtl	740	0.7	3.0	-	-
	B4d	790	1.4	3.8	-	-
	C2-fp	170	0.2	0.7	-	-
	C2-mtl	2 520	2.3	10.1	-	-
	total	5 120	5.5	21.5	-	-
450 mm	B1-fp	480	2.2	2.3	38	22
	B1-mtl	450	1.4	2.0	20	11
	B4d	420	1.9	2.1	38	15
	C2-fp	80	0.4	0.4	6	4
	C2-mtl	1 350	4.3	6.0	61	34
	total	2 780	10.2	12.8	163	86

Table 11. Simulation results for barley production. Potential and nutrient limited situation. Climate: Dabaa; grain and straw weight in kg dm ha^{-1}; N and P fertilizer requirements in kg ha^{-1} (N, P).

	Grain	Straw	N	P
Potential production 32 N + 3 P	6 700	5 600	145	70
Potential production 28 N + 4 P	6 700	5 600	155	60
N-limited production 32 N	2 400	2 000	-	5
N-limited production 28 N	2 100	1 800	-	0
P-limited production 3 P	2 000	1 700	0	-
P-limited production 4 P	2 600	2 200	10	-

Table 12. Simulation results for barley production in the Dabaa region. Grain and straw yield in kg dm ha^{-1}; N and P fertilizer requirements in kg ha^{-1} (N, P); I = infiltration during the growing season in mm.

Soil type	Water regime	Grain	Straw	N	P	I
BI-fp	rainfall 137 mm	0	1 250	0	0	75
	rainfall 150 mm	50	1 500	0	0	80
	250 mm	600	3 350	0	0	135
	300 mm	1 050	4 350	0	0	160
	450 mm	4 600	4 600	80	45	240
B3 (30-60)	rainfall 137 mm	100	1 850	0	0	75
	rainfall 150 mm	150	2 050	0	0	80
	210 mm	500	3 200	0	0	110
	250 mm	900	3 800	0	0	135
	300 mm	1 350	4 700	0	0	160
	450 mm	3 850	4 850	65	35	240
B3 (60-90)	rainfall 137 mm	100	1 750	0	0	75
	rainfall 150 mm	150	2 000	0	0	80
	250 mm	900	3 700	0	0	135
	300 mm	1 400	4 600	0	0	160
	450 mm	4 950	4 850	90	50	240
B4	rainfall 137 mm	50	1 400	0	0	75
	rainfall 150 mm	100	1 700	0	0	80
	250 mm	600	3 200	0	0	135
	300 mm	1 000	4 100	0	0	160
	450 mm	3 200	4 450	50	20	240
DS5	rainfall 137 mm	100	1 500	0	0	75
	250 mm	950	3 550	0	0	135
	300 mm	1 250	4 200	0	0	160
	450 mm	2 400	4 500	35	10	240
F3	rainfall 137 mm	50	1 350	0	0	75
	rainfall 150 mm	200	2 150	0	0	80
	250 mm	1 000	3 850	0	0	135
	300 mm	1 450	4 700	0	0	160
	450 mm	5 350	4 900	105	50	240

Table 13. The total area, the percentage saline, the suitable and cultivable area (ha) in the Dabaa region for the various soil types in two rainfall zones.

soil type	total area	% saline	100-125 mm rainfall zone: suitable area	100-125 mm: cultivable area 250 mm	100-125 mm: cultivable area 300 mm	100-125 mm: cultivable area 450 mm	125-150 mm rainfall zone: suitable area	125-150 mm: cultivable area 250 mm	125-150 mm: cultivable area 300 mm	125-150 mm: cultivable area 450 mm
B1-fp	30 420	5	19 110	3 440	2 480	1 530	9 790	2 550	1 860	980
B3 (30-60)	3 600	10	1 050	190	140	80	2 190	570	420	220
B3 (60-90)	1 800	10	520	90	70	40	1 100	290	210	110
B4	1 260	10	–	–	–	–	1 130	850	850	850
F1	1 610	15	1 370	250	180	110	–	–	–	–
F3, Ww	1 180	5	1 120	200	150	90	–	–	–	–
DS5	3 250	10	2 930	590	440	230	–	–	–	–
C1	4 350	10	3 690	550	370	180	230	60	40	20
total	47 470	10	29 790	5 310	3 830	2 260	14 440	4 320	3 380	2 180

Table 14. Total barley production in the Dabaa region for the three distinguished water regimes.

