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SIMULATION OF BARLEY PRODUCTION
IN THE NORTH-WESTERN COASTAL ZONE
OF EGYPT

G.W.J. van de Ven
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CABO-TT
Bornsesteeg 65
P.O. Box 14
6700 AA WAGENINGEN
The NETHERLANDS

CENTRUM VOOR AGROBIOLOGISCH ONDERZOEK (CABO)
Centre for Agrobiological Research

VAKGROEP THEORETISCHE TEELTKUNDE (TT), Landbouwhogeschool
Department of Theoretical Production Ecology, Agricultural University.

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SUMMARY

The north-western coastal zone of Egypt extends from Alexandria to the Lybian border over a length of ca. 500 km and a width of 15 to 30 km. The main agricultural activities at present are animal husbandry on natural range land, rainfed barley cultivation and tree cultivation, mainly 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 North-western 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 were 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, 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 sheet run-off and wadi flow, if any.

The results show that barley cultivation is only possible in locations where a considerable amount of sheet run-off and wadi flow is concentrated. The total area suitable for barley cultivation in that part of the region where no irrigation from canals is possible, is 125.700 ha. The maximum area cultivable without fertilizer application is 15% (18.500 ha) of the total assuming that part of the water from the remaining 85% of the acreage flows to the cultivated areas (350 mm infiltration). Grain yield is 16 * 10^6 kg and straw yield 81 * 10^6 kg. The cultivable area under an annual infiltration of 450 mm water is 10% (12.600 ha) and yields 60 * 10^6 kg grains and 60 * 10^6 kg straw. Fertilizer

applications of 340 * 10^3 kg N and 260 * 10^3 kg P are required to achieve these yields. The loss in cultivable area is more than compensated for by the increase in yield under higher water availability.

In the region where irrigation from canals is possible the cultivable area is 61.600 ha. This can all be used, assuming that enough irrigation water is available. Under 350 mm annual infiltration grain yield is 48 * 10^5 kg and straw yield 197 * 10^6 kg. Under a water regime of 450 mm annual infiltration grain yield is 116 * 10^6 kg and straw yield 227 * 10^6 kg. Fertilizer applications of 1330 * 10^6 kg N and 950 * 10^6 kg P are required. However, when enough irrigation water is available other crops will be more profitable than barley.

1. INTRODUCTION

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

The North-western Coastal Zone extends from Alexandria ca. 500 km west, to the Lybian border, over a width of 15-30 km. The main agricultural activities at present are animal husbandry on natural rangeland, rainfed barley culivation and tree cultivation, mainly 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.

Simulation runs to calculate barley production for different locations in the north-western coastal region of Egypt were carried out, using the CFWS-simulation model for annual crops (van Keulen & Wolf, 1985). 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.

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, 1970). A soil map was composed 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. Another important source of information are the SAMDENE and REMDENE Progress Reports (Ayyad et al., 1975-1982).

2. THE SIMULATION MODEL

A detailed description of the simulation model is given by Wolf et al. (1985), therefore only the adaptations necessary for the present study are treated here.

2.1 Input data

2.1.1 Barley

In Egypt another barley cultivar is used than the one originally defined in the plant data set, especially with respect to phenological development. Several parameters were changed, based on literature data and information supplied by Dr. Abou El Enein, a scientist specialized in barley research at the Agricultural Research Centre (ARC) in Cairo.

The values of the maximum development rates before and after anthesis (DVRC1 and DVRC2, respectively) had to be adapted for an Egyptian barley cultivar. At temperatures below 35 °C the development rate is linearly related to average temperature. At 35 °C the development rate has a maximum value. To calculate the development rate, the length of the vegetative and reproductive period and the average temperature sum during these periods are used.

The optimum length of the pre-anthesis growing period for the desert cultivars of barley is 75 days. The grain filling period is about 35 days. In "normal" years barley germinates between January 1 and 15. For both dates DVRC1 and DVRC2 are calculated and an average is used. Calculations are based on the Dabaa climate. The temperature sums (TSUM) over 75 days from January 1 and from January 15 are 1009 °C and 1034 °C, respectively. For the reproductive stage the temperature sums over the next 35 days are 577 °C and 628 °C. The maximum development rate per day is than the temperature at which maximum development occurs divided by the temperature sum.

$$\left.\begin{array}{lll} \text{1-1 to 15-3:} & \text{TSUM} & = 1009\ ^{\circ}\text{C} \\ & \text{DVRC1} & = \frac{35}{1009} = 0.0347\ \text{d}^{-1} \\ \text{15-1 to 30-3:} & \text{TSUM} & = 1034\ ^{\circ}\text{C} \\ & \text{DVRC1} & = \frac{35}{1034} = 0.0338\ \text{d}^{-1} \end{array}\right\} 0.034\ \text{d}^{-1}$$

$$\left.\begin{array}{lll} \text{16-3 to 20-4:} & \text{TSUM} & = 577\ ^{\circ}\text{C} \\ & \text{DVRC2} & = \frac{35}{577} = 0.0607\ \text{d}^{-1} \\ \text{1-4 to 5-5:} & \text{TSUM} & = 628\ ^{\circ}\text{C} \\ & \text{DVRC2} & = \frac{35}{628} = 0.0557\ \text{d}^{-1} \end{array}\right\} 0.058\ \text{d}^{-1}$$

The initial weight of the leaves in the original model, i.e. the weight at the moment nutrient uptake from the soil starts, was very low (18 kg d.m. ha^{-1}). Considering the normal sowing rates in Egyptian deserts, which range between 100 and 150 kg ha^{-1} (12% moisture), that value has been replaced by 30 kg d.m. ha^{-1} by changing TDW (total dry weight) from 60 to 100 kg d.m. ha^{-1}.

2.1.2 Climate

To obtain an average crop production for a region two methods exist. One is to use weather data, calculate crop production for each year over the period the weather data are available, and than calculate the average production over these years. Since rainfall is very erratic, daily rainfall data are needed to calculate the crop production for each year accurately.
Another method is to calculate crop production using climatic data, i.e. long term averages for the various data. Since no daily rainfall data are available over a longer period, the latter method is used.

The climatic data needed in the simulation model were calculated from Climatic Normals for five stations along the coast: Dekheila, Dabaa, Mersa Matruh, Sidi Barrani and Salloum (Figures 1 and 2). 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, since there are no meteorological stations in the inland area. To estimate rainfall further inland a map with lines of equal rainfall is used. 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 classes were distinguished, annual averages of: 50-75 mm; 75-100 mm; 100-125 mm. For these zones, artificial climatic data sets were calculated for an annual rainfall of 62, 87 and 112 mm, respectively.

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

The climatic data sets for each of the five meteorological stations and one example of a "mean climate", as used in the simulation runs are presented in Table 1.

2.1.3 Soils

a. Physical classification

Soil data from the FAO-reports on the north-western coastal region of Egypt were used for the simulation of barley production. The 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 North-western 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 their particle size distribution are tabulated, as distinguished 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, 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 growing barley. Only these areas are considered in the simulation study.

b. Chemical classification

Most of the soils in the area are calcareous and the average $CaCO_3$ percentage 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 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 (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 (Van de Ven, 1985). 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 disregarded. 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-ratio it may be concluded that the 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 sandy soils N.

El Hadidy et al. (1971) measured a 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, since no nitrogen fertilizers had been applied on this plot. It might have been an exceptional situation. From the same fertilizer experiment the N-recovery was calculated. 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 calciumnitrate and urea, 0.56 for ammonium sulphate and 0.74 for ammoniumnitrateIt 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 used:
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.

2.1.4 Run-off

Measured quantitative data about run-on/run-off in the area are very limited. In the FAO-project some estimates were made for the pilot areas. 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. Run-off is depending on rainfall intensity, infiltration capacity and 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 amount for barley cultivation (FAO, REMDENE).

When data from other sources than those referenced in Chapter 1 are used, they are referenced upon application.

2.2 Starting points for simulation

For each soil type in a region a short description of the classification, the soil moisture charachteristic and texture, the natural soil fertility and the agricultural potentiality are given. Simulation of barley production is carried out for each soil type in each region. A region is defined as the area to which one climatic data set applies.

2.2.1 Water regimes

Simulation runs have been carried out for various water regimes, i.e.:

- purely rainfed with complete and homogeneous infiltration;
- assuming availability of the amount of water needed for maximum production without fertilizer application;
- 450 mm infiltration annually;
- potential situation.

For some situations additional simulation runs were carried out based on literature data, e.g. for estimated run-off coefficients.

The mean climate with 450 mm infiltration annually is used to calculate the production of barley somewhere between the non-fertilized and the potential situation. The rainy season starts in October/November and ends in March. Barley growth starts around January 1, so only part of the rainfall, on average 47%, is available for plant growth after germination. This means that from the 450 mm infiltration annually, only 210 mm infiltrates during the growing period of barley. These 210 mm will have to be realized by collecting run-on, and in some situations irrigation is possible. On average these 210 mm give a reasonable yield (1500 kg grain d.m. ha^{-1}). The amounts of N and P fertilizer, needed to achieve these yields, are also calculated.

For the various rainfall zones, except for the zone with the average rain in a region, the "mean" climate is used, as explained in Subsection 2.1.2. This sometimes gives slightly different simulation results, compared to the use of the climatic data set of a specific station. These differences, related for instance to development rate and therefore potential production, are usually negligible. The results 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 fertilizer amounts required to achieve the calculated dry matter are presented in units of 5 kg ha^{-1}.

2.2.2 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, since infiltration is always complete, and no standing water occurs.
c. In the calculations no influence of a ground water table is assumed. In most locations the depth of the ground water 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 since no quantitative data are available about areas and depth of the groundwater table it is difficult to estimate the influence. Moreover, if the groundwater is quantitatively of importance, fruittrees are grown.

2.2.3 Present methods of barley cultivation

Various strategies for growing barley are practiced by farmers in the region. Some Bedouins 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. Since rainfall is very erratic, most Bedouins sow barley after the first 2 or 3 "heavy" rain showers. Usually the available amount of water is sufficient for germination, but for actual plant growth more showers are required. In that case germination usually takes place at the end of December - beginning of January (Bedouins, pers.comm.). Seeding is never done after January 8, the end of one of the rainfed periods distinguished by the Bedouins. The seeds are broadcast by hand and then the soil is ploughed. Harvesting is done between the middle of April and the middle of June. After that, the grains and the straw are stored. Harvesting is usually done by hired labour. Since the agricultural labour force drastically declined during the last 15 years (emigration and more rewarding jobs), the barley is sometimes left to be grazed. The barley stubble is grazed after the spring pasture is exhausted. After that the stored straw and grains are fed during the summer as supplements (Wilder, 1984).

Own observations in spring 1985 showed that barley had germinated in the beginning of February only. From literature (Sabet et al., 1968; Fathi et al., 1974; Wassif et al., 1979; Bakr Salem, 1985) it can be deduced that the growth of barley starts somewhere between December 1 and January 31. For the simulation study, January 1 was taken as an average starting day.

Considering the climatic data, especially rainfall and evaporation, it seems possible to start growth earlier, i.e. around the middle of December. Therefore calculations were also carried out assuming December 20 as emergence date for barley growth.

