ATLANTIC ZONE PROGRAMME

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ESTIMATION OF THE POTENTIAL AND ACTUAL YIELD OF BANANA IN THE ATLANTIC ZONE OF COSTA RICA

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The Atlantic Zone Programme (CATIE-AUW-MAG) is the result of an agreement for technical cooperation between the Centro Agronómico Tropical de Investigación y Enseñanza (CATIE), the Agricultural University Wageningen (AUW). The Netherlands and the Ministerio de Agricultura y Ganadería (MAG) of Costa Rica. The Programme, that was started in April 1986, has a long-term objective multidisciplinary research aimed at rational use of the natural resources in the Atlantic Zone of Costa Rica with emphasis on the small landowner.

PREFACE

General description of the research programme on sustainable Landuse.

The research programme is based on the document "elaboration of the VF research programme in Costa Rica" prepared by the Working Group Costa Rica (WCR) in 1990. The document can be summarized as follows:
To develop a methodology to analyze ecologicaly sustainable and economically feasible land use, three hierarchical levels of analysis can be distinguished.
1. The Land Use System (LUS) analyses the relations between soil type and crops as well as technology and yield.
2. The Farm System (FS) analyses the decisions made at the farm household regarding the generation of income and on farm activities.
3. The Regional System (RS) analyses the agroecological and socio-economic boundary conditions and the incentives presented by development oriented activities.

Ecological aspects of the analysis comprise comparison of the effects of different crops and production techniques on the soil as ecological resource. For this comparision the chemical and physical qualities of the soil are examined as well as the polution by agrochemicals. Evaluation of the groundwater condition is included in the ecological approach. Criterions for sustainability have a relative character. The question of what is in time a more sustainable land use will be answered on the three different levels for three major soil groups and nine important land use types.

Combinations of crops and soils

	Maiz	Yuca	Platano	Piña	Palmito	Pasto	Forestal I II III
Soil I	x	x	x		x	x	x
Soil II						x	x
Soil III	x			x	x	x	x

As landuse is realized in the socio-economic context of the farm or region, feasibility criterions at corresponding levels are to be taken in consideration. MGP models on farm scale and regional scale are developed to evaluate the different ecological criterions in economical terms or visa-versa.

Different scenarios will be tested in close cooperation with the counter parts.

SUMMARY

In the Atlantic zone, a case study is carried out to develop a methodology for sustainable land use planning. As part of this research the different potentials of the different kinds of land use have to be quantified. In this report the quantification of the land use for banana production is described. This is done by a simulation program based on WOFOST 4.1. and by a multiple regression estimation.

Banana is a perennial crop. When the mother plant is harvested one of the young suckers will take its place immediately. To describe the growth of banana the crop growth simulation model for annual crops, WOFOST 4.1. had to be changed. The biomass is distributed over the mother plant and the suckers. The root system is assumed to be used by the mother plant and the suckers together. When the mother plant is harvested, the new mother plant already has a certain age and development stage. The young plants are surrounded by older plants because the plants in one field have different development stages and thus less radiation can be intercepted by the young plants.

Next to these changes many parameters in the model had to be estimated. Often, information was lacking to estimate these parameters. Results of this model can not be discussed because the weather data were not available yet. To simulate the growth of banana by the modified WOFOST 4.1. model complete or almost complete weather data for a period of at least two hundred days have to be available in combinations with yield figures for the same location in the same period. These data are not available yet.

The multiple regression analysis has been based on the export figures of plantations surrounding some weather stations. The best model was achieved when the yield is related to the year of harvesting, the average daily hours of sunshine and the interaction between minimum and maximum temperature. In that case the adjusted R^2 was 47.8 percent.

It is clear that the describtion of the actual production in the Atlantic Zone by the model derived by the multiple regression analysis is more secure than the potential yield derived by the simulation model.

This multiple regression model can be used to get a better impression of the interaction of the production and the enviroment. In that way this information can be useful to define the parameters of the simulation model.

The use of the description of the banana production in the Atlantic Zone for a period of approximately ten years seems not enough to base an estimation of the potential production on.

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1 INTRODUCTION

The Agricultural University Wageningen (AUW), in cooperation with the Ministerio de Agricultura y Ganaderia (MAG) and the Centro Agronomico Tropical de Investigation y Enseñanza (CATIE) has carried out research in the Atlantic Zone since 1986. In the first years the research was mainly focused on describing the region, its climate, soil and farming systems.

The Atlantic Zone is an interesting area for agricultural research. At the moment, rapid deforestation and intensification of land use are creating a need for reconnaissance of sustainable land use. Therefore in 1991 the VF-program 'A methodology for planning of sustainable land use: a case study in Costa Rica' started. The research aims are: a) to develop ecologically and economically sustainable land use scenarios for (sub)regions of the Atlantic Zone in Costa Rica and b) to develop a methodology to analyze these scenarios. Land use planning aims at using land in such a way that several goals are satisfied in optimal combination and optimal degrees, within the technical limitations of crops and environmental conditions. Ir J. Bessembinder is working on a PhD-project 'Regional analysis of land use scenarios'. This project focuses on the agro-ecological aspects of land use, such as suitability of crops for climate and soil, production potential and use of fertilizers and chemicals.

In this study it was tried to quantify the potential production of one of the most important crops of the Atlantic Zone: banana. A crop growth simulation model was made to quantify the <u>potential</u> production of banana. This model was based on WOFOST 4.1 (van Diepen <u>et al.</u>, 1988). With WOFOST 4.1 it is possible to simulate the potential production (defined by crop characteristics, temperature and radiation), the water-limited production (limited by water availability or excess) and the nutrient-limited production (limited by nutrient availability or excess). The available weather data of the Atlantic Zone were used to estimate the potential production in the Atlantic Zone.

Accurate simulation of the potential production proved to be very hard. However, it was possible to analyze the <u>actual</u> production in the Atlantic Zone. The actual production was analyzed by multiple regression. This multiple regression analysis relates the actual production to the meteorological data and the year in which the production occurred.

After a general introduction about the Atlantic Zone and the banana production in Chapters 2 and 3, the crop growth simulation model is described and discussed in Chapter 4. Subsequently the multiple regression analysis is described and discussed in Chapter 5. Finally the different approximations are compared in Chapter 6 and conclusions are drawn.

The Atlantic Zone (Zona Atlantica) is the name of the research area of the Atlantic Zone Program. This area is arbitrarily defined as the entire province of Limón, the canton Sarapíqui of the province of Heredia and the canton Turrialba of the province of Cartago. It is situated on the east side of Costa Rica, bordered on one side by the Caribbean coast and on the other side by the Central and Talamancan mountains. Afterwards the research area was restricted to the northern part of this zone (figure 2.1).

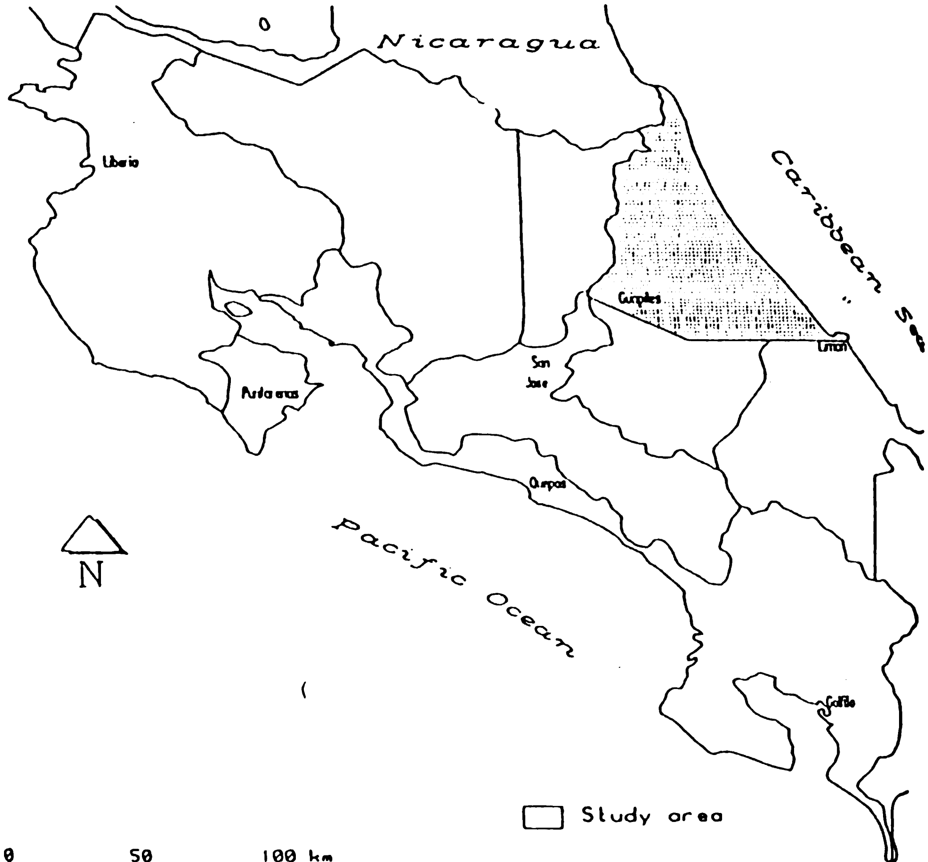

Figure 2.1. The research area, defined as the northern part of the Atlantic Zone.