Water regime	Soil type	area ha	Grain 10^6 kg	Straw 10^6 kg	N 10^3 kg	P 10^3 kg
250 mm	B1-fp	5 990	3.6	20.1	-	-
	B3 (30-60)	760	0.7	2.9	-	-
	B3 (60-90)	380	0.3	1.4	-	-
	B4	850	0.5	2.7	-	-
	F1	250	0.2	1.0	-	-
	F3, Ww	200	0.2	0.8	-	-
	DS5	590	0.6	2.1	-	-
	C1	610	0.5	2.3	-	-
	total	9 630	6.6	33.3	-	-
300 mm	B1-fp	4 340	4.6	18.9	-	-
	B3 (30-60)	560	0.8	2.6	-	-
	B3 (60-90)	280	0.4	1.3	-	-
	B4	850	0.9	3.5	-	-
	F1	180	0.2	0.8	-	-
	F3, Ww	150	0.2	0.7	-	-
	DS5	440	0.6	1.8	-	-
	C1	410	0.4	1.8	-	-
	total	7 210	8.1	31.4	-	-
450 mm	B1-fp	2 510	11.5	11.5	200	113
	B3 (30-60)	300	1.2	1.5	20	11
	B3 (60-90)	150	0.7	0.7	14	8
	B4	850	2.7	3.8	43	17
	F1	110	0.4	0.5	7	4
	F3, Ww	90	0.5	0.4	9	5
	DS5	230	0.5	1.0	8	2
	C1	200	0.8	1.0	13	7
	total	4 440	18.3	20.4	314	167

Table 15. Simulation results for barley production. Potential and nutrient-limited situation. Climate: Mersa Matruh; grain and straw yield in kg dm ha^{-1}; N and P fertilizer requirements in kg ha^{-1} (N, P).

	Grain	Straw	N	P
Potential production 32 N + 3 P	6 500	5 300	135	65
Potential production 28 N + 4 P	6 500	5 300	145	55
Potential production 15 N + 1 P	6 500	5 300	175	85
N-limited production 32 N	2 400	2 000	-	5
N-limited production 28 N	2 100	1 700	-	0
N-limited production 15 N	1 100	900	-	5
P-limited production 3 P	2 000	1 600	0	-
P-limited production 4 P	2 700	2 200	20	-
P-limited production 1 P	700	500	0	-

Table 16. Simulation results for barley production in the Matruh region. Grain and straw yields in kg dm ha^{-1}; N and P fertilizer requirements in kg ha^{-1} (N, P); I is infiltration during the growing season in mm.

Soil type	Water regime	Grain	Straw	N	P	I
B1	180 mm	100	1 900	0	0	95
	250 mm	600	3 350	0	0	135
	300 mm	1 050	4 350	0	0	160
	450 mm	4 550	4 850	80	45	240
B2	137 mm	0	1 200	0	0	75
	250 mm	1 100	4 050	0	0	135
	300 mm	1 800	4 800	0	0	160
	450 mm	4 500	4 900	90	35	240
F1	130 mm	100	1 300	0	0	75
	150 mm	150	2 050	0	0	80
	250 mm	900	3 800	0	0	135
	300 mm	1 350	4 700	0	0	160
	450 mm	3 850	4 850	65	35	240
F2	137 mm	100	1 300	0	0	75
	250 mm	900	3 700	0	0	135
	300 mm	1 400	4 600	0	0	160
	450 mm	4 950	4 850	90	50	240
F3	180 mm	300	2 600	0	0	95
	250 mm	1 000	3 850	0	0	135
	300 mm	1 450	4 700	0	0	160
	450 mm	5 350	4 900	105	50	240
P1	150 mm	100	1 500	0	0	80
	200 mm	350	2 000	0	0	105
	250 mm	800	3 450	15	15	135
	300 mm	1 500	4 000	40	25	160
	450 mm	4 500	4 900	125	65	240

Table 19. Simulation results for barley production. Potential and nutrient-limited situation. Climate: Sidi Barrani; grain and straw weight in kg dm ha^{-1}; N and P fertilizer requirements in kg ha^{-1} (N, P).

	Grain	Straw	N	P
Potential production 32 N + 3 P	6 600	5 300	135	70
Potential production 28 N + 4 P	6 600	5 300	145	60
N-limited production 32 N	2 400	2 000	-	5
N-limited production 28 N	2 100	1 700	-	0
P-limited production 3 P	2 000	1 600	0	-
P-limited production 4 P	2 700	2 200	20	-

Table 20. Simulation results for barley production in the Barrani region. Grain and straw yields in kg dm ha^{-1}; N and P fertilizer requirements in kg ha^{-1} (N, P); I is infiltration during the growing season (mm).