3. BARLEY PRODUCTION IN THE REGION BURG EL ARAB-EL ALAMEIN

3.1 Introduction

For simulating barley production in the region Burg El Arab-El Alamein 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 a strip of 20-30 km wide along the coast 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 for each month and the dates for irrigation are set at 5, 15 and 25 for each month. A farmer usually does not irrigate more than twice a month, but rain may fall in between the two irrigation events. In this case rain is distributed together with the irrigation water, which means that in between irrigations no water is added to the soil. To compensate partly for this effect, the number of irrigations is set to 3 instead of 2.

"Irrigation" in this context refers to both run-on and irrigation from the canals. So it comprises 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, in dependence of water and nutrient availability.

3.2 Barley yields for various soil types

3.2.1 The potential and the nutrient-limited situation

The potential yield amounts to 6600 kg grains 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 135 kg N and 70 kg P ha^{-1} or 145 kg N and 60 kg P ha^{-1}. The nitrogen-limited yield, when 32 kg N is available is 2400 kg grains ha^{-1} and for 3 kg available phosphorus the maximum yield is 2000 kg grains ha^{-1}. For a natural soil fertility level of 28 kg N and 4 kg P ha^{-1}, the maximum yields are 2100 and 2700 kg grains ha^{-1}, respectively.

The harvest index is a result of the dry matter distribution, which is introduced in the model as a forcing function. In the potential situation the value of the harvest index is about 0.55, depending on the exact lenght of the growth period. In the water limited situation the harvest index is much lower (ca. 0.18), because water stress often occurs during grainfilling. This results in lower grain yields. In the nutrient-limited situation the same dry matter distribution as in the potential situation 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.

3.2.2 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.

a. Frontal Plain

Irrigation water is available from the Mariut (Extension) Canal. Simulation results are presented in Table 4. From these results it may be concluded that growing barley under rainfed conditions, without any additional water (e.g. run-on) is not feasible. Grain yields are only 100 kg d.m. ha^{-1} in this situation, while 125 kg grains ha^{-1} are sown. Normal sowing rates are 90-130 kg ha^{-1}. If crop performance is poor and expected grain yields are low like this, the barley is usually grazed by sheep.

Without any nitrogen and/or phosphorus fertilizer application the maximum grain yield is about 900 kg ha^{-1} (Table 4), which requires 55 mm of irrigation or run-on water, spread in time. 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.

When growth would start 10 days earlier, i.e. December 20, the calculated yields are much higher, especially for the lower production levels. Under rainfed conditions the grain yield increases to 300 kg ha^{-1} and the straw yield to 3300 kg ha^{-1}. Under irrigation with 65 mm grain yield increases from 1100 to

2300 kg ha^{-1}, while straw yield only increases with 100 kg ha^{-1} to 4700 kg ha^{-1}. Fertilizer requirements in this case are 25 kg N and 20 kg P ha^{-1}. The higher yields are partly caused by the lower average temperature: transpiration and evaporation are somewhat lower and more rain is available, so water stress is reduced, especially during the grainfilling period. Maintenance respiration is reduced a little too, the total growth period is a few days longer and peak leaf area is somewhat higher.

b. Mariut Tableland

Irrigation water is available from the Nasr Canal for the whole Tableland region with soil type B1. Simulation results are presented in Table 5. Under rainfed conditions no grain yield is produced at all. Irrigation with 75 mm of water, evenly distributed over the growth period results in a yield of 1000 kg grains ha^{-1} and no fertilizer is needed to achieve this. Irrigation with 110 mm yields 2000 kg grains ha^{-1}. Fertilizer requirements are 15 kg ha^{-1} of both N and P.

When growth starts December 20, grain yields are almost doubled to 1900 kg ha^{-1} under irrigation with 75 mm of water and 3500 kg ha^{-1} with 110 mm irrigation.

3.2.3 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 the 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 and Table 5 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.

3.2.4 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.

Irrigation is possible from cisterns and galleries, but the total amount of water is limited. Galleries are underground ditches, dug in ancient times. The depth of the ditches is ca. 1 m and they are located 2 to 5 m beneath the surface. Most galleries collapsed and are out of use, some are rebuilt and water can be with drawn from them.

The results for this soil type are presented in Table 6. Because the land is sloping and gullied a yield reduction of 25% is assumed compared to even and level land. This results in a grain yield of 150 kg ha^{-1} under rainfed conditions. Irrigation with 55 mm of water increases the grain yield to 700 kg ha^{-1} and no fertilizer application is required. Irrigation with 110 mm yields 2400 kg ha^{-1}, but additional fertilizer application of 45 kg N ha^{-1} and 15 kg P ha^{-1} is required.

When barley growth starts on December 20, the grain yield increases to 200, 1400 and 3600 kg ha^{-1} for no, 55 mm and 110 mm irrigation, respectively. To avoid the 25% yield reduction, erosion controlling measures are necessary.

3.2.5 Conclusions

From the simulated results it may be concluded that growing barley under rainfed conditions, without any additional water, either from run-on or irrigation, is not a feasible activity. In the region Burg El Arab-El Hammam irrigation is possible from the existing canals. Irrigation with 110 mm of water, evenly distributed over the growing season and using additional fertilizers gives reasonable to good yields. Simulation runs are executed for the actual rainfall and even then yields are poor, so for lower rainfall zones no simulation runs are carried out, but the additional amount of water needed to obtain the same productions are calculated.

3.3 Regional barley production

From the calculated barley yield per ha, the barley production for the whole region can be calculated, since the area per soil type can be estimated. These areas are estimated using the soil map and data from FAO reports nr. 5 and 2 (1970) and REMDENE Progress Report 2 III (1981). All the land suitable for field crops is situated east of El Hammam. The whole area to which the Dekheila climatic data set is applied, roughly situated between Burg El Arab and El Alamein, covers an area of 171.670 ha. From this area 35% is suitable for barley cultivation. The area per soil type is given in Table 7. The maximum barley production per soil type in the absence of fertilizer application is calculated and the production with a total infiltration during the growing season of 210 mm. Grain and straw production and fertilizer requirements are presented.

The maximum production of the whole region, without any fertilizer application is $48.3 * 10^6$ kg grain and $196.5 * 10^6$ kg straw. To increase the production to $116.9 * 10^6$ and $226.7 * 10^6$ kg, respectively, fertilizer applications of $1.33 * 10^6$ kg N and $0.95 * 10^6$ kg P are required.

Water requirements for the production of barley as calculated in Table 7 are presented in Table 8. To reach the maximum production without fertilizer application in the 150-200 mm rainfall zone, on soil types with the Mariut Tableland soil moisture characteristic, 75 mm of irrigation is required and on the other soil types 55 mm. For the other rainfall zones the requirements to reach the same production are higher. Therefore, the water requirements per soil type are calculated for each rainfall zone separately. Only the soil types present in a certain rainfall zone are considered.

Infiltration of 210 mm equals irrigation with 110 mm for the zone with 150-200 mm rainfall. Again for other rainfall zones, water requirements to reach the same infiltration of 210 mm are calculated.

For the maximum production without fertilizer application a total of $48.5 * 10^6$ m^3 of water is required. For barley production with 210 mm infiltration $71.6 * 10^6$ m^3 of water is required.

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 be considered elsewhere.

4. BARLEY PRODUCTION IN THE REGION EL ALAMEIN-FUKA

4.1 Introduction

The procedure followed is the same as in the preceding chapter. The climatic data set from Dabaa meteorological station is used for the region El Alamein-Fuka. The most important difference compared to the region Burg El Arab-El Alamein is that in this region no irrigation canals exist. Plans exist to extend the Nasr Canal up to Dabaa. 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.

Simulation runs are, except for the water regimes applied in the preceding chapter, also carried out for 1.6 times rainfall, based on a run-off coefficient of 0.2 and a ratio beneficiary area to catchment area of 1:3 as in the El Dabaa pilot area (FAO, 1970). In the Fuka pilot area the run-off coefficient is 0.20-0.25. If dykes would be constructed according to the proposals of FAO, a ratio beneficiary area to catchment area of 1:6.4 could be realized. The total amount of water received would then be 2.6 times rainfall. In the 125-150 mm rainfall zone, infiltration would be 156 mm during barley growth, starting at January 1. This amount approaches closely that associated with a mean annual water supply of 350 mm as used in the simulation runs (164 mm infiltration), so yields will be comparable. For the other rainfall zones more run-off should be collected to obtain identical yields. At Fuka village the average rainfall is 110 mm yr^{-1}.

4.2 Barley yields for various soil types

4.2.1 The potential and the nutrient-limited situation

Potential production amounts to 7000 kg grains ha^{-1} and 6000 kg straw ha^{-1} (Table 9). 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 155 kg N and 80 kg P ha^{-1} or 165 kg N and 70 kg P ha^{-1}.

The N-limited production with 32 kg ha^{-1} of available N is 2400 kg grains and 2000 kg straw ha^{-1} and for 3 kg ha^{-1} of available P the yields are 2000 and 1700 kg ha^{-1}, respectively. The N-limited production with 28 kg ha^{-1} of available N is 2100 kg grains and 1800 kg straw ha^{-1} and for 4 kg ha^{-1} available P the yields are 2600 and 2200 kg ha^{-1}, respectively.

4.2.2 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, presented in Table 10, show that under rainfed conditions no grains are produced at all and only 900 kg straw ha^{-1} can be harvested. Under a water regime with infiltration equal to 1.6 times rainfall the grain yield is 100 kg ha^{-1} and the straw yield is 2300 kg ha^{-1}. This is still not profitable, considering the 90-130 kg ha^{-1} sowing rate. Under the mean climate with 350 mm annual infiltration, i.e. 104 mm additional infiltration, the grain yield is 1000 kg ha^{-1}. Under the mean climate with 450 mm annual infiltration or 150 mm infiltration during barley growth, the grain production is 2400 kg ha^{-1} and the straw production is 5100 kg ha^{-1}. To achieve this yield, application of 35 kg N ha^{-1} and 25 kg P ha^{-1} is required.

Assuming emergence on December 20, the production is at a reasonable level under the mean climate of 350 mm infiltration annually: 1800 kg grains ha^{-1} and 4400 kg straw ha^{-1}. Application of 10 kg ha^{-1} of both N and P fertilizers is required. This amount is so low that it will be difficult to apply. The most practical solution would be to apply no fertilizers at all and accept yields that are a little lower.

4.2.3 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.

The simulation results are presented in Table 11.

Under rainfed conditions no grains are produced at all. Assuming a water regime with infiltration equal to 1.6 times rainfall, grain yield is 200 kg ha^{-1}. Under the mean climate with 350 mm infiltration annually, grain yield on the shallow soils of 30 to 60 cm depth is 700-1000 kg ha^{-1}, with a mean of 850 kg ha^{-1}. No fertilizers are needed. On the deeper soils of 60 to 90 cm the grain yield is 1000 kg ha^{-1} and the straw yield 4650 kg ha^{-1}. Application of 5 kg P fertilizer ha^{-1} is required. For the mean climate with 450 mm infiltration annually, the grain production on the shallow soils and the deeper soils is 2000 and 2750 kg ha^{-1}, respectively, and straw yields are 5000 kg ha^{-1} and 5100 kg ha^{-1}. On the shallow soils 30 kg N ha^{-1} and 20 kg P ha^{-1} fertilizer application is required. On the deeper soils this is 45 kg N and 25 kg P ha^{-1}.