In several reports, published by the Atlantic Zone Program, extensive information can be found on subjects like climate, soils, vegetation and land use (Oostrom, 1993). Here they are briefly presented.

2.1 Climate

The climate of the northern part of the Atlantic Zone can be characterized as tropical humid. Small temperature changes occur throughout the year. Annual variation of temperature is dominated by the monsoon with the highest temperature before the onset of the summer rains (Portig, 1976). The amount of rainfall varies from 3500 mm per year in the south to 7000 mm per year in the north. The rainfall is well distributed over the year. Mean annual temperature is 25-26 °C and a few degrees lower in the mountains in the south. The most common winds, the northern, northwestern and southwestern winds are not strong, in contrast to the less frequent eastern and southeastern winds. This climate enables crop growth throughout the year. This goes also for weeds, pests and diseases, especially fungi. Table 2.1 shows the average weather data of the weather station Carmen to give an impression of the weather in the Atlantic Zone.

month	precipitation (mm)	minimum temperature (°C)	maximum temperature (°C)	number of dry days	potential ET (mm)
January	281	19.8	29.6	11.4	101
February	188	20.0	29.5	10.0	99
March	170	20.6	30.3	12.7	119
April	217	21.1	30.7	12.9	117
May	275	22.1	31.5	11.2	121
June	327	22.1	31.1	8.3	106
July	457	21.8	30.4	5.6	106
August	417	21.9	31.0	7.2	112
September	224	22.0	31.5	10.6	113
October	283	21.7	31.2	10.1	109
November	414	21.3	30.3	8.3	95
December	377	21.3	29.8	8.8	103
annual	3630	-	-	117.1	1301

Table 2.1. Historical monthly averages of weather station Carmen. (Kruseman et. al., 1994).

2.2 Soil and landscape

The Atlantic Caribbean lowland has been a sedimentation area since early Tertiary. This sedimentation has a volcanic origin. The coast line is made up by a narrow strip of succeeding beach ridges with parallel canals. Behind the ridges and canals, coastal swamps occur, gradually passing into alluvial plain. This flat landscape is at a few locations interrupted by remnants of basaltic volcanoes.

The soil in the Northern part of the Atlantic Zone is in general very fertile but the drainage is bad, especially near the coastline.

2.3 Vegetation and land use

Till recently, most of the area was covered by tropical moist, wet forest and pre-montane wet forest. At the present most of the forest has been destroyed as a result of wood extraction and conversion into pasture and crop land (Veldkamp et al, 1992). At the moment only 25 % of the land is still natural vegetation like forest. The national government is trying to conserve these parts by creating national parks, like Parc National Tortuguero.

The land use in the Atlantic Zone is very variable with regard to crops, management and field size. In the plain lowlands banana plantations are found, as well as small size farms which produce beans, chili peppers, maize or cassava. Also large areas are used for pasture. These areas are used extensively. The production area of palmito is increasing and wood extraction is still important in this region.

3 BANANA

Banana is one of the most important export products of Costa Rica. Costa Rica exported 1,487,714 10^3 kg of bananas in 1991, which makes Costa Rica one of the biggest banana exporting countries of the world. Over ninety percent of the bananas was produced in the Atlantic Zone. Bananas are usually produced in semi-industrialized plantations of 100-300 ha. In 1992 about 40.000 ha was used for banana production in the Atlantic Zone. These plantations are often owned by international fruit companies and sometimes by local people who sell their bananas to the fruit companies.

During the Spanish colonization Banana was already one of the export products. In the 1920's the banana plantations were struck by the Panama disease, Fusarium oxysporum, followed by labor unrest in the 1930's. The plantations were moved to the Pacific side of the country. In the 1960's cultivars which were tolerant to the Panama disease became available, so the banana plantations were re-established in the Atlantic Zone (Van Sluys, 1987).

The Atlantic Zone is very suitable for producing bananas because of the constant high rainfall in this zone. Therefore banana lacks need for irrigation. Much money is spend on land preparation and many fertilizers and biocides are used, but still Black Sigatoka and nematodes affect the banana production. The areas which have the best combination of climate and soil are occupied by the banana plantations. Everywhere drainage systems are used. Drainage conditions are very important in determining the aptitude of the soil.

3.1 Family

Banana belongs to the family of Musaceae. It is a triploid (AAA) and has three genomes of the wild banana Musa acuminata. Till 1955 the most important cultivar was 'Gros Michel'. After 1955 it was gradually replaced by cultivars of the Cavendish group which are tolerant to the Panama disease. The most common cultivars today are 'Poyo', 'Robusta', 'Giant Cavendish', 'Valery' and 'Grand Nain' (Stover and Simmonds, 1987). The differences between these cultivars are very small (Sanchez and S-+c, 1985).

3.2 Ecology

All the large banana production areas are situated in the tropics between 20° latitude north and south of the equator (Simmonds, 1966). The optimum temperature for foliage growth is 26-28°C (Ganry, 1980) and for fruit growth 29-30°C. The temperature should always be higher than 10 °C otherwise chilling will occur (Aubert, 1971). Besides temperature, rainfall also determines the production areas of banana. The banana demands very much water. Clavo (1969) mentioned a total of 1326 mm of evapotranspiration per year for Guapiles, Costa Rica. Banana is very sensitive for water shortage because of the weak root system. On the other hand banana can not stand poor drainage conditions. In that case shortage of oxygen will occur. Drainage is a very important factor determining the aptitude of soil for the growth of banana.

3.3 Physiology

The banana is a monocotyl plant (figure 3.1), the pseudostem is made of sheaths of the leaves. All leaves are formed in a central meristem on top of the rhizome.

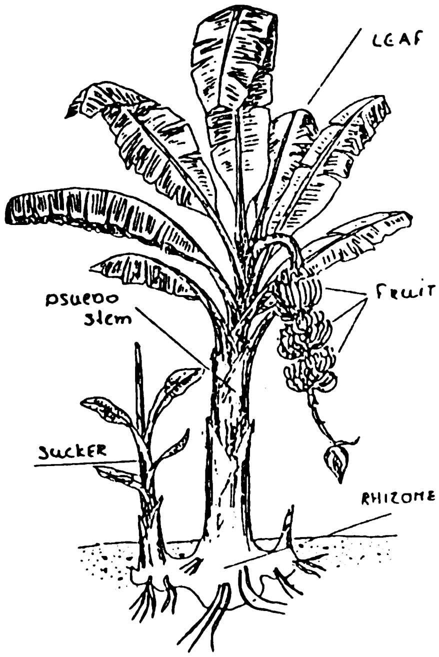

Figure 3.1. The banana plant (Lassoudière, 1978).

Leave formation continues till the initiation of the flower. Under favorable conditions a new leaf is formed each seven to ten days. The banana leaf is known as one of the biggest leaves on earth. The leaves can become over 3 m^2 and the total leaf area of one plant can become over 45 m^2. The average photosynthetically active leaf area of the cultivar Valery is 26 m^2 at florescence (Soto, 1985). That means that in case of a plant density of 1800 plants per hectare a leaf area index of 4.68 ha ha^{-1} can be obtained (excluding the leaf area of the suckers).

Bananas do not produce seeds, because they are triploid. They are reproduced by suckers. Suckers are formed by the rhizome. Almost directly after harvesting, the selected sucker (the new mother plant) starts to initialize its own suckers (figure 3.2). The mother plant produces a few suckers of which one takes her place after harvesting (see also paragraph 4.3). The first sword sucker (sucker with strong pseudostem and small leaves) which has a good position towards the mother plant is selected to become the new mother plant. The other suckers are removed, normally in an early stage.

The moment of selection of the sucker varies within time.

This variation, together with micro-environmental differences, causes the moment of harvesting will vary between plants within one field. This variation leads to a desynchronisation of the development stages of the banana in one field. Figure 3.3 shows the development of the distribution of the development stages of the plants in the field. The distribution becomes more and more uniform. So after a few year all development stages are found and each week bananas can be harvested.

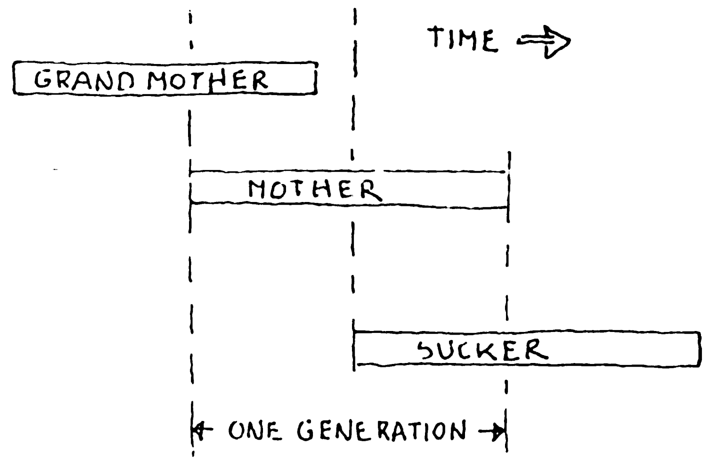

Figure 3.2. A diagram of the overlapping generations of the banana plant. The sucker starts to grow before the mother is harvested.