Soil type	Water régime	Grain	Straw	N	P	I
B1	180 mm	150	2 000	0	0	95
	250 mm	600	3 350	0	0	135
	300 mm	1 050	4 350	0	0	160
	450 mm	4 550	4 850	80	45	240
B2	180 mm	500	3 350	0	0	95
	250 mm	1 100	4 050	0	0	135
	300 mm	1 800	4 800	0	0	160
	450 mm	4 500	4 900	90	35	240
B3 (30-60)	180 mm	300	2 600	0	0	95
	250 mm	900	3 800	0	0	135
	300 mm	1 350	4 700	0	0	160
	450 mm	3 850	4 850	65	35	240
B3 (60-90)	180 mm	300	2 500	0	0	95
	250 mm	900	3 700	0	0	135
	300 mm	1 400	4 600	0	0	160
	450 mm	4 950	4 850	90	50	240
F1	140 mm	100	1 700	0	0	75
	170 mm	300	2 600	0	0	90
	250 mm	900	3 800	0	0	135
	300 mm	1 350	4 700	0	0	160
	450 mm	3 850	4 850	65	35	240

Table 21. The total area, the percentage saline, the suitable and cultivable area in ha in the Barrani region for the various soil types and the various water regimes.

Soil type	total area	% saline	suitable area	cultivable area 250 mm	300 mm	450 mm
B1-fp	2 110	5	2 000	780	540	280
B2	160	5	150	150	150	150
B3 (30-60)	4 630	10	4 170	1 630	1 130	580
B3 (60-90)	2 320	10	2 090	820	560	290
F1 140 mm	10 600	15	9 010	2 160	1 620	900
F1 170 mm	10 600	15	9 010	3 150	2 250	1 170
C1	6 200	15	5 270	2 640	1 480	630
total	36 610		31 700	11 330	7 730	4 000

Table 22. Total barley production in the Barrani region for the three distinguished water regimes.

Water regime	Soil type	area ha	Grain 10^6 kg	Straw 10^6 kg	N 10^3 kg	P 10^3 kg
250 mm	B1-fp	780	0.5	2.6	-	-
	B2	150	0.2	0.6	-	-
	B3 (30-60)	1 630	1.5	6.2	-	-
	B3 (60-90)	820	0.7	3.0	-	-
	F1	5 310	4.8	20.2	-	-
	C1	2 640	2.4	10.0	-	-
	total	11 330	10.1	42.6	-	-
300 mm	B1-fp	540	0.6	2.3	-	-
	B2	150	0.3	0.7	-	-
	B3 (30-60)	1 130	1.5	5.3	-	-
	B3 (60-90)	560	0.8	2.6	-	-
	F1	3 870	5.2	18.2	-	-
	C1	1 480	2.0	7.0	-	-
	total	7 730	10.4	36.1	-	-
450 mm	B1-fp	280	1.3	1.4	22	13
	B2	150	0.7	0.7	14	5
	B3 (30-60)	580	2.2	2.8	38	20
	B3 (60-90)	290	1.4	1.4	26	15
	F1	2 070	8.0	10.0	135	72
	C1	630	2.4	3.1	41	22
	total	4 000	16.0	19.4	276	147

Table 23. Operations to be carried out for the various water regimes.

Operation	250 mm	300 mm	450 mm
sowing	+	+	+
ploughing	shallow	shallow	deep
harrowing	-	+	+
weed control	-	optional	optional
fertilizer application	-	-	+
water harvesting	-	+	+
harvesting	+	+	+
threshing	+	+	+
winnowing	+	+	+
transport	+	+	+

Table 24. Labour requirements for agricultural operations in barley cultivation according to various sources and the estimate used for further analysis. All data are in h ha^{-1}, except the ones marked with '*', these are in h ton^{-1}.

operation	mechanization level	Egyptian data	FAO	the Netherlands	developing countries	estimate used
sowing	hand labour	0.75	8.5	2-4	3	4
ploughing	animal traction					
	shallow	5	42	-	18	18
	deep	-	-	16-27	28	28
	tractor					
	shallow	3	-	-	-	3
	deep	-	-	2-14	6-17	11
harrowing	animal traction	6	-	3-5	24	6
	tractor	2	-	1-3	10	2
weed control	hand labour	120	-	-	145	120
	handsprayer	-	-	4-5	25	25
fertilizer application	hand labour	0.75	-	2	35	5
harvesting	hand labour	13*	60*	12*	110*	13*
	selfbinder	-	-	8-16	5	5
	combine	1.7	-	2-10	4	4
threshing	animal traction	19*	30*a	-	190b	30*a
	mechanical	3*	-	11-25	10b	6*a
winnowing	hand labour	-	-	-	1-5*	-
transport	animal traction	30*	-	28-30	42*	14*
	tractor	-	-	-	-	8*

a: including winnowing
b: data for rice

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