Assuming emergence on December 20, calculated yields are higher again: 2200 kg grains ha^{-1} and 4800 kg straw ha^{-1} with 174 mm infiltration during the growth cycle. This requires application of 35 kg N and 10 kg P ha^{-1}.

4.2.4 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.

The simulation results are presented in Table 12. Because the land is sloping and gullied, again a yield reduction of 25% is assumed.

Under rainfed conditions with homogeneous infiltration no grains are produced at all. Under a water regime with infiltration equal to 1.6 times rainfall 100 kg grains ha^{-1} and 1700 kg straw ha^{-1} are produced. The yield increases with increasing water availability to 750-1800 kg grains ha^{-1}, depending on soil depth, with 210 mm infiltration. Since it is unknown what proportion of this soil type is shallow and produces 750 kg grains ha^{-1} and what proportion is deeper and produces 1800 kg ha^{-1}, an average of 1300 kg grains ha^{-1} is assumed to be representative for this soil type. The same procedure is followed for the straw, which yields 3300 kg ha^{-1} with 210 mm infiltration. Fertilizer requirements are 20 kg N ha^{-1}, only.

Assuming emergence on December 20, the grain yield increases to 2300 kg ha^{-1} with an identical straw yield of 3300 kg ha^{-1}. Fertilizer requirements are 40 kg N and 15 kg P ha^{-1}.

4.2.5 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 simulation results are presented in Table 13.

Under rainfed conditions with homogeneous infiltration the yield is 100 kg grains ha^{-1} and 1700 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 1300 kg grains and 3600-4800 kg straw ha^{-1}, if infiltration is 210 mm. Again the arithmetic average of the different values for straw production (4200 kg) is assumed to be representative for this soil type. The fertilizer requirements to achieve this production are 15 kg N ha^{-1} only.

Assuming emergence on December 20, at least double grain yields are achieved. The increases in straw yields are less.

4.2.6 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. This soil type, F1, has been distinguished because of its different origin, but barley production on both types is identical (Table 11).

4.2.7 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 simulation results are presented in Table 14.

Under rainfed conditions no grains are produced at all and straw production is 1500 kg ha^{-1}. Under the mean climate with 350 mm infiltration annually, 1200 kg grains ha^{-1} and 4900 kg straw ha^{-1} are produced. This increases to 3300 kg grains and 5100 kg straw ha^{-1} under a mean climate with 450 mm infiltration annually. Fertilizer requirements in that case are 55 kg N and 30 kg P ha^{-1}.

Assuming emergence on December 20, increases the yield to 4500 kg grains and 5100 kg straw ha^{-1}, with associated fertilizer requirements of 85 kg N and 45 kg P ha^{-1}.

4.2.8 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 of the surface area and soil the other half. The surface run-off coefficient for the rock is estimated about 0.5, so the natural water regime is 210 mm (1.5 * 140 mm). This approaches 1.6 times rainfall, so no special simulation runs are carried out, especially considering the results at 1.6 times rainfall. The simulation results are: identical to those for soil type B3, but only half of the area can be cultivated.

4.2.9 Conclusions

From the simulated results it may be concluded that growing barley under rainfed conditions, even with a run-off coefficient of 0.2 and a ratio of beneficiary area to catchment area of 1:3, is not a feasible activity. In the El Alamein-Fuka 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 enough to irrigate 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, 1970). Only at a few places, where substantial amounts of run-off water concentrate, continuous barley cultivation is a feasible activity.

4.3 Regional barley production in the El Alamein-Fuka area

The area covered by the various soil types in the region is given in Tables 15 and 16. Since 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 estimation of the percentage saline soils for each potentiality class. The soils suitable for barley cultivation are concentrated close to the coast. From areas more inland only a limited amount of water runs off to the coastal zone, because the land is only slightly sloping (FAO, 1970), so all additional water originates from redistribution on a restricted scale.

4.3.1 Water availability and cultivable area

Annual infiltration of 350 mm is about 2.5 times rainfall (140 mm), which implies that 1.5 times rainfall or 210 mm water has to be supplied by run-on.

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, 1970). Considering this and the soil map, it is assumed that the dune depressions receive run-off from about five times the beneficiary area, i.e. 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. To obtain the production calculated for a mean climate with 350 mm annual infiltration, 14% of the area of the dune depressions can be cultivated, assuming that the run-off coefficient over short courses of water flow is 0.25. If a water regime with 450 mm infiltration annually is required, only 10% of the area can be cultivated.

The other soil types suitable for barley cultivation, i.e. B1, B3, B4, F3, Ww, F4 and C1 comprise 42.800 ha. The catchment area for run-off consists of the surrounding rocky ridges, which are 3 to 10 m higher than the cultivated soils. In most places the rock is at the surface, but locally less than 30 cm loamy sand to sandy loam may occur over the rock (FAO, 1970). Considering this nature of the surface a run-off coefficient of 0.15 for long courses of water flow is estimated. From the soil map of the pilot areas Fuka and Dabaa it is deduced that the ratio catchment area to beneficiary area is about 1. The soil in the 125-150 mm rainfall zone receives about 160 mm water annually, i.e. 68 mm infiltration during the growing season of barley in this case. To reach the infiltration of 164 mm during barley growth under the calculated infiltration of 350 mm annually, only part of the suitable area can be cultivated. The estimated run-off coefficient is 0.20 for short courses of water flow, since the area is only slightly sloping (FAO, 1970), so the cultivable area, is 15% of the total area. For the 100-125 mm rainfall zone the annual infiltration is 130 mm and the maximum cultivable area is 11%. Again transport losses will be considered later. For an infiltration of 210 mm the proportion of soil that can be cultivated is 10% for the 125-150 mm rainfall zone and 8% for the 100-125 mm rainfall zone. For soil type C1 the proportions are 14% and 10% under the 350 mm water regime and 9% and 7% under the 450 mm water regime. This is calculated from the natural water regime and the fraction of the area available for cultivation.

4.3.2 Barley yield

As stated before, only part of the cultivable area can be used to obtain a good barley yield. Assuming a water regime providing 164 mm of water during the growth cycle of barley, about 5530 ha can be cultivated. If the requirement is 210 mm infiltration, the area reduces to 3890 ha, i.e. 70%. However, the average grain yield increases from 850 to 2250 kg ha^{-1}, more than 2.5-fold. Hence the reduction in area is more than compensated by the increase in yield. Of course application of fertilizers is necessary to achieve these high yields.

The maximum barley production for the region El Alamein-Fuka without using any fertilizers is $5 * 10^6$ kg. When using about 125.000 kg of N and 85.000 kg of P fertilizers, the yield can be increased to $9 * 10^6$ kg. To obtain either one of these yield levels additional water has to be supplied from surrounding areas by using dykes or something similar. These dykes have to be constructed and maintained. In an economic analysis of the region this has to be taken into account. At some places dykes have been constructed already, but they are only few in number.

The conclusion from the preceding analysis is that purely rainfed barley cultivation is not a feasible activity in this region, but reasonable yields can be obtained by supplying additional water and fertilizers.

5. BARLEY PRODUCTION IN THE REGION FUKA-NEGEILA

5.1 Introduction

The procedure followed is identical to the one in the preceding chapters. The climatic data set for the Mersa Matruh meteorological station is used for the region Fuka-Negeila. 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. West of Fuka it can be a substantial part of the total water available for plant growth.

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

Data about run-off coefficients, wadi flow, etc. for the whole region, are available from 3 pilot areas, as described by FAO (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 explanation of the water regime applied in the simulation runs will be given for each soil type in the relevant paragraph.

In the FAO reports (1970) the fraction of the wadi flow that is utilized in average years is estimated. That is usually only 20 to 30% of the total wadi flow, the rest flowing to the sea. For the simulation, only the fraction utilized is taken into account for estimating the amount annually available for plant growth. The amount of water lost is disregarded. The amount of water annually available is calculated, assuming that the run-off is evenly distributed over the whole area.

5.2 Barley yields for various soil types

5.2.1 The potential and nutrient-limited situation

Under optimum conditions the yield is 6800 kg grains and 5600 kg straw ha^{-1} (Table 17). Depending on the 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 are 145 kg N and 75 kg P ha^{-1}, 155 kg N and 65 kg P ha^{-1} or 190 kg N and 95 kg P ha^{-1}, respectively.

The N-limited production on soils with a natural fertility of 32 kg N ha^{-1} is 2400 kg grains and 2000 kg straw ha^{-1}. On soils with 28 kg ha^{-1} available N the production is 2100 and 1700 kg ha^{-1}, respectively and on soils with 15 kg N ha^{-1} it is 1100 and 900 kg ha^{-1}. The P-limited production on soils with 3 kg available P ha^{-1} is 2000 kg grains and 1600 kg straw ha^{-1}, on soils with a P supply of 4 kg ha^{-1} it is 2700 and 2200 kg ha^{-1} and on soils with 1 kg P ha^{-1} it is 700 and 500 kg ha^{-1}, respectively.

5.2.2 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 are presented in Table 18. The results for the mean climate with 350 and 450 mm annual infiltration in this region are identical to the results for the same climate in the region El Alamein-Fuka (Table 10).

They are repeated in Table 18 to complete the set with results, but will not be discussed again.

The mean climate with 120 mm and 180 mm water are based on literature data from FAO (1970). 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. The amount is based on 112 mm rainfall, a sheet run-off coefficient of 0.075 and a ratio beneficiary area to catchment area of 1:1 ((1 + 0.075) * 112 = 120 mm). No simulation runs are carried out for this water regime, since 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 of 0.075 and a ratio beneficiary area to catchment area of 1:1.

Under normal conditions, 180 mm of water annually, the yield west of Mersa Matruh is 100 kg grains and 1600 kg straw ha^{-1}. East of Mersa Matruh it is 300 kg grains and 2700 kg straw ha^{-1}.

Assuming emergence on December 20, only the straw yield increases to 1900 kg ha^{-1} for the region Mersa Matruh-Negeila.

Cultivation of barley under natural conditions, including wadi flow, is therefore not profitable.

5.2.3 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.

The simulation results are presented in Table 19.

This soil type only occurs in the northern plain at El Qasr. Under the dunes a large aquifer exists, 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 (1970). In the present situation excess water seeps through the dunes and is lost to the sea.

Under rainfed conditions 100 kg of grains and 1400 kg straw ha^{-1} are produced. Under a mean climate with 300 mm annual infiltration, 800 kg grains and 4500 kg straw ha^{-1} are produced. This increases to 2600 kg grains and 5100 kg straw ha^{-1} under a climate with 450 mm infiltration annually. To achieve this yield, 45 kg N and 25 kg P ha^{-1} have to be applied and 1470 m^3 ha^{-1} of water is needed.

Assuming emergence on December 20 increases the yield to 4200 kg grains and 5100 kg straw ha^{-1}. The fertilizer requirements for that situation are 85 kg N and 40 kg P ha^{-1}, while 1610 m^3 ha^{-1} of water has to be added to the soil, distributed over time.

5.2.4 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 simulation results are presented in Table 20. The results for 350 mm and 450 mm infiltration annually are identical to the values in Table 11. These values are not discussed here again. The mean of the calculated values for 30 and 60 cm soil depth is assumed to be representative for this soil type.

The mean climate with 130 mm of annual infiltration is based on 112 mm rainfall (100-125 mm zone), an average sheet run-off coefficient of 0.075 and a ratio beneficiary area to catchment area of 1:2 ((1 + 0.075 * 2) * 112 = 130 mm). This approaches closely the rainfall of 137 mm, so this water regime is used 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 a wadi passes through the depression, but this is of minor importance.