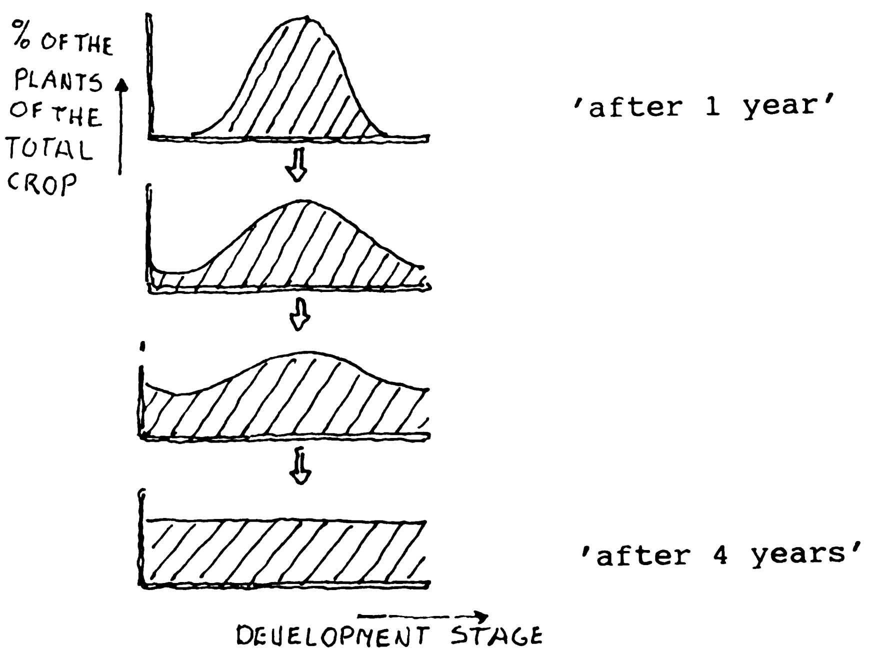

Figure 3.3. The distribution of development stages in time.

The roots of the banana are situated in the upper layer of the soil. Soto (1985) found that 85 to 90 percent of the roots are situated in the first 65 centimeters of the soil. The length and weight of roots are correlated with leaf area, which may indicate some kind of functional balance (Waaijenberg, 1991).

4 SIMULATION MODEL

The simulation of the potential production of banana is based on WOFOST 4.1 (van Diepen et al., 1988). WOFOST 4.1 has been developed to simulate the growth of an annual crop. In order to simulate the growth of banana, which is a perennial crop, adjustments had to be made. The crop is divided in classes characterized by the date of initiation (paragraph 4.2). The cultivars of the Cavendish group, used in the Atlantic Zone are so much alike that the differences were neglected. The influences of fungi, herbs, viruses, nematodes and insects were not taken into account. In addition, limitations of water and nutrients on the potential production were not considered. The management on which the simulation has been based was assumed to be similar to the management in the Atlantic Zone. For instance a plant density of 1800 plants per hectare was assumed.

First a general introduction about WOFOST 4.1. is given in paragraph 4.1, followed by a description of the specific changes which had to be made in order to simulate the growth of banana.

4.1 WOFOST 4.1.

WOFOST is the acronym for WOrld FOod STudies. The model describes the growth and production of annual crops in physical terms determined by crop species, soil type, hydrologic conditions and weather during the growing season. In principle, the model is applicable anywhere where the crops are produced although the model has been developed primarily for agriculture in the tropics. The calculated theoretical productions allow evaluation of the relative importance of principal constraints to crop production, such as light, temperature, water and macro-nutrients. The modeling can be seen as a point analysis. It does not take the geographical scale into account, although the model is mainly intended for national and regional planning.

Crop growth and soil water balance are described with a time resolution of one day. Nutrient uptake is calculated for the whole growing season at once.

WOFOST 4.1 is divided into modular sections and subsections. Each section corresponds to a FORTRAN subroutine. The main program WMAIN41 takes care of correspondence with the user and calls the subroutines APPLE and NUTRIE. In the subroutine APPLE the daily crop growth is simulated. APPLE uses many other subroutines which calculate specific parts of the simulation. The subroutine NUTRIE calculates the nutrient balance at the end of the simulation. The climate, soil and crop data are written down in -.DAT files. The outcome of the crop growth simulation and the nutrient balance is stored in the file WOFOST.OUT.

In this study the main program WMAIN41 is adjusted to perform more than one simulation necessary to describe the growth of a perennial crop.
Most of the adjustments are made in subroutine APPLE. The subroutine CLIMRD had to be adjusted to be able to read the daily weather data instead of the normal procedure of interpolating the monthly averages. Other adjusted subroutines are mentioned when the adjustments are described.

4.2 At class level

As described in paragraph 3.3, all the development stages are eventually present in one field. The simulation is based on this situation. Therefore, the crop has to be divided in classes. A class is defined as the part of the crop which started a new generation on a certain day. Classes are created on a daily basis according to the time resolution of WOFOST 4.1.

In paragraph 4.2.1 the relation diagram of the growth of a certain class is described. This relation diagram shows the assumed relations between different physiological processes of the banana. The simulation of the growth of a class starts after the transition of sucker into mother plant. The initial situation of a class is described in paragraph 4.2.2. The determination of the class-sizes is described in paragraph 4.3.

4.2.1 Relation diagram

Figure 4.1 shows the relation diagram of the potential growth of banana.

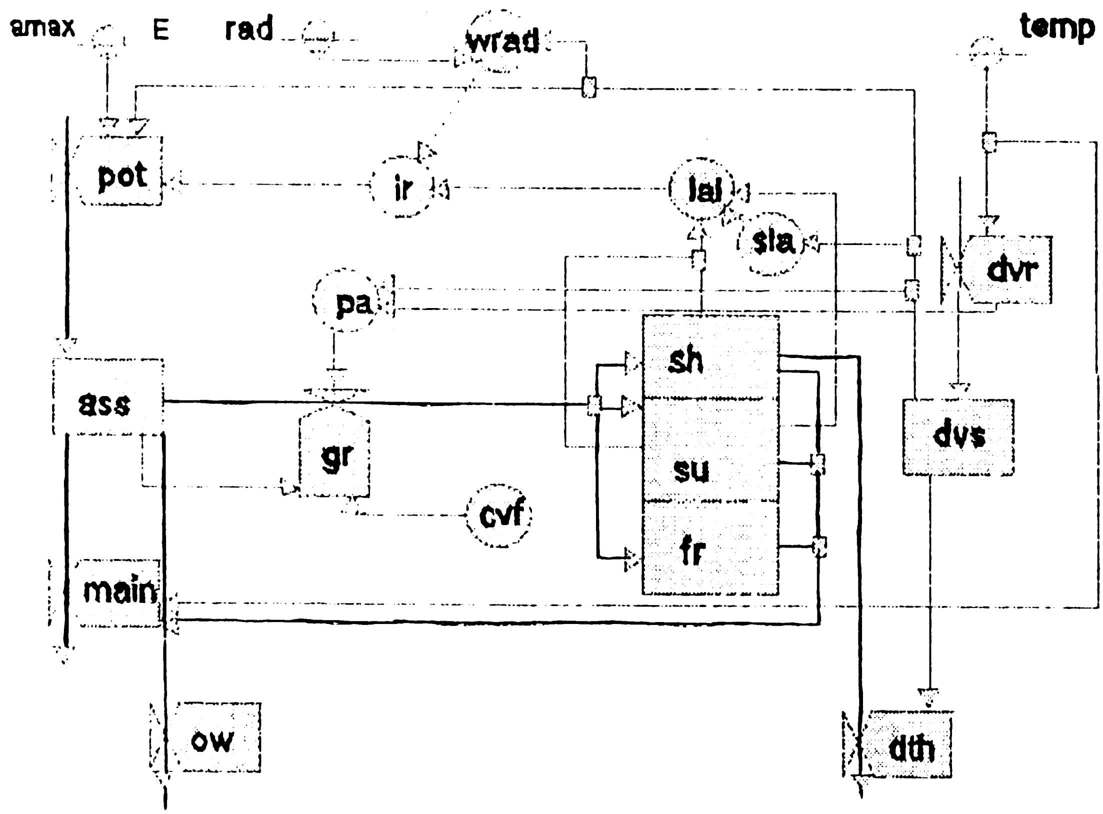

Figure 4.1. Relation diagram of the individual banana plant. Amax = maximum assimilation determined by the crop, ass = assimilation, cvf = conversion factors, dth = death rate, dvr = development rate, dvs = development stage, E = initiel light use efficiency, fr = biomass of fruit, gr = growth, ir = intercepted radiation, lai = leaf area index, main = maintenance respiration, ow = maintenance of the root system, pa = partitioning of assimilates, pot = potential photosyntheses, rad = radiation over the crop, sh = biomass of rhizome, pseudostem and leaves, sla = specific leaf area, su = biomass of suckers, temp = temperature, wrad = interceptable radiation (which can be used by the plant).

The interceptable radiation, which can potentially be used by a class, is different for each class. The interceptable radiation for classes which are just initialized will be smaller than for classes which are initialized earlier, due to differences in height. Schut (1992) described the influences of plant height on interceptable radiation for barley. Assumptions for bananas are based on these principles. The fraction of the radiation over the crop available for a class is strongly related to the height of its plants. The height is strongly related to the development stage. So the interceptable radiation for a class can be described as a product of the radiation over the crop and a function of its development stage. The height of the surrounding plants is assumed to be constant. The available interceptable radiation decreases exponentially when a plant is shorter than its surrounding plants. The height of the plant in relation to its age is described by Stover and Simmonds (1987) and can be translated into a relation between height and development stage. The relation between the fraction of the radiation that is interceptable for a class and the development stage of that class is described in subroutine RADIAJ (called by subroutine TOTASJ) and obtained by linear interpolation (figure 4.2).

The amount of interceptable radiation which is actually intercepted by the plant, depends on the leaf area and is described as in the standard WOFOST 4.1 subroutine TOTASS, in which the leaf area of the mother plant and the suckers are taken together. This intercepted radiation will determine the amount of formed assimilates.

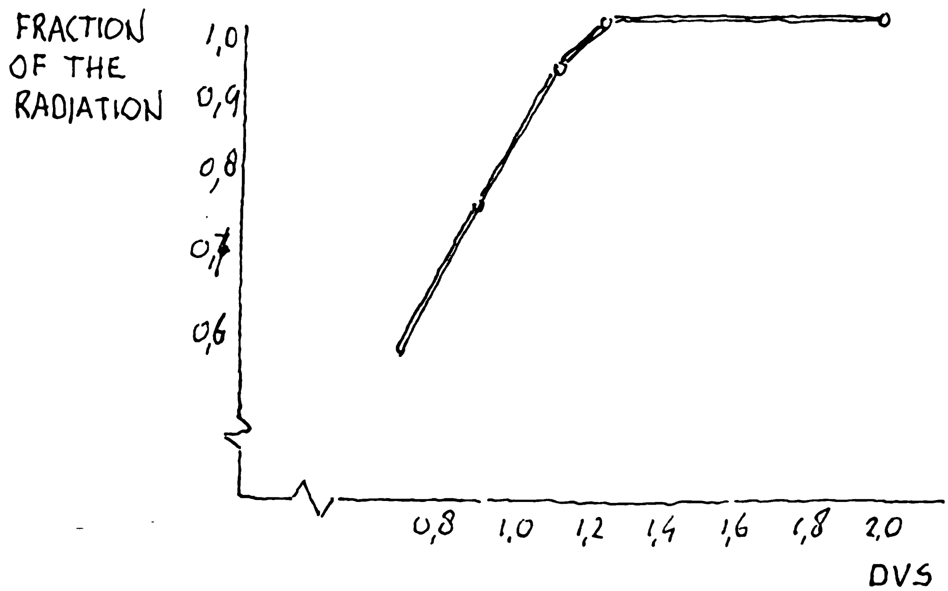

Figure 4.2. Fraction of the radiation available for a class, depending on its development stage (DVS).

These assimilates will used for maintenance respiration and growth. The assimilates will be distributed over different parts of the crop. In this study the crop is divided in the following parts: root system, shoot, storage organs and suckers. It is assumed that the root system has a constant biomass, similar to pasture (Lantinga, personal communication). In that case growth rate is equal to death rate. Growth and maintenance respiration of the roots are described together as 'maintenance of the root system' and this is assumed to be a constant part of the produced assimilates. It is assumed that the root system is used by both mother plant and suckers. The biomass of the shoot (sh) consists of the biomass of rhizome, pseudostem and leaves of the mother plant. The biomass of storage organs (fruit and rachis) is described as 'so'. The biomass of the suckers (su) consists of the biomass of leaves, pseudostem and the rhizome of the suckers. Partitioning of assimilates over different parts of the plant depends on the development stage but also on the development rate (Jansen, personal communication). When the development rate is low, less leaves are initialized, thus a smaller part of the available assimilates will be used by the leaves. In paragraph 4.3 the relation between development rate, development stage and biomass partitioning is further quantified.

The leaf area of the mother plant and the suckers are combined to calculate assimilation. In this study a constant specific leave area of the mother plant is assumed. The specific leaf area of the leaves of the suckers is assumed ~~to~~ be 40 % of the specific leaf area of the mother plant. A reason for this low percentage is the fact that the first leaves formed by a sucker are sword leaves which are thicker and subsequently have a lower specific leave area than normal leaves (Waaijenberg, 1991). Another reason for this low percentage is to compensate for the over-estimation of the biomass of the suckers. During the growth of the mother plant, the suckers which will not become the next generation are removed in an early stage. However, the biomass of these suckers is included until the end of the simulation.

Over-estimation of the biomass of the suckers and their relative low amount of leaves lead also to an over-estimation of the respiration of the suckers. To correct for this over-estimation the relative respiration rate of rhizome, pseudostem and leaves of the suckers is assumed to be 50 % of the relative respiration rate of the shoot.

4.2.2 Transition of sucker into mother plant

The initial biomass of the mother plant is a combination of biomass stored in the selected sucker and a part of the biomass that is re-distributed from the just harvested mother plant. It is not known which parts of the just harvested (old) mother plant are used by the new generation, but it is assumed that only the root system of the old mother plant is used. The biomass of the rhizome, the pseudostem and the leaves of the old mother plant is assumed not to be used by the sucker. The biomass of the suckers is divided over a few different suckers. Only one sucker is used for the next generation. Which part of the biomass is in the selected sucker, is not known. This amount depends on the frequency of removal of the other suckers. Removal of suckers can be described as death or as a loss of biomass at the moment of changing of sucker into mother plant. In this model the last option is chosen. It is assumed that 50 % of the biomass of the suckers is in the sucker which becomes the new mother plant.

For a proper simulation, more information is needed on the initialization of the new mother plant; a) which part of the biomass of the mother plant can be used by the next generation and with which efficiency, b) which part of the total biomass of the suckers is in the sucker which becomes mother plant.

When the sucker becomes mother plant, its leaves have a certain age. The distribution of the age of the green leaves at the initiation of the mother plant is described in figure 4.3 (Bessembinder, personal communication). The actual distribution is not known. The first leaves formed by a sucker are sword leaves. These leaves have a lower specific leaf area. When a sucker becomes mother plant all these sword leaves are assumed to be already dead.

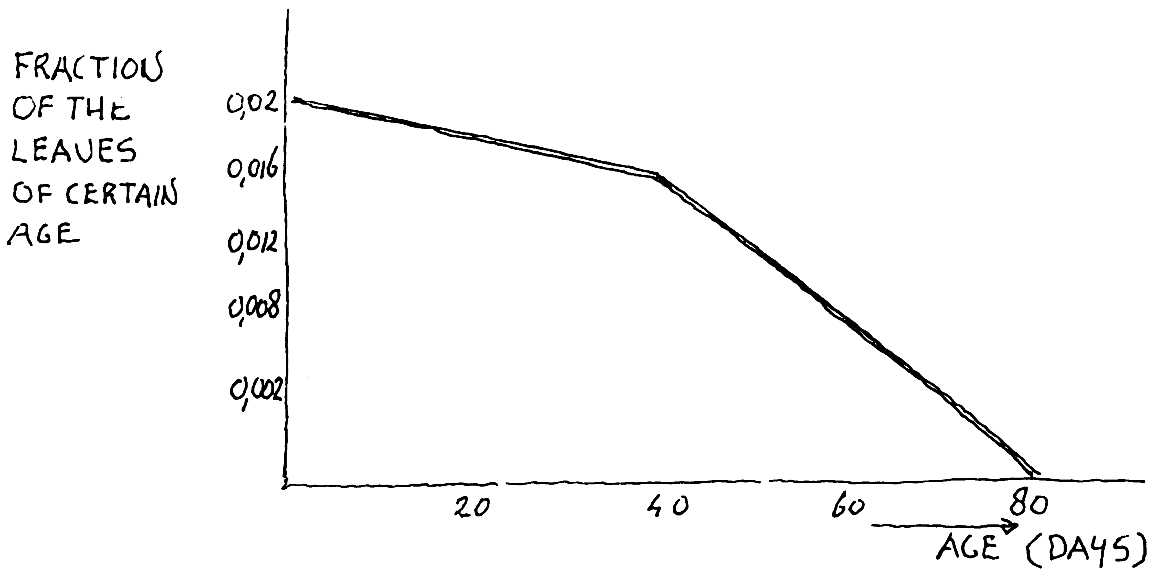

Figure 4.3. Distribution of the age of the leaves of the sucker at the moment the mother plant is harvested.

The initial development stage of the new mother plant is assumed to be constant and is set at such a value that the development rate before and after the anthesis is the same. The initial value is assumed to be 0.8. An explanation for this value is given in paragraph 4.3.

4.3 At crop level

The simulation at crop level is based on the situation that the field exists for at least a few years so a total desynchronisation of development stages within the field can be assumed. The simulation at crop level can be seen as a combination of simulations of the classes. The only interaction between classes is the interception of light by the surrounding plants. These influences have been described at class level (see paragraph 4.2.1).

The first years after planting of the plantation, the differences in development stage between plants are small. These differences will become larger because; a) variation of the moment of initialization of the sucker which becomes the next mother plant, b) micro-environmental differences within the field.

Each day the development rate is assumed equal for all classes (independent of their development stage). However, there might be differences between days due to the influences of temperature.

The initial development stage of the new mother plant is set in such a way that the maximum development rate before and after anthesis (development stage 1.0) is the same. The minimum number of days from anthesis to harvest is 120. There are at least 24 days between the moment of harvest of the old mother plant and the anthesis of the next mother plant. In case of an initial development stage of 0.8 and the same development rates before and after anthesis, the time needed to reach development stage 1.0 (anthesis) will be one fifth of the time from anthesis to harvest. The distribution of the development stages of the plants will finally become uniform and all development stages will be represented by, approximately, the same number of plants.