Under the water regime with a supply of 150 mm of water annually the production is 100 kg grains and 1100 kg straw ha^{-1}. In the 100-125 mm rainfall zone the yields are 100 kg grains ha^{-1} and 1550 kg straw ha^{-1}.

Assuming emergence on December 20, results in a yield of 200 kg grains and 1800 kg straw ha^{-1} in the 125-150 mm rainfall zone.

5.2.5 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.

The simulation results are presented in Table 20, with soil depth 60-90 cm and under the water regime with rainfall (137 mm). F2 is situated mainly in the 100-125 mm rainfall zone. Assuming an average sheet run-off coefficient of 0.075 and a ratio beneficiary area to catchment area of 1:2, the annual amount of water received is 140 mm. This is comparable with 137 mm rain which falls on average in Mersa Matruh, so the data set of that station is used.

Under natural conditions no grains are produced and only 1100 kg straw ha^{-1} can be harvested. When more water is available during plant growth, e.g. 164 mm yields increase to 1000 kg grains and 4650 kg straw ha^{-1}.

Assuming emergence on December 20 results in a yield of 100 kg grains and 1300 kg straw ha^{-1}, so cultivating barley under natural conditions is not profitable. When water supply is increased to 350 mm the yield increases to 2100 kg grains and 4700 kg straw ha^{-1}.

5.2.6 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 simulation results for this soil type are presented in Table 21. The results for the mean climate with 350 mm and with 450 mm annual infiltration in this region are identical to the results in the region El Alamein-Fuka, so they are not discussed any further.

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 to the lower rainfall zone and the one with 180 mm to the higher rainfall zone.

The grain yield under the water regime with 180 mm is 200 kg grains and 2100 kg straw ha^{-1}. The yields are not calculated for the lower rainfall zones separately.

Assuming emergence on December 20 results in a yield of 300 kg grains and 2600 kg straw ha^{-1} for 180 mm water supply annually.

5.2.7 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 (Table 21), the sheet run-off and wadi flow received are the same, so the results are not discussed any further here (Subsection 5.2.6).

5.2.8 Soil type P1

- 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 simulation results are presented in Table 22.

The area of soil type P1 in this region is limited and the average annual rainfall is about 125 mm. Assuming a sheet run-off coefficient of 0.075 and a ratio beneficiary area to catchment area of 1:2, the mean climate with 130 mm infiltration is the most appropriate climatic data set. Production under this water regime is limited to 1000 kg straw ha^{-1} only and no grains are produced. Without fertilizer application, but with additional water, a maximum yield of 200 kg grains and 2100 kg straw ha^{-1} can be obtained. Under a water supply of 450 mm annually (210 mm infiltration during the growing season of barley), 2400 kg grains and 5100 kg straw ha^{-1} can be produced.

Assuming emergence on December 20 results in a grain yield of 3800 kg ha^{-1} and a straw yield of 5000 kg ha^{-1}.

5.2.9 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 region Fuka-Negeila, 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 sheet run-off coefficient for long courses of water flow is 0.075 and the ratio beneficiary area to catchment area is 1:1. This all adds up to a water regime of 250 mm (C1 + 0.5 + 0.075) * 140 + 26 = 250 mm). C1 only occurs in the 125-150 mm rainfall zone.

The simulation results are presented in Table 20. Grain yield is 350 kg ha^{-1} and straw yield 3100 kg ha^{-1}.

Assuming emergence on December 20, the yield increases to 650 kg grains and 3600 kg straw ha^{-1}.

5.2.10 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 region Fuka-Negeila, C2 is a complex of rock and B1. Again half of 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 sheet run-off coefficient for long courses of water flow is 0.075 and the ratio beneficiary area to catchment area is 1:1. This adds up to 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 (Table 18), but barley is only cultivated on half of the area covered by C2.

5.2.11 Conclusions

From the simulated results it may be concluded that growing barley under rainfed conditions, without any improvement in water management, can not be succesful. The Fuka-Negeila region receives a reasonable amount of wadi flow, which is, however, only partly used (about 25%) while the remainder flows off to sea. The limiting factor for barley cultivation in this region, is not the absolute amount of water, but the water management. To obtain reasonable yields, dykes would have to be constructed and maintained and some areas would need terracing.

5.3 Regional barley production

The maximum regional barley production without application of fertilizers and the production under the water regime of 450 mm infiltration annually are calculated, so the total area per soil type in the region Fuka-Negeila is required.

The surface area per soil type is given in Table 23. In Tables 23 and 24 the area suitable for agriculture is presented, being the total area minus the saline area. For both rainfall zones the natural water regime, i.e. the present regime without any improvements in water management, is presented. The fraction of the area that can be cultivated with barley without using fertilizers, is calculated using the same formula as in the preceding chapter. The maximum water supply in the non-fertilized situation for all soil types, except two, is 350 mm annually. For soil type B2 it is 300 mm and for soil type P1 it is 200 mm. Since soil type B2 can be completely irrigated, the whole area can be cultivated. The same calculations are performed for the 450 mm annual infiltration, replacing 350 by 450 (Table 24).

The cultivable area and the yields of grains and straw per soil type for the whole region are presented in Tables 25 and 26, for both water regimes. In the unfertilized situation 7080 ha can be cultivated out of 49.800 ha suitable for barley cultivation, i.e. 14%. Total grain yield is $5.7 * 10^6$ kg and the total straw yield is $29.8 * 10^6$ kg. Under a water regime of 450 mm infiltration annually, 4780 ha or 10% can be cultivated. Total grain yield is $11.2 * 10^6$ kg and total straw yield is $104 * 10^6$ kg. Additional fertilizer is required to achieve these yields: 130.000 kg N and 99.000 kg P for the whole region.

Hence, also in the region Fuka-Negeila the reduction in cultivable area when a higher water availability per unit area is required for barley growth, is more than compensated by the higher grain yield per unit area. Wether this is a feasible activity or not depends on the price of fertilizers and the method of application. This question must thus be considered in an economic analysis. The grain yield under the water regime with 450 mm infiltration is about two times the grain yield in the unfertilized situation and the straw yield is decreased by about 25%. The 2300 ha which is not used for barley cultivation under the 450 mm water regime can be used for animal grazing.

6. BARLEY PRODUCTION IN THE REGION NEGEILA - SIDI BARRANI

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 Organization were used.

In this region no pilot areas from the FAO project were situated, hence only little is known about the water regimes. A run-off coefficient of 0.075 is assumed. This value is derived as an average of the run-off coefficients for other parts of the North-western Coastal Region. The total wadi flow in the region is estimated at 2.220.000 m^3, but most of the wadis in the Sidi Barrani area are situated inland at a distance of 20-50 km from the coast (FAO, 1970). Only in the eastern part some wadi flow may reach the coast. Soil type B2, situated in this area, is the only soil type that can use the wadi flow. For all other soil types wadi flow is assumed to be zero.

6.2 Barley yields for various soil types

6.2.1 The potential and the nutrient limited situation

The potential production is 6900 kg grain and 5700 kg straw ha^{-1} (Table 27). 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 150 kg N and 75 kg P ha^{-1} or 160 kg N and 65 kg P ha^{-1}, respectively.

The N-limited production is 2400 kg grains and 2000 kg straw ha^{-1} when 32 kg N ha^{-1} is available and 2100 kg grains and 1700 kg straw ha^{-1} when 28 kg N ha^{-1} is available. The P-limited production is 2000 kg grains and 1600 kg straw ha^{-1} with 3 kg available P and 2700 kg grains and 2200 kg straw ha^{-1} when 4 kg P is available.

6.2.2 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 are presented in Table 28.

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, 84 mm infiltrates during the growing period of barley when growth starts on January 1. The yield is 100 kg grains and 1600 kg straw ha^{-1} in this case and no fertilizer application is required.

Assuming emergence on December 20, only straw yield increases to 1900 kg ha^{-1}. The results under a water regime with 350 mm and with 450 mm water are not discussed here again. They are identical to the results for these water regimes in the other regions (e.g. Table 10).

6.2.3 Soil type B2

For the simulation results for this soil type is referred to subsection 5.2.3. 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.

6.2.4 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.

The simulation results are presented in Table 29. The results for the water regimes of 350 and 450 mm infiltration annually are identical to those calculated for the other regions, so they are not discussed again.

For this soil type two soil depth classes were distinguished in the other regions. Since no specific information is available for the Sidi Barrani area, the same subdivision has been applied for this region, with the 30-60 cm soil depth covering twice the area with the 60-90 cm soil depth.

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 200 kg grains and 2050 kg straw ha^{-1}. On the deeper soils the barley production is 200 kg grains and 2100 kg straw ha^{-1}. No fertilizer application is required.

Assuming emergence on December 20, results in an increase in grain yield to 400 kg ha^{-1} for the shallow soils and 350 kg ha^{-1} for the deeper soils. Straw yield increases to 2400 kg ha^{-1} and 2250 kg ha^{-1}, respectively.

6.2.5 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.

The simulation results are presented in Table 29.

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 is situated in the 125-150 mm rainfall zone. The ratio beneficiary area to catchment area is 1:1 and the sheet 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 the grain production is 200 kg and the straw production is 1800 kg ha^{-1}. Under the water regime of 140 mm the yield is 100 kg grains and 1100 kg straw ha^{-1}.

Assuming emergence on December 20, results in an increased yield of 450 kg grains and 2200 kg straw ha^{-1} for the 170 mm rainfall annually. For the 100-125 and 125-150 mm rainfall zone grain yield is 100 kg ha^{-1} and straw yield is 1400 kg ha^{-1}.

6.2.6 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 areas it is assumed, that C1 mainly exists of moderately deep soils of 30-60 cm and that it covers half of 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 * 170 mm). The simulation results are identical to the ones presented in Table 20 for this water regime.

6.2.7 Conclusions

Although in the region Negeila-Sidi Barrani the yields are somewhat higher than in the other regions, because of the higher rainfall, they are still 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 are estimated conservatively.

6.3 Regional barley production

The maximum barley production in the region without using fertilizers and the production under the water regime with 450 mm infiltration are calculated, using data from the REMDENE Progress Report 2 (III) (1981).

The area per soil type, the fraction cultivable area and the barley production are presented in Table 30, for the unfertilized situation and in Table 31 for the water regime with 450 mm annual infiltration. Table 30 shows that 5860 ha of the total area of 36.610 ha can be used, i.e. 16%. The grain yield is $5 * 10^6$ kg and the straw yield is $27 * 10^6$ kg. When the cultivated area is reduced to 11% and therefore the amount of water per unit cultivated area increases to 450 mm, $8 * 10^6$ kg grains and $20 * 10^6$ kg straw are produced. To achieve the latter yields, fertilizer application of $90 * 10^3$ kg N and $80 * 10^3$ P is required.

The conclusion is identical to the conclusions for the other regions: the loss in cultivable area under a higher water regime is more than compensated by the increase in yield per unit area.

7. FINAL REMARKS

In most areas of the North-western Coastal Zone of Egypt water is the limiting factor for plant growth. In addition to rain, sheet run-off and/or wadi flow are necessary for a succesful barley crop.

The calculated barley production levels, as presented in this report, are based on many assumptions. Most of these assumptions have been presented explicity 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.