Plants which have a development stage over 2.0, are harvested. When the distribution of the development stages is uniform, the fraction of the crop, which enters the development stage over 2.0 in a certain period, is related to the development rate. When, for instance, on a certain day a development rate of 0.005 d^{-1} occurs all development stages will increase with 0.005. All plants which had a development stage over 1.995 will enter the harvestable stage over 2.0. The development rate at this day is 0.005/1.2 of the total cycle so a fraction of 0.005/1.2 can be harvested. In banana plantations plants are harvested once a week, but in this model it is assumed that plants are harvested daily. Thus the time resolution of harvesting corresponds with the time resolution of growth simulation. When the development rate in a period is known, distribution of the harvestable plants per day and consequently the distribution of initiation of the next generation (classes) is known and the simulation can start. So each day a new class is defined.

The initial biomass of the first generation to be simulated had to be estimated and is set at 1800 kg ha^{-1}. In case of a plant density of 1800 plants per hectare, a just initialized mother plant has a biomass of 1.0 kg (excluding its root system). This value was confirmed by own observations. The initial biomass of the following generations depends on previous generations. The initial biomass of a new generation can be determined by simulating the growth of the previous generation. This was not carried out, because it would take too much time. The initial biomass of the new mother plant is assumed to be constant.

In addition the class-sizes have to be determined. The class-sizes are determined by the development rate of all days of the period over which the simulation is carried out.

Each day a simulation can be carried out. The classes which are initialized before the first simulation day can not be taken into account. Therefore the production can not be estimated before the plants initialized on the first day are harvestable.

4.4 Assumptions of the simulation

To make a simulation model as described in this chapter a lot of physiological and environmental information is needed. This information was not always available. In this paragraph, the estimation of physiological parameters and interpretation of environmental data are discussed.

4.4.1 Environmental assumptions

Meteorological data are available for ten stations in the Atlantic Zone. Interpolation of the data of the different weather stations provide a good indication of the weather at each location within the Atlantic Zone. Jansen is making this interpolation and would finish it in 1993. Until this interpolation is available, meteorological data from the station Cobal, recorded in 1976 are used in the simulation model. The weather station Cobal is situated on a representative location in the Atlantic Zone in which banana is grown. The data 1976 was the most complete set. The weather conditions are about the same as the weather conditions of the weather station Carmen (see paragraph 2.1). The missing values are estimated in an easy way by taking the average of the value of the day before and after. Nonhebel (1993) concluded that the best way to estimate missing values is to use weather data from nearby stations, when available. Since these data will only be used for testing purposes, I did not follow this time consuming procedure.

The available meteorological data have been transformed in a way that the data could be used in WOFOST 4.1. In WOFOST 4.1 monthly weather data are used which are transformed into daily data by using linear interpolation between monthly averages. Of the weather stations in the zone, daily values are available and have been used in WOFOST 4.1. This gives more accurate results than use of interpolated weather data.

4.4.2 Physiological assumptions

Not all physiological parameters are known of banana and many of them were very hard to estimate. In this paragraph my assumptions are discussed. The parameters are described in the same order as in the CROP.DAT file (excluding the parameters to simulated the nutrient balance). The acronyms used in WOFOST 4.1 are also mentioned.

The life span of leaves growing at an average temperature of 35 °C (SPAN) is set at 125 days (Stover and Simmonds, 1987).

The lower threshold temperature for physiological ageing of leaves (TBASE) is set at 10 °C (Aubert, 1971).

The initial light-use efficiency of CO_2 assimilation of single leaves (EFF) is set at 0.33 which is a standard value (Lövenstein et al, 1992).

The crop group number to describe the drought sensitivity (DEPNR) is set at 1 (on the scale 1, drought sensitive, to 5, drought tolerant), because the banana plant is known to be very drought sensitive (Stover and Simmonds, 1987).

The maximum post-anthesis development rate of the crop (DVRC2) is set at 0.0083 d^{-1}, because the minimum time needed from anthesis to harvest is 120 days (Stover and Simmonds, 1987).

The maximum pre-anthesis development rate (DVRC1) is also set at 0.0083 d^{-1} in order to have a uniform distribution of development stages of the plants within one field, as discussed in paragraph 4.2.2.

The minimum time needed from harvest of the old mother plant to anthesis of the new mother plant is 24 days (Simmonds, 1966) and depends on the initial development stage. The initial development stage is set at 0.8 in order to reach anthesis (development stage 1.0) in 24 days under favorable conditions. This value is discussed in paragraph 4.3.

The extinction coefficient for diffuse visible light (KDIF) is set at 0.7, which is a standard value (Lövenstein et al, 1992).

The efficiency of conversion of assimilates into shoot, storage organs and suckers (CVL, CVO and CVS) is set at the standard value for non-legumes, which is 0.68 Kg Kg^{-1} (Lövenstein et al, 1992).

The specific pod area (SPA), which can be regarded as the specific fruit area is not taken into account and set at 0.0 ha Kg^{-1}.

The relative increase in maintenance respiration rate per 10 °C increase in temperature (Q10) is set at the standard value of 2.0 (Lövenstein et al, 1992).

The relative maintenance respiration rate of the mother plant, the storage organs and the suckers is set at respectively 0.025, 0.01 and 0.012 kg CH_2O kg^{-1} d^{-1}. The values of mother plant and suckers are a combination of the standard values of leaves and stem (Lövenstein et al, 1992) because both mother plant and suckers can be seen as a functional combination of these two. The biomass of the mother plant is assumed to be partitioned into 67 % leaves and 33 % 'stem'. The biomass of the suckers is assumed to be partitioned into 33 % leaves and 67 % 'stem'. Next to that the relative maintenance respiration of the suckers has to be corrected.The biomass of the suckers is over-estimated because the removal of the sucker which are not used as next generation is described at the end of the simulation. In reality this happens during the cycle. The maintenance respiration of the storage organs is set at a standard value of 0.01 (Lövenstein et al, 1992).

The maximum relative death rate of leaves due to water stress (PERDL) is set at the standard value of 0.03 d^{-1} (van Diepen et.al., 1988).

The relative death rate of the suckers is set at 0.0. Suckers do not exceed development stage 0.8. In this range of development stages no natural death occurs. The removal of the suckers is not described as death (see paragraph 4.2.1).

Assimilates used by the root system are described as a constant part of the produced assimilates. This part is set at 0.1 (Lantinga, personal communication). The remaining part of the assimilates are distributed over the leaves and pseudostem (sh), the storage organs (so) and the suckers (su). Both development stage and development rate determine distribution of the remaining assimilates. The only available information was obtained from own observations in the field and the basic principles described by Jansen (personal communication) and Lövenstein et al (1992). The following assumptions could be made; a) suckers are formed approximately directly after initiation of its mother, b) all leaves are formed before development stage 1.0, c) storage organs are initiated at development stage 1.0 and

d) leaves will not grow in the last stages before harvesting. Figure 4.4 shows the partitioning of assimilates in relation to the development stage (in cast of a maximal development rate).

Partitioning of the assimilates is not only determined by the development stage but also by the development rate. The amount of assimilates used by the leaves depends on initialization of new leaves. The initialization of new leaves depends on the development rate (Jansen, personal communication). Quantification of the influence of the development rate was not possible. Thus, the relation between partitioning of assimilates and development rate could only be estimated roughly.