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

No data about soil fertility from plant analyses were available, except the ones mentioned in Subsection 2.1.3. 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.

By improving the methods of water collection a larger part of the available amount of water could be used. The sheet run-off coefficient could increase and more of the wadi flow could be used.

The Salloum climatic data set could not be used, since the soil map is only available up to Sidi Barrani.

In the course of time it became clear that in reality barley growth starts around the middle of December. This means that for average years the simulation results for the starting date December 20 are more realistic than for January 1. Because of limited time this is not changed in this report, but it should be kept in mind.

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OVERVIEW OF SOIL CLASSIFICATION (source FAO)

Four main soil groups are distinguished and two less important ones, because of the small area they comprise (see e. and f.). The list of characters at the end of each soil group contains the codes for the soil types distinguished within the group. Only the ones relevant for barley cultivation are listed.

a. Wind blown soils
- Coastal dunes.

These consist of shifting and cemented oolitic sand. In places where the ground water is not too deep, fig trees can be grown. The shifting sand can be a threat to cultivated areas, which can be covered.
- Inland dunes.

These are composed of weathered oolitic and quartz sand and are fixed by the natural vegetation. The inland dunes are not suitable for agriculture, but have a high value as range land.
DS5

b. Soils of the former beach plains and dune depressions
These are situated inland of the oolitic dunes, have a level topography, are predominantly well-drained, consist of sandy loam to loam. Well-drained soils are not saline and suitable for all crops. Some poorly drained parts are saline and not suitable.
B1, B2, B3, B4, B4d

c. Soils of the alluvial fans and outwash plains
These have a slightly sloping topography and are subdivided according to depth of the soil profile.
F1, F1e, F2, F3, F4

d. Rock land
This is covered by less than 30 cm soil and is not suitable for agriculture.

e. Soils of elongated depressions in the plateau
P1

f. Soils of the wadis
Ww, Wb

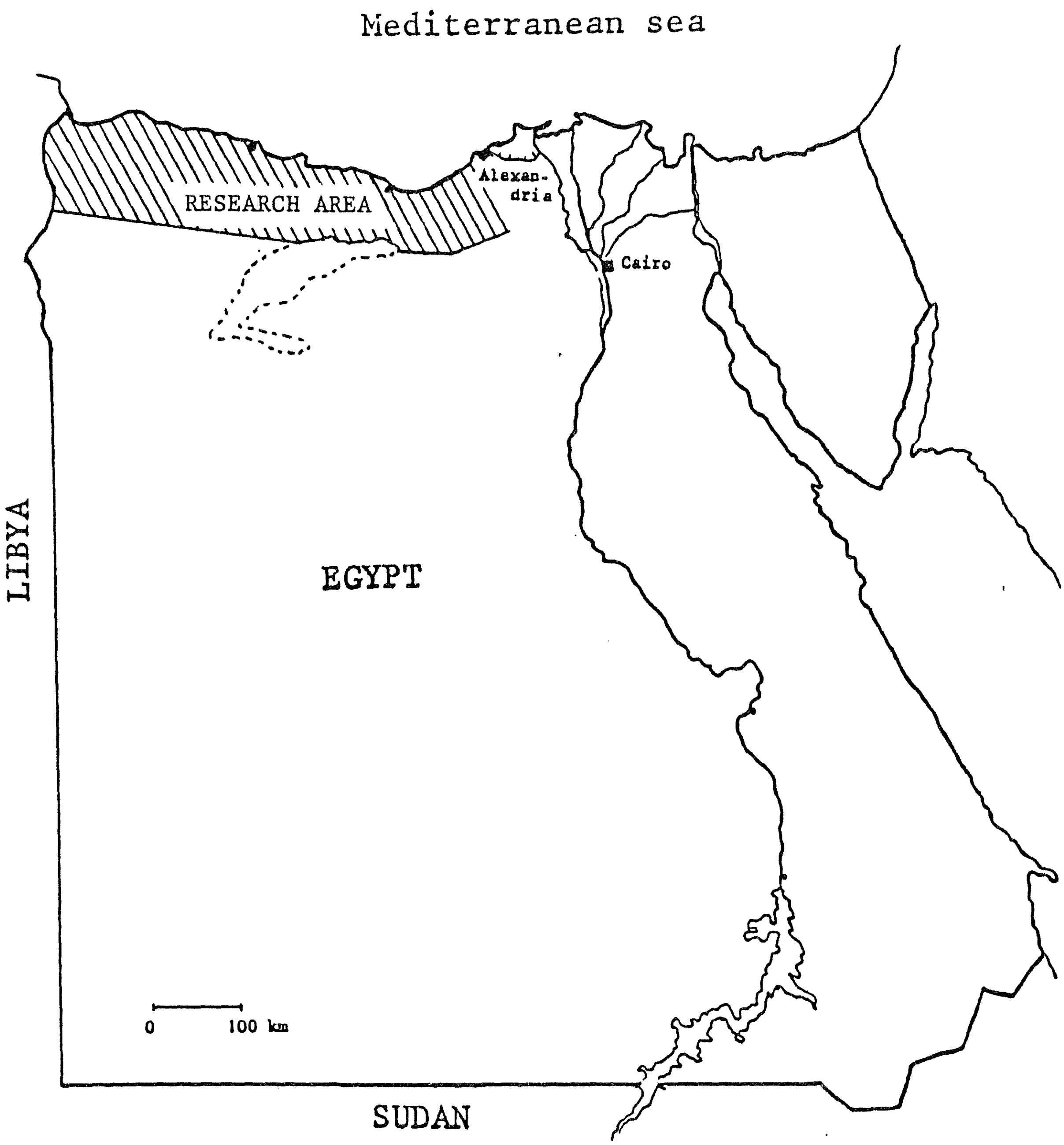

Figure 1. Map of Egypt and location of the research area.

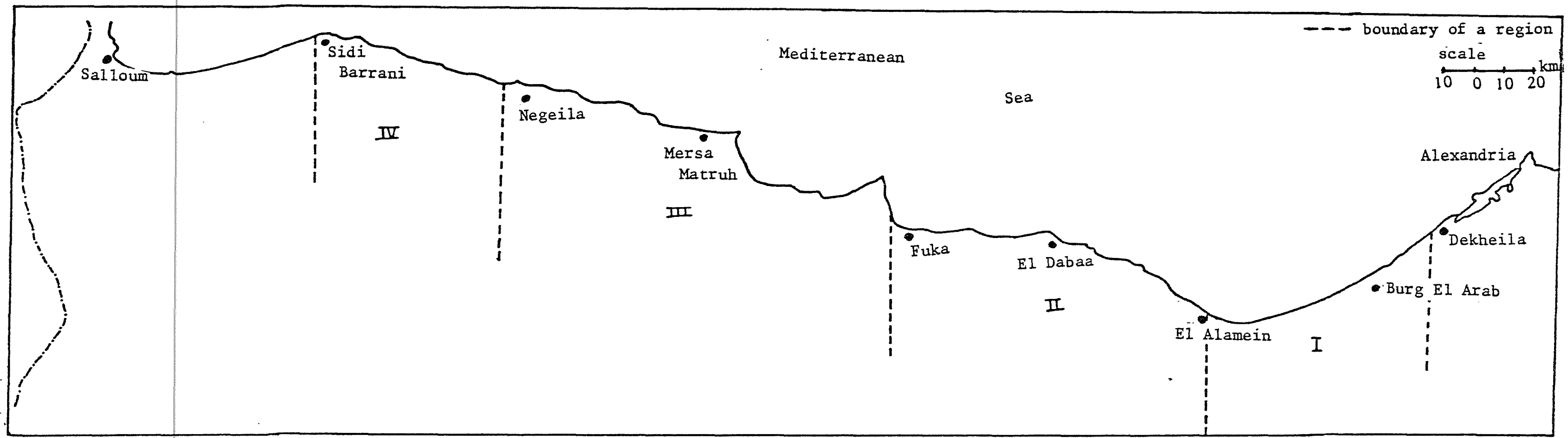

Figure 2. Map of the North-western Coastal Zone of Egypt, with the four regions for which simulation has been carried out.

I. Region Burg El Arab-El Alamein

II. Region El Alamein-Fuka

III. Region Fuka-Negeila

IV. Region Negeila-Sidi Barrani

Table 1. Climatic data set for the 5 meteorological stations along the coast and for one calculated "mean climate". TEMP = montly average of daily air temperature (°C), Rain = montly 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 behind 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} (G.W., S.W.); N and P fertilizer requirements in kg ha^{-1} (N, P).

Start		G.W.	S.W.	N	P
Jan. 1	potential production 32 N + 3 P	6600	5200	135	70
Jan. 1	potential production 28 N + 4 P	6600	5200	145	60
Dec. 20	potential production 32 N + 3 P	6300	4900	125	65
Dec. 20	potential production 28 N + 4 P	6300	4900	135	55
-	N-limited production 32 N	2400	2000	-	5
-	N-limited production 28 N	2100	1700	-	0
-	P-limited production 3 P	2000	1600	0	-
-	P-limited production 4 P	2700	2100	10	-

Table 4. Simulation results for barley production. Climate: Dekheila; soil type: B1, Frontal Plain; grain and straw weight in kg dm ha^{-1} (G.W., S.W.); N and P fertilizer requirements in kg ha^{-1} (N, P); infiltration during the growing season in mm (I).

Start	Water regime	G.W.	S.W.	N	P	I
Jan. 1	rainfall 184 mm	100	2700	0	0	97
Jan. 1	irrigation 55 mm	900	4300	0	0	153
Jan. 1	irrigation 65 mm	1100	4500	0	5	163
Jan. 1	irrigation 110 mm	3100	4900	50	30	210
Dec. 20	rainfall 184 mm	300	3300	0	0	104
Dec. 20	irrigation 65 mm	2300	4600	25	20	171
Dec. 20	irrigation 110 mm	4600	4600	80	45	217

Table 5. Simulation results for barley production. Climate: Dekheila; soil type: B1, Mariut Table Land; grain and straw weight in kg dm ha^{-1} (G.W., S.W.); N and P fertilizer requirements in kg ha^{-1} (N, P); infiltration during the growing season in mm (I).

Start	Water regime	G.W.	S.W.	N	P	I
Jan. 1	rainfall 184 mm	0	2100	0	0	97
Jan. 1	irrigation 75 mm	1000	3800	0	0	190
Jan. 1	irrigation 110 mm	2000	4400	15	15	210
Dec. 20	rainfall 184 mm	100	2500	0	0	104
Dec. 20	irrigation 75 mm	1900	4300	10	15	183
Dec. 20	irrigation 110 mm	3500	4500	50	30	217

Table 7. Barley production in the region Burg El Arab-El Hammam for the different soil types. Area per soil type in ha; grain and straw weight in kg dm ha^{-1} and in 10^6 kg for the whole region (G.W., S.W.); N and P fertilizer requirements in kg ha^{-1} and in 10^3 kg for the whole region (N, P). The first part gives the maximum production without fertilizer application, the second part the production under 110 mm irrigation yr^{-1}.

no fertilizer application

Soil type	Area	G.W.		S.W.	
		kg ha^{-1}	10^6 kg	kg ha^{-1}	10^6 kg
B1, Frontal Plain	11930	900	10.7	4300	51.3
C2, Frontal Plain	1500	450	0.7	2150	3.2
B1, Mariut Table Land	23855	1000	23.9	3800	90.6
C2, Mariut Table Land	20340	500	10.2	1900	38.6
B4d, Coastal Plain	4000	700	2.8	3200	12.8
Total	61625		48.3		196.5

under irrigation with 110 mm yr^{-1}

Soil type	Area	G.W.		S.W.		N		P	
		kg ha^{-1}	10^6 kg	kg ha^{-1}	10^6 kg	kg ha^{-1}	10^6 kg	kg ha^{-1}	10^6 kg
B1, Frontal Plain	11930	3100	37.0	4900	58.5	50	600	30	360
C2, Frontal Plain	1500	1550	2.3	2450	3.7	25	40	15	20
B1, Mariut Table Land	23855	2000	47.7	4400	105.0	15	360	15	360
C2, Mariut Table Land	20340	1000	20.3	2200	44.7	7.5	150	7.5	150
B4d, Coastal Plain	4000	2400	14.8	3700	9.6	45	180	15	60
Total	61625		116.9		226.7		1330		950

Table 6. Simulation results for barley production. Climate: Dekheila; soil type: B4d; grain and straw weight in kg dm ha^{-1} (G.W., S.W.); N and P fertilizer requirements in kg ha^{-1} (N, P); infiltration during the growing season in mm (I).

Start	Water regime	G.W.	S.W.	N	P	I
Jan. 1	rainfall 184 mm	200	2700	0	0	97
Jan. 1	irrigation 55 mm	900	4300	0	0	153
Jan. 1	irrigation 110 mm	3200	4900	60	20	210
Dec. 20	rainfall 184 mm	300	3300	0	0	104
Dec. 20	irrigation 55 mm	1900	4500	35	10	162
Dec. 20	irrigation 110 mm	4800	4500	90	35	217

Table 8. Water requirements in 10^6 m^3 (W.R.) for the different rainfall zones in the Burg El Arab-El Hammam region to achieve the yields mentioned in Table 7. Between brackets the fraction of the soil type occurring in a rainfall zone is given. The upper part is for maximum production without fertilizer application, the lower part for 210 mm infiltration during the growing season; starting date Jan. 1.

Soil type	150-200 mm	125-150 mm	100-125 mm	75-100 mm	total W.R.
	no fertilizer application				
B1, Frontal Plain	2.2 (1/3)	6.4 (2/3)	-	-	8.6
C2, Frontal Plain	0.3 (1/3)	0.8 (2/3)	-	-	1.1
B1, Mariut Table Land	-	11.7 (1/2)	13.2 (1/2)	-	24.9
B1/Rd, Mariut Table Land	-	-	5.6 (1/2)	6.3 (1/2)	11.9
B4d, Coastal Plain	0.8 (1/2)	1.2 (1/2)	-	-	2.0
	under irrigation with 210 mm yr^{-1}				
B1, Frontal Plain	4.4	11.0	-	-	15.4
C2, Frontal Plain	0.6	1.4	-	-	2.0
B1, Mariut Table Land	-	16.5	18.0	-	34.5
B1/Rd, Mariut Table Land	-	-	7.7	8.3	16.0
B4d, Coastal Plain	1.7	2.0	-	-	3.7

Table 9. Simulation results for barley production. Potential and nutrient limited situation. Climate: Dabaa; grain and straw weight in kg dm ha^{-1} (G.W., S.W.); N and P fertilizer requirements in kg ha^{-1} (N, P).

Start		G.W.	S.W.	N	P
Jan. 1	potential production 32 N + 3 P	7000	6000	155	80
Jan. 1	potential production 28 N + 4 P	7000	6000	165	70
Dec. 20	potential production 32 N + 3 P	6700	5600	145	70
Dec. 20	potential production 28 N + 4 P	6700	5600	155	60
-	N-limited production 32 N	2400	2000	-	5
-	N-limited production 28 N	2100	1800	-	0
-	P-limited production 3 P	2000	1700	0	-
-	P-limited production 4 P	2600	2200	10	-

Table 10. Simulation results for barley production. Climate: Dabaa; soil type: B1, Frontal Plain; grain and straw weight in kg dm ha^{-1} (G.W., S.W.); N and P fertilizer requirements in kg ha^{-1} (N, P); infiltration during the growing season in mm (I).

Start	Water regime	G.W.	S.W.	N	P	I
Jan. 1	rainfall 140 mm	0	900	0	0	60
Jan. 1	rainfall times 1.6	100	2300	0	0	97
Jan. 1	mean 350 mm	1000	4300	0	0	164
Jan. 1	mean 450 mm	2400	5100	35	25	210
Dec. 20	rainfall 140 mm	0	1100	0	0	65
Dec. 20	rainfall times 1.6	300	1800	0	0	105
Dec. 20	mean 350 mm	1800	4400	10	10	174
Dec. 20	mean 450 mm	3900	5000	65	35	224

Table 11. Simulation results for barley production. Climate: Dabaa; soil type: B3; grain and straw weight in kg dm ha^{-1} (G.W., S.W.); N and P fertilizer requirements in kg ha^{-1} (N, P); infiltration during the growing season in mm (I); maximum rooting depth of the soil in cm (RDMso).

Start	Water regime	RDMso	G.W.	S.W.	N	P	I
Jan. 1	rainfall 140 mm	30	0	1400	0	0	60
		60	0	1300	0	0	60
		90	0	1200	0	0	60
Jan. 1	rainfall times 1.6	30	200	2900	0	0	97
		60	200	2700	0	0	97
		90	200	2600	0	0	97
Jan. 1	mean 350 mm	30	700	4600	0	0	164
		60	1000	4800	0	5	164
		90	1000	4500	0	5	164
Jan. 1	mean 450 mm	30	1200	4900	15	10	210
		60	2800	5100	45	25	210
		90	2700	5100	40	25	210
Dec. 20	rainfall 140	60	100	1600	0	0	65
Dec. 20	rainfall times 1.6	60	500	3200	0	0	105
Dec. 20	mean 350 mm	60	2200	4800	35	10	174
Dec. 20	mean 450 mm	60	4300	5000	90	25	224

Table 12. Simulation results for barley production. Climate: Dabaa; soil type: B4; grain and straw weight in kg dm ha^{-1} (G.W., S.W.); N and P fertilizer requirements in kg ha^{-1} (N, P); infiltration during the growing season in mm (I); maximum rooting depth of the soil in cm (RDMso).

start	water regime	RDMso	G.W.	S.W.	N	P	I
Jan. 1	rainfall 140 mm	30	0	1000	0	0	60
		90	0	900	0	0	60
Jan. 1	rainfall times 1.6	30	100	2300	0	0	97
		90	100	2300	0	0	97
Jan. 1	mean 350 mm	30	600	3400	0	0	164
		90	900	4500	0	0	164
Jan. 1	mean 450 mm	30	1000	3600	0	0	210
		90	2400	5000	40	10	210
Dec. 20	rainfall 140 mm	30	0	1700	0	0	65
		90	0	1200	0	0	65
Dec. 20	rainfall times 1.6	30	500	2600	0	0	105
		90	400	2800	0	0	105
Dec. 20	mean 350 mm	30	1400	3500	0	0	174
		90	1900	4500	25	5	174
Dec. 20	mean 450 mm	30	2100	4000	20	5	224
		90	4000	4800	80	30	224

Table 13. Simulation results for barley production. Climate: Dabaa; soil type: DS5; grain and straw weight in kg dm ha^{-1} (G.W., S.W.); N and P fertilizer requirements in kg ha^{-1} (N, P); infiltration during the growing season in mm (I); maximum rooting depth of the soil in cm (RDMso).

start	water regime	RDMso	G.W.	S.W.	N	P	
Jan. 1	rainfall 140 mm	30	100	1700	0	0	60
		60	100	1700	0	0	60
Jan. 1	rainfall times 1.6	30	200	2700	0	0	97
		60	200	3300	0	0	97
Jan. 1	mean 350 mm	30	800	3400	0	0	164
		60	800	4600	0	0	164
Jan. 1	mean 450 mm	30	1300	3600	5	0	210
		60	1300	4800	15	0	210
Dec. 20	rainfall 140 mm	60	200	2000	00	0	65
Dec. 20	rainfall times 1.6	60	600	3600	0	0	105
Dec. 20	mean 350 mm	60	1900	4800	25	5	174
Dec. 20	mean 450 mm	60	2600	5000	45	15	224

Table 14. Simulation results for barley production. Climate: Dabaa; soil type: F3; grain and straw weight in kg dm ha^{-1} (G.W., S.W.); N and P fertilizer requirements in kg ha^{-1} (N, P); infiltration during the growing season in mm (I).

start	water regime	G.W.	S.W.	N	P	
Jan. 1	rainfall 140 mm	0	1500	0	0	60
Jan. 1	rainfall times 1.6	200	2800	0	0	97
Jan. 1	mean 350 mm	1200	4900	0	10	164
Jan. 1	mean 450 mm	3300	5100	55	30	210
Dec. 20	rainfall 140 mm	100	1800	0	0	65
Dec. 20	rainfall times 1.6	400	3400	0	0	105
Dec. 20	mean 350 mm	2200	4900	25	20	174
Dec. 20	mean 450 mm	4500	5100	85	45	224

Table 15. Barley production in the region El Alamein-Fuka for the various soil types without fertilizer application. Total area, suitable and cultivable area (15% and 11%) in ha for the 2 rainfall zones; total cultivable area in ha in the region; grain and straw weight in dm ha^{-1} and in 10^6 kg for the whole region (G.W.; S.W.).

Soil type	125-150 mm				100-125 mm					G.W.		S.W.	
	Area												
	Total	Suitable %	Suitable ha	Cultivable	Total	Suitable %	Suitable ha	Cultivable	Total cultivable	kg ha^{-1}	10^6 kg	kg ha^{-1}	10^6 kg
B1	10300	95	9790	1470	20120	95	19110	2100	3570	900	3.2	4300	15.4
B3 (30-60)	2430	90	2190	330	1170	90	1053	120	440	800	0.4	4700	2.1
(60-90)	1220	90	1100	170	580	90	520	60	220	1000	0.2	4650	1.0
B4	1260	90	1130	170	-	-	-	-	170	750	0.1	3950	0.5
F1	-	-	-	-	1610	85	1370	190	190	800	0.2	4700	0.9
F3, WW	-	-	-	-	1180	95	1120	120	120	1200	0.2	4900	0.6
DS5	-	-	-	-	3250	90	2930	410*	410	800	0.3	4000	1.6
C1	250	90	230	30*	4100	90	3690	470**	400	400	0.3	2350	1.9
Total				2170					5520		4.6		24.0

* 14%
** 10%

Table 16. Barley production in the region El Alamein-Fuka for the various soil types under 210 mm infiltration during the growing season. Cultivable area in ha for two rainfall zones and total for the region; grain and straw weight in kg dm ha^{-1} and in 10^6 kg for the whole region (G.W., S.W.); N and P fertilizer requirements in 10^3 kg for the whole region (N, P).

soil	cultivable area (ha)			G.W.		S.W.		N	P
	125-150 mm	100-125 mm							
type	(10%)	(8%)	total	kg ha^{-1}	10^6 kg	kg ha^{-1}	10^6 kg		
B1	980	1530	2510	2400	6.0	5100	12.8	88	63
B3 (30-60)	220	80	300	2000	0.6	5000	1.5	9	6
(60-90)	110	40	150	2750	0.4	5100	0.8	6	5
B4	110	-	110	1700	0.2	4300	0.4	2	1
F1	-	140**	140	2000	0.3	5000	0.7	3	3
F3, WW	-	90	90	3300	0.3	5100	0.5	5	3
DS5	-	290**	290	1300	0.4	4200	1.2	4	0
C1	20*	280***	300	1000	0.6	2500	1.5	6	6
Total	1440	1450	3890		8.8		19.3	123	85

* 9%, ** 10%, *** 7%.