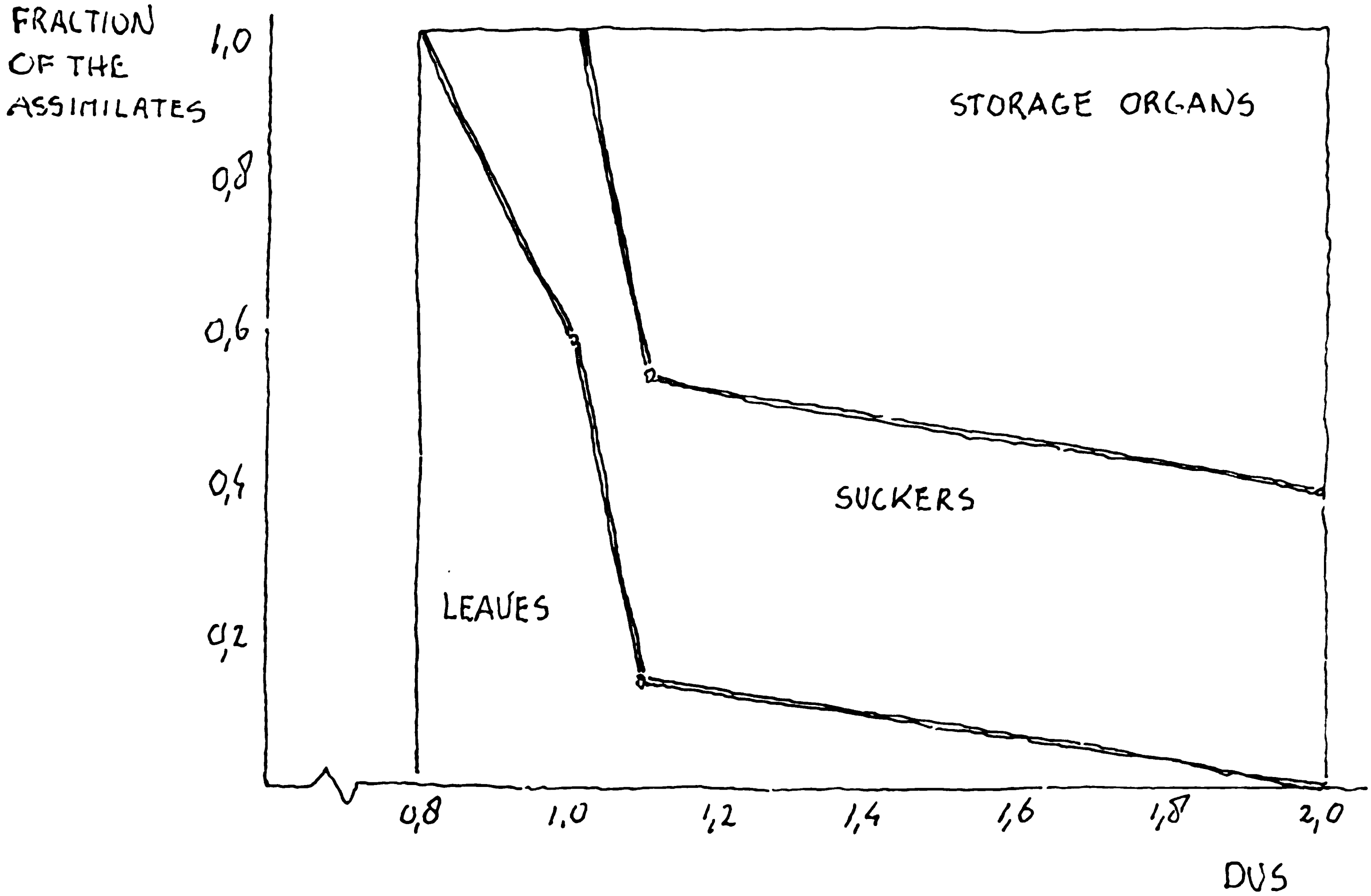

Figure 4.4. Relation between partitioning of assimilates and development stage, based on the situation of maximal development rate.

The fraction of the assimilates used for the storage organs (FSO) is assumed to be independent of the development rate, since the storage organs are formed after initialization of the last leaf. The fraction of the assimilates used by the leaves (FLV) can be described as:

$$FLV=(0.5+0.5*\frac{development\ rate}{maximum\ development\ rate})*maximum\ FLV$$

in which 'the maximum FLV' will occur when the development rate is maximum. The fraction of assimilates used by the sucker can be described by the part which is not used by roots, storage organs and leaves.

Not much is known about the specific leaf area as a function of development stage of the crop (SLATB). A constant specific leaf area of 0.0025 ha kg^{-1} is assumed. The specific leaf area is defined as leaf area per kg biomass of leaves, pseudostem and rhizome. Normally, the specific leaf area is only based on the biomass of the leaves. Therefore, the value of the specific leaf area has to be lower than normal (Lövenstein <u>et al</u>, 1992). The specific leaf area of the sucker is assumed to be 0.001 ha kg^{-1}, because of reasons described in paragraph 4.2.2).

The reduction factor for development rate as a function of temperature (DVRETB) is obtained by linear interpolation (figure 4.5). Interpolation is based on the description of Samson (1986).

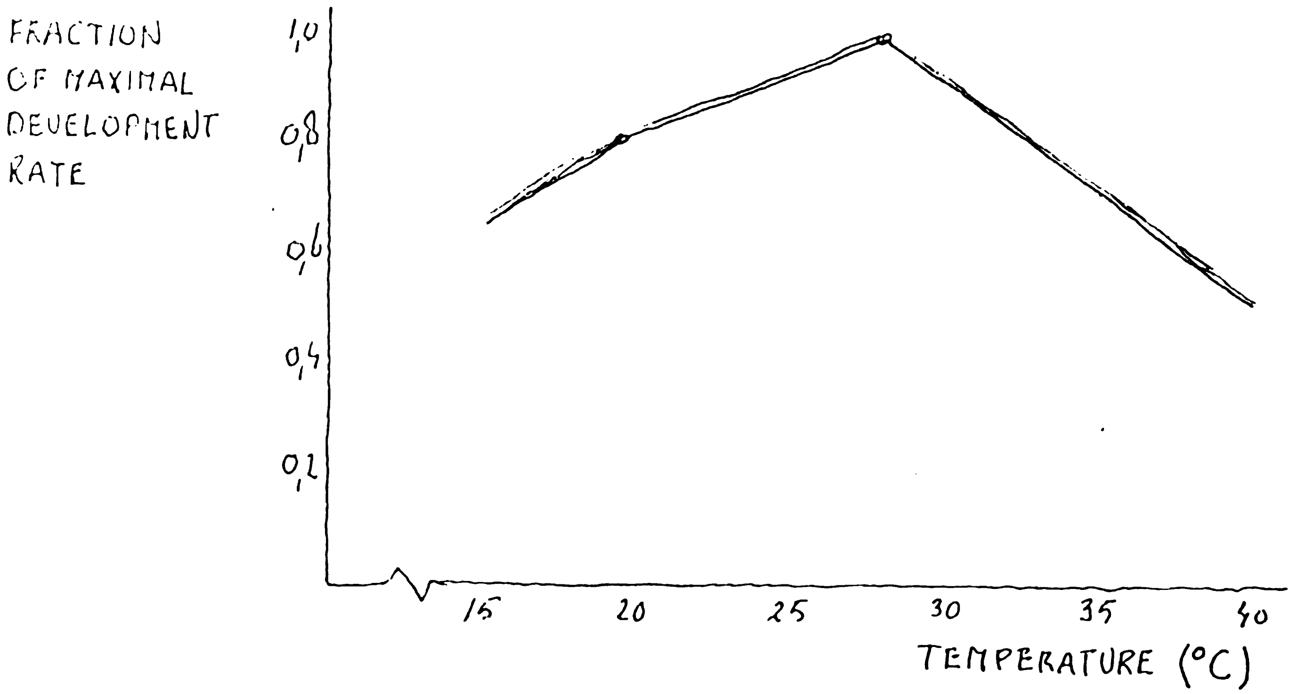

Figure 4.5. The development rate as function of temperature.

The maximum leaf CO_2 assimilation rate as function of development stage of the crop (AMAXTB) is not known. Here it is assumed to have a constant standard value of 40.0 Kg ha^{-1} h^{-1} (Lövenstein <u>et al</u>, 1992).

The correction factor of maximum leaf CO_2 assimilation rate for sub-optimum average day temperatures (TMPFTB) as described in figure 4.6 is obtained by linear interpolation (Lövenstein <u>et al</u>, 1992). In literature a precise optimal value is described of leaf growth (Simmonds, 1966). Therefore, an optimum value instead of an optimal range of maximal CO_2 assimilation is assumed.

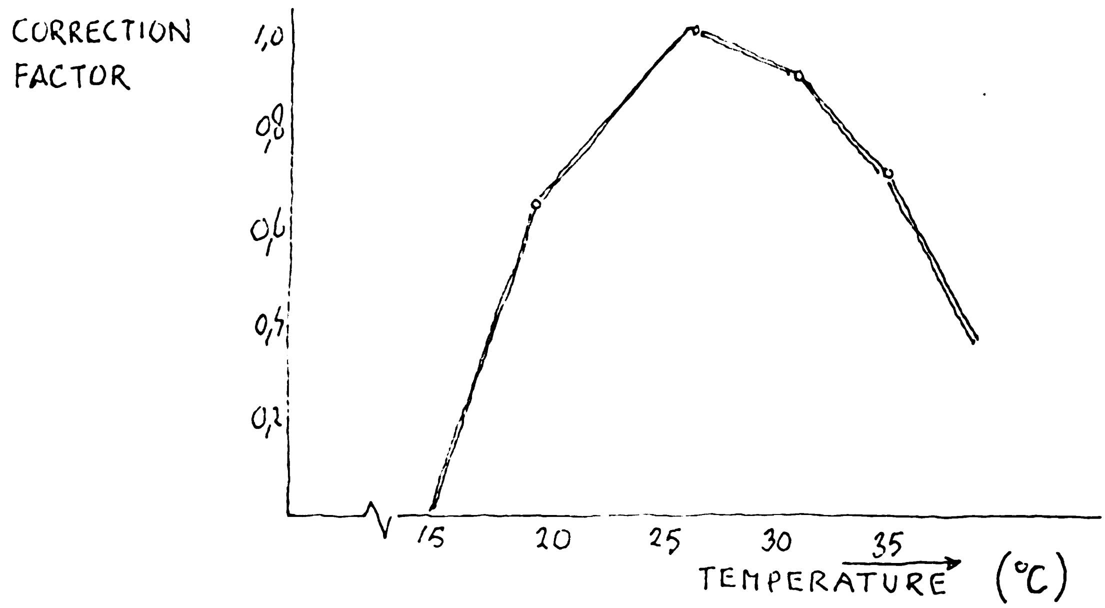

Figure 4.6. Correction factor of maximum leaf assimilation rate as function of average day temperature.

The reduction of daily gross CO_2 assimilation rate only occurs below approximately 3 °C (van Diepen et al., 1998) and is not relevant in the Atlantic Zone.

4.5 Results

The weather in the Atlantic zone has to be defined to estimate the potential productions of banana. The data of the weather stations in the Atlantic Zone have to be interpolated. This interpolation is not yet available. The model was tested by using the weather data of the weather station Cobal in 1976. The weather data of 1977 are assumed to be similar to the weather data of 1976. To get an impression of the behavior of the model, the results of simulations of three classes are described in Appendix 2. The simulations of these classes started respectively on the first of January, the first of May and the first of September. Next to that the production of the whole year is estimated by combining the simulations of all classes.