Table 17. Simulation results for barley production. Potential and nutrient limited situation. Climate: Mersa Matruh; grain and straw weight in kg dm ha^{-1} (G.W, S.W.); N and P fertilizer requirements in kg ha^{-1} (N, P).

start		G.W.	S.W.	N	P
Jan. 1	potential production 32 N + 3 P	6800	5600	145	75
Jan. 1	potential production 28 N + 4 P	6800	5600	155	65
Jan. 1	potential production 15 N + 1 P	6800	5600	190	95
Dec. 20	potential production 32 N + 3 P	6500	5300	135	65
Dec. 20	potential production 28 N + 4 P	6500	5300	145	55
Dec. 20	potential production 15 N + 1 P	6500	5300	175	85
-	N-limited production 32 N	2400	2000	-	5
-	N-limited production 28 N	2100	1700	-	0
-	N-limited production 15 N	1100	900	-	5
-	P-limited production 3 P	2000	1600	0	-
-	P-limited production 4 P	2700	2200	20	-
-	P-limited production 1 P	700	500	0	-

Table 18. Simulation results for barley production. Climate: Mersa Matruh; soil type: B1, Frontal Plain; grain and straw weight in kg dm ha^{-1} (G.W., S.W.); N and P fertilizer requirements in kg ha^{-1} (N, P); infiltration during the growing season in mm (I).

start	water regime	G.W.	S.W.	N	P	
Jan. 1	mean 180 mm	100	1600	0	0	84
Jan. 1	mean 350 mm	900	4300	0	0	164
Jan. 1	mean 450 mm	2400	5100	35	25	210
Dec. 20	mean 180 mm	100	1900	0	0	90
Dec. 20	mean 350 mm	1800	4400	10	10	174
Dec. 20	mean 450 mm	3900	4900	65	35	224

Table 19. Simulation results for barley production. Climate: Mersa Matruh; soil type: B2; grain and straw weight in kg dm ha^{-1} (G.W., S.W.); N and P fertilizer requirements in kg ha^{-1} (N, P); infiltration during the growing season in mm (I).

start	water regime	G.W.	S.W.	N	P	
Jan. 1	rainfall (137 mm)	100	1400	0	0	63
Jan. 1	mean 300 mm	800	4500	0	0	140
Jan. 1	mean 450 mm	2600	5100	45	25	210
Dec. 20	rainfall (137 mm)	200	1600	0	0	67
Dec. 20	mean 300 mm	1600	4600	15	10	149
Dec. 20	mean 450 mm	4200	5100	85	40	224

Table 20. Simulation results for barley production. Climate: Mersa Matruh; soil type F1, F2; grain and straw weight in kg dm ha^{-1} (G.W., S.W.); N and P fertilizer requirements in kg ha^{-1} (N, P); infiltration during the growing season in mm (I); maximum rooting depth of the soil in cm (RDMso).

Start	water regime	RDMso	G.W.	S.W.	N	P	I
Jan. 1	rainfall (137 mm)	30	100	1200	0	0	63
		60	100	1100	0	0	63
		90	0	1100	0	0	63
Jan. 1	mean 150 mm	30	100	1600	0	0	70
		60	100	1500	0	0	70
Jan. 1	mean 250 mm	30	400	2300	0	0	117
		60	300	3000	0	0	117
Jan. 1	mean 350 mm	30	700	4600	0	0	164
		60	1000	4800	0	5	164
		90	1000	4500	0	5	164
Jan. 1	mean 450 mm	30	1200	4900	0	10	210
		60	2800	5100	45	25	210
		90	2700	5100	40	25	210
Dec. 20	rainfall (137 mm)	60	100	1400	0	0	67
		90	100	1200	0	0	67
Dec. 20	mean 150 mm	30	200	1800	0	0	75
		60	200	1800	0	0	75
Dec. 20	mean 250 mm	30	700	3700	0	0	125
		60	600	3500	0	0	125
Dec. 20	mean 350 mm	30	1800	4600	10	10	174
		60	2200	4800	20	15	174
		90	2000	4600	15	15	174
Dec. 20	mean 450 mm	30	2700	4900	35	25	224
		60	4300	5000	75	40	224
		90	4100	5000	70	40	224

Table 21. Simulation results for barley production. Climate: Mersa Matruh; soil type F3; grain and straw weight in kg dm ha^{-1} (G.W., S.W.); N and P fertilizer requirements in kg ha^{-1} (N, P); infiltration during the growing season in mm (I).

Start	Water regime	G.W.	S.W.	N	P	I
Jan. 1	mean 180 mm	200	2100	0	0	84
Jan. 1	mean 350 mm	1200	4900	0	10	164
Jan. 1	mean 450 mm	3300	5100	55	30	210
Dec. 20	mean 180 mm	300	2600	0	0	90
Dec. 20	mean 350 mm	2200	4900	25	20	174
Dec. 20	mean 450 mm	4500	5100	85	45	224

Table 22. Simulation results for barley production. Climate: Mersa Matruh; soil type: P1; grain and straw weight in kg dm ha^{-1} (G.W., S.W.); N and P fertilizer requirements in kg ha^{-1} (N, P); infiltration during the growing season in mm (I).

Start	Water regime	G.W.	S.W.	N	P	I
Jan. 1	mean 130 mm	0	1000	0	0	60
Jan. 1	mean 200 mm	200	2100	0	0	93
Jan. 1	mean 450 mm	2400	5100	75	40	210
Dec. 20	mean 150 mm	100	1500	0	0	75
Dec. 20	mean 200 mm	300	2500	0	5	100
Dec. 20	mean 450 mm	3800	5000	105	55	224

Table 23. Total area, suitable area and cultivable area in ha per soil type for both rainfall zones without fertilizer application; total cultivable area in ha for the region Fuka-El Negeila without fertilizer application; natural water regime in mm (N.W.R.).

soil type	100 - 125 mm zone						125 - 150 mm zone						
	Area				cultivable area		Area				cultivable area		Total cult. area (ha)
	total (ha)	suitable %	suitable ha	N.W.R.	%	ha	total (ha)	suitable %	suitable ha	N.W.R.	%	ha	
B1	2280	95	2170	120	12	260	1460	95	1390	180	21	290	550
B2	-	-	-	-	-	-	270	95	260	300	100	260	260
F1	22920	85	19480	130	12	2340	9310	85	7910	150	16	1270	3610
F2	920	90	830	130	12	100	-	-	-	-	-	-	100
F3	4540	95	4310	120	12	520	2920	95	2770	180	21	580	1100
Wb	270	95	260	120	12	30	130	95	120	180	21	30	60
P1	130	95	120	130	75	50	-	-	-	-	-	-	50
C1	-	-	-	-	-	-	3880	85	3300	240	38	630	630
C2	7240	95	6880	180	21	720	-	-	-	-	-	-	720
Total	38300					4020	17970					3060	7080

Table 24. Suitable area and cultivable area in ha per soil type for both rainfall zones under a water regime with 210 mm infiltration during the growing season; total cultivable area in ha for the region Fuka-El Negeila under a water regime with 210 mm infiltration during the growing season; the natural water regime in mm (N.W.R.).

soil type	100 - 125 mm zone				125 - 150 mm zone				total cult. area (ha)
	Area		cultivable		Area		cultivable		
	suitable	N.W.R.	%	ha	suitable	N.W.R.	%	ha	
B1	2170	120	8	170	1390	180	14	190	360
B2	-	-	-	-	260	450	100	260	260
F1	19480	130	8	1560	7910	150	11	870	2430
F2	830	130	8	70	-	-	-	-	70
F3	4310	120	8	340	2770	180	14	390	730
Wb	260	120	8	20	120	180	14	20	40
P1	120	130	8	10	-	-	-	-	10
C1	-	-	-	-	3300	250	24	400	400
C2	6880	180	14	480	-	-	-	-	480
Total	34050			2650	15750			2130	4780

Table 25. Barley production in the region Fuka Negeila for the various soil types without fertilizer application; grain and straw weight in kg dm ha^{-1} and 10^6 kg for the whole region (G.W.; S.W.).

soil type	cultivable area (ha)	G.W.		S.W.	
		kg ha^{-1}	10^6 kg	kg ha^{-1}	10^6 kg
B1	550	900	0.5	4300	2.4
B2	260	800	0.2	4500	1.2
F1	3640	800	2.9	4700	17.0
F2	100	1000	0.1	4700	0.5
F3	1100	1200	1.3	4900	5.4
Wb	60	1200	0.1	4900	0.3
P1	50	200	0.0	2100	0.1
C1	630	400	0.3	2350	1.5
C2	720	450	0.3	2150	1.6
Total	7080		5.7		29.8

Table 26. Barley production in the region Fuka-Negeila for the various soil types with 210 mm infiltration during the growing season. Grain and straw weight in kg dm ha^{-1} and 10^6 kg for the whole region (G.W., S.W.); N and P fertilizer requirements in kg ha^{-1} and in 10^3 kg for the whole region (N, P).

soil type	cultivable area (ha)	G.W.		S.W.		N		P	
		kg ha^{-1}	10^6 kg	kg ha^{-1}	10^6 kg	kg ha^{-1}	10^3 kg	kg ha^{-1}	10^3 kg
B1	360	2400	0.9	5100	1.8	35	13	25	9
B2	260	2600	0.7	5100	1.3	45	11	25	7
F1	2430	2000	5.9	5000	12.2	20	49	20	49
F2	70	2800	0.2	5100	0.4	45	3	25	2
F3	730	3300	2.4	5100	3.7	55	40	30	22
Wb	40	3300	0.1	5100	0.2	55	2	30	1
P1	10	2400	0.0	5100	0.0	75	1	40	0
C1	400	1000	0.4	2500	1.0	10	4	10	4
C2	480	1200	0.6	2550	1.2	15	7	10	5
Total	4780		11.2		21.8		127		99

Table 27. Simulation results for barley production. Potential and nutrient limited situation. Climate: Sidi Barrani; grain and straw weight in kg dm ha^{-1} (G.W.; S.W.); N and P fertilizer requirements in kg ha^{-1} (N, P).

Start		G.W.	S.W.	N	P
Jan. 1	potential production 32 N + 3 P	6900	5700	150	75
Jan. 1	potential production 28 N + 4 P	6900	5700	160	65
Dec. 20	potential production 32 N + 3 P	6600	5300	135	70
Dec. 20	potential production 28 N + 4 P	6600	5300	145	60
-	N-limited production 32 N	2400	2000	-	5
-	N-limited production 28 N	2100	1700	-	0
-	P-limited production 3 P	2000	1600	0	-
-	P-limited production 4 P	2700	2200	20	-

Table 28. Simulation results for barley production. Climate: Sidi Barrani; soil type: B1, Frontal Plain; grain and straw weight in kg dm ha^{-1} (G.W.; S.W.); N and P fertilizer requirements in kg ha^{-1} (N, P); infiltration during the growing season in mm (I).