When the simulation was started at the first of January, the initial biomass of the shoot was assumed to be 1800 kg ha^{-1}. The simulation cycle was completed after 191 days. This period is to be too short to complete a generation. The average time to complete one generation is approximately 300 days (Bessembinder, personal communication).

At the moment of harvest, the biomass of storage organs was 6140 kg ha^{-1} (harvest index of 45 %) and the biomass of suckers was 7052 kg ha^{-1}. Firstly, the harvest index is very high. Secondly, the biomass of the suckers was far more than the biomass of the leaves, pseudostem and rhizome of the mother plant. This is due to a too fast decrease of biomass of the mother plant and an over-estimation of the biomass of the suckers. The latter can be caused by a wrong partition of the assimilates and/or by a under-estimation of the respiration of the sucker.

During this simulation a maximum leaf area index of 8.02 occurred, which was based on the leaves of both mother plant and suckers. The leaf area index was too high. The maintenance respiration of the extra leaves will exceed the benefit of extra light interception. Soto (1985) described an optimal leaf area index of the mother plants of 4.68. The leaf area index of the suckers is at most 50 % of the leafs of the mother plant (Bessembinder, personal communication). Combining those two leaf area indexes will be less than 8.02.

The results of the simulations of the other two classes were similar. When the simulation was started at the first of May, assuming an initial biomass of 1800 kg ha^{-1}, the simulation cycle was completed after 172 days. At the moment of harvest the biomass of storage organs was 5881 kg ha^{-1} (harvest index of 49 %) and the biomass of suckers was 5485 kg ha^{-1}. The maximum leaf area index during this simulation was 7.63 ha ha^{-1}. When the simulation was started at the first of September, assuming an initial biomass of 1800 kg ha^{-1}, the simulation was completed after 190 days. At the moment of harvest the biomass of storage organs was 6786 kg ha^{-1} (harvest index of 50 %) and the biomass of suckers was 6287 kg ha^{-1}. The maximum leaf area index during this simulation was 7.64 ha ha^{-1}.

The yearly storage organ production was estimated by combining simulations of all classes, as described in paragraph 4.3. When the initial biomass was assumed to be constant (1800 kg ha^{-1}), the yearly storage organ production was 12652 kg ha^{-1}. The yearly banana production was calculated under the assumptions that the dry matter content was 30 % and 50 % of the biomass of the storage organs was stored in banana fruits. Under these assumptions, the yearly banana production was 21087 kg ha^{-1}, approximately 1162 boxes of 18.14 kg per ha per year. Often, the actual production is more than 1162 boxes per ha per year (Appendix IV).

4.6 Conclusions

The model does not give a good approximation of the potential production of banana in the Atlantic Zone. The potential production is even less than the actual production.

Quantifation of the physiological parameters, necessary to simulate the growth of banana, proved to be hard. Not enough information was available. For instance, no information was available about the partition of the assimilates and about the transition of sucker into mother plant. Further research is necessary to define the parameters more precisely, but this will cost a lot of time. An other option is to use a simpler simulation model (P.C. LINTUL). The question is whether such a simple model is accurate enough to describe the production differences within the Atlantic Zone.

5 THE RELATION BETWEEN CLIMATE AND PRODUCTION

The production of banana per ha depends mainly on soil, management and climate. In this chapter is tried to describe the relation between production and climate by using multiple regression analysis.

In the first paragraph the situation in the Atlantic Zone is described, followed by a description of the method and results in respectively paragraph 5.2 and 5.3. The conclusions are drawn in paragraph 5.4.

5.1 Description of the situation in the Atlantic Zone

The only production figures available are the export figures of the national research institute of Costa Rica 'Corbana'. The figures are expressed in 1000 boxes of 18.14 Kg. A major disadvantage is that the bananas sold at the local and the black market are not included.

The influences of the soil are not taken into account because; a) only the total production of plantations is available and a plantation normally has different soil types and b) only the best, well prepared soils are used to produce bananas, which reduces the influences of the soil.

The influences of management are hard to estimate. The year in which the production occurs, the size and the age of the plantation and whether the plantation is owned by an international cooperation or by a local owner are interrelated with the management of the plantation. Therefore, only the production year is taken into account.

The weather stations in the Atlantic Zone provide daily data of radiation, minimum temperature, maximum temperature, vapor pressure (three times a day), wind velocity, rainfall and hours of sunshine. The production is described per year so the weather data have to be summarized over a year. The climate parameters are not independent. For instance when it rains, less hours of sunshine will occur or when the minimum temperature is high, the maximum temperature can be expected to be high also. The effect of the interactions between climate parameters is also taken into account.

5.2 Methods

As described in paragraph 3.3, development stages of the banana plants will become uniformly distributed. It is assumed that the distribution of the development stages within one field needs about three years to become uniform. So only plantations older than three years are included in the analysis.

The plantations surrounding the weather stations in the Atlantic Zone, are assumed to have the same weather conditions as the weather stations.

The production at the beginning of a year depends on the weather of the year before. This is not taken into account in the analysis.

Radiation and wind velocity are not taken into account in the analysis because too much data are missing. Vapor pressure is also not used because a not explainable increase of vapor pressure occurred at most of the weather stations (figure 5.1). This increase is probably due to changes in the equipment to measure the vapor pressure. Kamstra and Jansen are investigating the data of the different weather stations on this kind of disruptions. The results of their research will become available in 1994 (Bessembinder, personal communication).

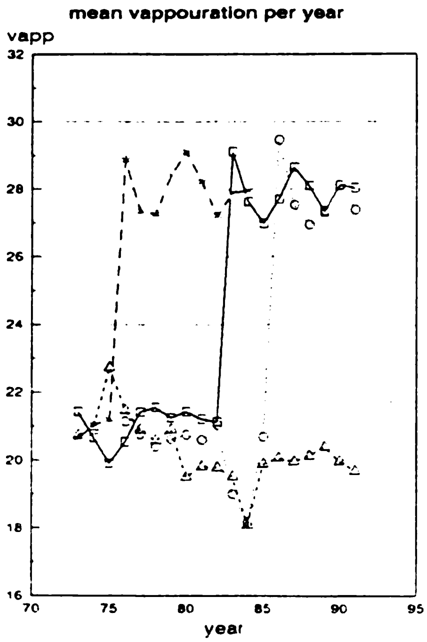

Figure 5.1. Average vapor pressure over the years of different weather stations in the Atlantic Zone.

The multiple regression analysis was carried out with Genstat 5. The best model to describe the production of banana was selected by using the Cp-criterium of Mallows (Oude Voshaar, 1991). Five parameters were used to describe the production; a) year of the production (YEAR), b) average daily minimum temperature over a year (TMIN), c) average daily maximum temperature over a year (TMAX) d) average daily rainfall over a year (RAIN) and e) average hours of sunshine over a year (SSH). The possible effects of interactions between two climate parameters are also taken into account.

The annual average of a parameter was not used when twenty or more daily values were missing or when ten or more subsequent daily values were missing.

The production of the plantation 'Productora Trópical' in 1986 is unexplainable and is therefore not taken into account.

5.3 Results

The model which has the lowest Cp-criterium is described in equation 5.1. All the used regression variables by equation 5.1 are significant (t-value of at least 3.97). The Cp-value of this model was 6.68 and the adjusted R^2 was 47.8 percent. This means that the production increases 78.1 boxes ha^{-1} per year. Next to that locations which have one additional hour of sunshine per day produce 457 boxes ha^{-1} $year^{-1}$ extra. Locations which have an increase in the product of average minimum temperature and maximum temperature of one $(^{\circ}C)^2$ produce 6.52 additional boxes ha^{-1} $year^{-1}$.

$$Yield = -10.54 + 0.078 * YEAR + 0.46 * SSH + 0,0065 * ITITA$$

Equation 5.1. Model to describe the actual production of banana in the Atlantic Zone. The production is expressed in 1000 boxes ha^{-1} $year^{-1}$. The model takes interaction between minimum and maximum temperature into account. YEAR is the number of years after 1900, SSH is the average number of hours of sunshine per day and ITITA is the interaction term of average daily minimal and maximal temperature in a year.

The use of interaction factors leads to slightly better models than models without interaction terms. However, interaction terms are relatively hard to interpret. Therefore, also models without interaction terms are described. The best model without interaction terms has a Cp-value of 4.12 and an adjusted R^2 of 47.3 percent. The model is described by equation 5.2 and is almost as good as the other model but easier to interpret.

$$Yield = -14.34 + 0.077 * YEAR + 0.21 * TMIN + 0.12 * TMAX + 0.45 * SSH$$

Equation 5.2. Model to describe the actual production of banana in the Atlantic Zone, expressed in 1000 boxes ha^{-1} $year^{-1}$. YEAR is the number of years after 1900, TMIN is the average daily minimal temperature in a year, TMAX is the average daily maximal temperature in a year and SSH is the average number of hours of sunshine per day in a year.

The most significant effect is caused by YEAR, (t = 6.31). A model without the YEAR effect had a Cp-value of 21.3 and an adjusted R^2 of 35.4 percent. The increase in production over the years is probably due to optimalization of the management. For instance, manuring of the field and use of biocides will increase the production.

The production also increases when a higher average daily minimal or maximal temperature is reached. This indicates that the optimal temperature to produce banana is higher than the temperature in the Atlantic Zone.