Start	Water regime	G.W.	S.W.	N	P	I
Jan. 1	rainfall (171 mm)	0	1300	0	0	83
Jan. 1	mean 180 mm	100	1600	0	0	84
Jan. 1	mean 350 mm	1000	4300	0	0	164
Jan. 1	mean 450 mm	2400	5100	35	25	210
Dec. 20	rainfall (171 mm)	100	1700	0	0	90
Dec. 20	mean 180 mm	100	1900	0	0	91
Dec. 20	mean 350 mm	1800	4400	10	10	174
Dec. 20	mean 450 mm	3900	5000	65	35	224

Table 29. Simulation results for barley production. Climate: Sidi Barrani; soil type: Fl, B3; grain and straw weight in kg dm ha^{-1} (G.W., S.W.); N and P fertilizer requirements in kg ha^{-1} (N, P); infiltration during the growing season in mm (I); maximum rooting depth of the soil in cm (RDMso).

Start	water regime	RDMso	G.W.	S.W.	N	P	I
Jan. 1	rainfall (171 mm)	30	200	1900	0	0	83
		60	200	1700	0	0	83
		90	100	1600	0	0	83
Jan. 1	mean 140 mm	30	100	1400	0	0	65
		60	100	1100	0	0	65
Jan. 1	mean 180 mm	30	200	2100	0	0	84
		60	200	2000	0	0	84
		90	200	2200	0	0	84
Jan. 1	mean 350 mm	30	700	4600	0	0	164
		60	1000	4800	0	5	164
		90	1000	4500	0	5	164
Jan. 1	mean 450	30	1200	4900	15	10	210
		60	2800	5100	45	25	210
		90	2700	5100	40	25	210
Dec. 20	rainfall (171 mm)	30	500	2300	0	0	90
		60	400	2100	0	0	90
		90	300	2000	0	0	90
Dec. 20	mean 140 mm	30	100	1400	0	0	69
		60	100	1400	0	0	69
Dec. 20	mean 180 mm	30	500	2400	0	0	91
		60	400	2400	0	0	91
		90	300	2100	0	0	91
Dec. 20	mean 350 mm	30	1800	4600	10	10	174
		60	2200	4800	20	15	174
		90	2000	4600	15	15	174
Dec. 20	mean 450 mm	30	2700	4900	35	25	224
		60	4300	5000	75	40	224
		90	4100	5000	70	40	224

Table 30. Barley production in the region Negeila-Sidi Barrani without fertilizer application for the various soil types. Total, suitable and cultivable area in ha; grain and straw weight in kg ha^{-1} and in 10^6 kg for the whole region (G.W.; S.W.).

	Area	Suitable		cultivable		G.W.		S.W.	
soil type	total	%	ha	%	ha	kg ha^{-1}	10^6 kg	kg ha^{-1}	10^6 kg
B1	2110	95	2000	21	420	900	0.4	4300	1.8
B2	160	95	150	100	150	800	0.1	4500	0.7
B3 30 - 60 cm	4630	90	4170	21	880	800	0.7	4700	4.1
60 - 90 cm	2320	90	2090	21	440	1000	0.4	4650	2.0
F1 100 - 125 mm	10600	85	9010	14	1260	800	1.0	4700	5.9
125 - 150 mm	10600	85	9010	19	1710	800	1.4	4700	8.1
C1	6200	85	5270	19	1000	400	0.8	2350	4.7
Total	36610				5860		4.8		27.3

Table 31. Barley production in the region Negeila-Sidi Barrani with 210 mm infiltration for the various soil types. Cultivable area in ha; grain and straw weight in kg dm ha^{-1} and in 10^6 kg for the whole region (G.W.; S.W.); N and P fertilizer requirements in kg ha^{-1} and 10^3 kg (N, P).

Soil type	cultivable area		G.W.		S.W.		N		P	
	%	ha	kg ha^{-1}	10^6 kg	kg ha^{-1}	10^6 kg	kg ha^{-1}	10^3 kg	kg ha^{-1}	10^3 kg
B1	14	280	2400	0.7	5100	1.4	35	10	25	7
B2	100	150	2600	0.4	5100	0.8	45	7	25	4
B3 30 - 60 cm	14	580	2000	1.2	5000	2.9	20	12	20	12
60 - 90 cm	14	290	2750	0.8	5100	1.5	45	13	25	7
F1 100 - 125 mm	10	900	2000	1.8	5000	4.5	20	18	20	18
125 - 150 mm	13	1170	2000	2.3	5000	5.9	20	23	20	23
C1	12	630	1000	1.3	2500	3.2	10	6	10	6
Total		4010		8.4		20.1		89		78

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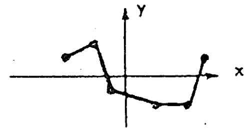
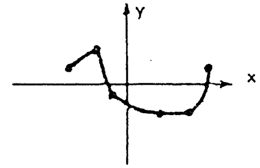
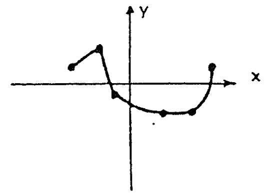
CSMP III Statement	Equivalent Mathematical Expression
INTEGRATOR Y = INTGRL (IC, X) where: $IC = y \mid_{t=t_s}$ Alternative 'Specification' Form: Y = INTGRL (IC, X, N) where: Y = output array IC = initial condition array X = integrand array N = number of elements in the integrator array (N must be coded as a literal integer constant)	$y(t) = \int_{t_s}^{t} x\,dt + y(t_s)$ where: t_s = start time t = time $\dot{y} = \int_{t_s}^{t} \dot{x}\,dt + \dot{y}(t_s)$ Equivalent Laplace Transfer Function: $\frac{Y(s)}{X(s)} = \frac{1}{s}$
DERIVATIVE Y = DERIV (IC, X) where: $IC = \frac{dx}{dt} \Big\vert_{t=t_s}$	$y = \frac{dx}{dt}$ Equivalent Laplace Transfer Function: $\frac{Y(s)}{X(s)} = s$
IMPLICIT FUNCTION Y = IMPL (IC, P, FOFY) where: IC = first guess P = error bound FOFY = output name from final statement in algebraic loop definition	$y = f(y)$ $\lvert y - f(y) \rvert < p \lvert y \rvert$
DEAD TIME (DELAY) Y = DELAY (N, P, X) where: P = delay time N = number of points sampled in interval p (integer constant) and must be > 3, and < 16,378	$y = x(t-p)\ ;\ t > p$ $y = 0\ ;\ t < p$ Equivalent Laplace Transfer Function: $\frac{Y(s)}{X(s)} = e^{-Ps}$
ZERO–ORDER HOLD Y = ZHOLD (X1, X2)	$y = x_2\ ;\quad x_1 > 0$ y = last output ; $x_1 < 0$ $y\vert_{t=t_s} = 0$ Equivalent Laplace Transfer Function $\frac{Y(s)}{X(s)} = \frac{1}{s}(1 - e^{st})$
DOUBLE PRECISION FLOATING-POINT TO SINGLE PRECISION Y = ZZRND (DNUMBR) where: DNUMBR is a double precision floating-point number. Y = rounded single precision value of DNUMBR	To convert the double precision floating-point number, DNUMBR, to single precision, rounding to hexadecimal digit.

CSMP III Statement	Equivalent Mathematical Expression
ARBITRARY FUNCTION GENERATOR (LINEAR INTERPOLATION) Y = AFGEN (FUNCT, X)	 $y = f(x)$
ARBITRARY FUNCTION GENERATOR (QUADRATIC INTERPOLATION) Y = NLFGEN (FUNCT, X)	 $y = f(x)$
FUNCTION GENERATOR WITH DEGREE OF INTERPOLATION CHOSEN BY USER Y = FUNGEN (FUNCT, N, X) where: FUNCT = function name N = degree of interpolation to be used. May be 1, 2, 3, 4, or 5 X = value of abscissa	 $y = f(x)$
ARBITRARY FUNCTION OF 2 VARIABLES Y = TWOVAR (FUNCT, X, Z)	$y = f(x, z)$
SLOPE OF A CURVE Y = SLOPE (FUNCT, N, X) where: FUNCT = name of curve N = degree of interpolation to be used X = value of abscissa	$y = \frac{df}{dx}$ at x
SAMPLING INTERVAL SWITCH Y = SAMPLE (P1, P2, {P3 / N}) where: P_1 = start time for sampling to occur P_2 = last time for sampling to occur P_3 = time interval between samples if entered as a floating-point number N = number of sampling intervals if entered as a fixed-point number	$y = 1.0\ ;\ TIME = p_1 + k\,p_3 < p_2$ $k = 0, 1, 2, \ldots$ or $y = 1.0\ ;\ TIME = p_1 + k(p_2 - p_1)\,/\,n \leq p_2$ $k = 0, 1, 2, \ldots$ $y = 0.0$ otherwise

CSMP III Statement	Equivalent Mathematical Expression	
NOT Y = NOT (X)	$y = 1;$ $y = 0;$	$x < 0$ $x > 0$
AND Y = AND (X1, X2)	$y = 1;$ $y = 0;$	$x_1 > 0, x_2 > 0$ otherwise
NOT AND Y = NAND (X1, X2)	$y = 0;$ $y = 1;$	$x_1 > 0, x_2 > 0$ otherwise
INCLUSIVE OR Y = IOR (X1, X2)	$y = 0;$ $y = 1;$	$x_1 < 0, x_2 < 0$ otherwise
EXCLUSIVE OR Y = EOR (X1, X2)	$y = 1;$ $y = 1;$ $y = 0;$	$x_1 < 0, x_2 > 0$ $x_1 > 0, x_2 < 0$ otherwise
NOT OR Y = NOR (X1, X2)	$y = 1;$ $y = 0;$	$x_1 < 0, x_2 < 0$ otherwise
EQUIVALENT Y = EQUIV (X1, X2)	$y = 1;$ $y = 1;$ $y = 0;$	$x_1 < 0, x_2 < 0$ $x_1 > 0, x_2 > 0$ otherwise
COMPARATOR Y = COMPAR (X1, X2)	$y = 0;$ $y = 1;$	$x_1 < x_2$ $x_1 > x_2$
OUTPUT SWITCH Y1, Y2 = OUTSW (X1, X2)	$y_1 = x_2, y_2 = 0;$ $y_1 = 0, y_2 = x_2;$	$x_1 < 0$ $x_1 > 0$
INPUT SWITCH RELAY Y = INSW (X1, X2, X3)	$y = x_2;$ $y = x_3;$	$x_1 < 0$ $x_1 > 0$
RESETTABLE FLIP-FLOP Y = RST (X1, X2, X3)	$y = 0;$ $y = 1;$ $y = 0;$ $y = 1;$ $y = 0;$ $y = 1;$	$x_1 > 0$ $x_2 > 0, x_1 < 0$ $x_1 < 0, x_2 < 0,$ { $x_3 > 0, y(t - \Delta t) = 1$ $x_3 > 0, y(t - \Delta t) = 0$ $x_3 < 0, y(t - \Delta t) = 0$ $x_3 < 0, y(t - \Delta t) = 1$ }
FUNCTION SWITCH Y = FCNSW (X1, X2, X3, X4)	$y = x_2;$ $y = x_3;$ $y = x_4;$	$x_1 < 0$ $x_1 = 0$ $x_1 > 0$