The positive relation between production and average hours of sunshine over a year, confirms the ideas of Soto (personal communication) that sunshine is important in determining the production in a certain area.

5.4 Conclusions

The results of the multiple regression analysis show that the actual production can be described as a linear combination of the production year and environmental circumstances.

The production of plantations in the same area can differ significantly. This might be a result of; a) differences in management, b) the use of the export figures of Corbana instead of the actual production, c) some of the plantation owners might pretend to have a smaller plantation to suggest a higher production per hectare (Soto, personal communication), d) differences in soil type and e) climatic differences within one area. The influence of the first four possibilities is hard to estimate and can not be taken into account. The influence of climatic differences can be estimated. Interpolation of the available data of all weather stations will make it possible to determine the climate on each location in the Atlantic Zone. Interpolation of weather data will also make it possible to include plantations in the analysis which are situated between weather stations.

Although the actual production can be described with the multiple regression analysis, this can not directly be used for a land evaluation study. For a land evaluation study it is necessary to determine the potential production. The relation between the actual production and the potential production can be determined by studying the development of the actual production over the years. The production of banana increases each year towards its potential. An estimation of the potential production is not very reliable after extrapolation of the increase in actual production. The extrapolation will become more accurate when more data are used in the multiple regression analysis. For instance, more plantations, more production years or additional parameters.

6 CONCLUSIONS AND RECOMMENDATIONS

The goal of this research was to estimate the potential production of banana at different locations in the Atlantic zone. These estimations will be used in the land evaluation study of Bessembinder (1992).

The best way to estimate the potential production is with crop growth simulation models. These models require information about a large number of physiological parameters and relations between parameters. In this study, a simulation model was developed based on WOFOST 4.1. However, this model was not validated. Its estimation of the potential production was lower than the actual production. Many physiological parameters and their relations with other parameters were not known and had to be estimated. Also not enough weather data were available.

Other models can be used, but these models can only describe the actual production. I developed a multiple regression model, which approximately described the actual production. However, for the land evaluation study the potential production has to be known. The relation between the actual production and the potential production still has to be determined.

Further research might involve one of the following suggestions;

- Firstly, the data of the weather stations in the Atlantic Zone have to be interpolated. Information of the climate at each location of the Atlantic Zone is necessary for the simulation of the growth of banana.
- Secondly, the simulation model based on WOFOST 4.1 can be improved if more information about the physiological parameters and their relations become available. However, this is a lot of work and will probably take years.
- Subsequently, a more simplified simulation model (P.C. LINTUL) can be developed.
- Finally, the regression analysis can be further specified and hopefully a reliable relation between the actual production and the potential production can be found. This can be done by extrapolating the increase of the actual production over years and by comparing the relation between actual and potential production for banana with the relation for other crops.

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APPENDIX 1

Simulation model program to describe the growth of bananas

Only the subroutines which are changed are described in this Appendix. The variables are explained in the book of Van Diepen *et.al.* (1988).

```
C   ****************************************************************
C   *                                                              *
C   *                CENTRE FOR WORLD FOOD STUDIES                 *
C   *                                                              *
C   *                                                              *
C   *                CROP GROWTH SIMULATION MODEL                  *
C   *                WOFOST   Version 4.1 (December 1987)          *
C   *                                                              *
C   *                                                              *
C   *                MICRO VERSION  FORTRAN 66                     *
C   *                                                              *
C   *   Documentation of this version will be available Jan.'88   *
C   *                Centre for World Food Studies                 *
C   *                c/o CABO                                      *
C   *                P.O.Box 14                                    *
C   *                6700 AA Wageningen                            *
C   *                Netherland                                    *
C   *                                                              *
C   ****************************************************************


C***********************************************************************
C       Chapter 1 in documentation
      PROGRAM WMAIN4J
C***********************************************************************
C       Author: C. Rappoldt, revised by C.A. van Diepen, 1987
C       Changed by: Jeroen van Velzen
C***********************************************************************
C       Main program for interactive use of the simulation routine.
C       Subroutines and functions called : APPLEH, CLMRDJ, CRPRDJ, MENU,
C       PAUZE, SOILRD.
C j     CRPRDJ will select bananas and asks for the value of ITDWA
C j     The climate will be red from CLM41J.DAT
C j     The nutrient balance is not taken into account and has been removed


C 1.1 ************* DECLARATIONS, COMMON BLOCKS
      IMPLICIT REAL(A-H,J-Z)
      IMPLICIT INTEGER(I)
      DIMENSION TOTB(566),JDVR(566),TDWI(566)

C     DATA BLOCK WITH SIMULATION RESULTS
      COMMON /OUT/IDANTH,IDHALT,DVSHAL,WLV,WSU,TWLV,TWSU,TWSO,TWRT,TAGP
      COMMON /OUT/MREST,GASST,RATIO,HINDEX
      COMMON /OUT/RAINT,TOTINF,TOTIRR,DRAINT,EVWAT,EVSOL,WUSE
      COMMON /OUT/TSR,CRT,PERCT,MWC,TWE,TRC
      COMMON /OPT/RDMO,LVOPT,SUOPT,SOOPT,HIOPT,RATOPT,DUROPT,WUSEO
      COMMON /WAT/TWLVW,TWSUW,TWSOW,HIWAT,RATIOW
```

```
C     PLANT NUTRIENT AND SOIL FERTILITY DATA BLOCK has been removed

C     PLANT DATA BLOCK
      INTEGER CROPT,DSL,AIRDUC
      COMMON /PLANT/CROPT,DSL,AIRDUC,SPAN,TBASE,RDMCR,DLO,DLC,EFF
      COMMON /PLANT/CFET,DEPNR
      COMMON /PLANT/TDWIL,RDI,DVRC1,DVRC2,RRI,KDIF,CVL,CVO,CVR,CVS
      COMMON /PLANT/SPA,SSA,Q10,RML,RMO,RMR,RMS,PERDL,PERRT,PERST
      COMMON /PLANT/FRTB(30),FLTB(30),FSTB(30),FOTB(30),SLATB(30)
      COMMON /PLANT/DVRETB(30),AMAXTB(30),TMPFTB(30),TMNFTB(30)

C     CLIMATE DATA BLOCK
      COMMON /CLMT/ELEV,GEOP,A,B
      COMMON /CLMT/AVRADJ(366),TMINJ(366),TMAXJ(366),VAPPJ(366)
      COMMON /CLMT/WINDJ(366),RAINJ(366),SSHJ(366)

C     SOIL AND WATER DATA BLOCK
      INTEGER DRAINS,FUNRAI
      CHARACTER*1 SOLNAM
      COMMON /SOILS/SOLNAM(30)
      COMMON /SOILS/SOPE,SO,KSUB,SMTAB(30),CONTAB(30),SMO,KO,PFTAB(30)
      COMMON /SOILS/FUNRAI,SSI,SSMAX,WAV,ZTI,DRAINS,DD,RDMSOL,NOTINF
      COMMON /SOILS/SMI,SM,SMFCF,SMW,RDM

C       start values of *OLD
      DATA ISOILO/0/

      OPEN ( 9,FILE='SOIL41.DAT',STATUS='OLD',ACCESS='SEQUENTIAL')
      OPEN ( 8,FILE='CROP41.DAT',STATUS='OLD',ACCESS='SEQUENTIAL')
      OPEN (10,FILE='CLIM4J.DAT',STATUS='OLD',ACCESS='SEQUENTIAL')
      OPEN (11,FILE='MENU.DAT',STATUS='OLD',ACCESS='SEQUENTIAL')
      OPEN ( 2,FILE='LPT2',STATUS='OLD')

C       unit-number of screen, keyboard, printer and WOFOST.OUT :
C       computer dependent !!!!
      ISCR  = 6
      ICNS  = 5
      IPRN  = 2
      IFILE = 1

C       output specifications :
      IDOUT = 10
      IBAL  =  3
C       initialization flag indicating use of WOFOST.OUT
      IIWOUT = 0
C       flag ISPEED : used to increase speed of simulation
      ISPEED= 1

C 1.2 ************* MAIN LOOP, INTERACTIVE USE OF SIMULATION PROGRAM

C 1.3 ************ CHOICE BETWEEN CROPS,CLIMATES AND SOILS

C j Crop is Bananas

      WRITE (ISCR,1001)
      CALL CRPRDJ(ISCR)
C j intitiation of the initial biomass
      DO 20 IDJ = 1,366
```

```
      TDWI(IDJ) = TDWIL
20      CONTINUE
C j climate is read from CLM41J.DAT

      WRITE (ISCR,1002)
      CALL CLMRDJ(ISCR)

C j Soil has not been changed yet

c       CALL MENU(ISCR,11)
c       WRITE (ISCR,1000)
c       READ (ICNS,2010) ISOIL
      ISOIL = 5
      IF (ISOILO.NE.ISOIL) CALL SOILRD(ISOIL,ISCR)
      ISOILO = ISOIL

C j The simulation result are writen in WOFOST.OUT
      OPEN (IFILE,FILE='WOFOST.OUT',STATUS='NEW',ACCESS='SEQUENTIAL')
C 1.3.1 ****** day running
      IYEARB = 0
65      IYEARB = IYEARB + 1
      IF (IYEARB.GE.2) GOTO 90
      IDAYB = 0
75      IDAYB = IDAYB + 1

C 1.4 ************* OTHER SIMULATION INPUT PARAMETERS

C j     montly or daily rainfall data
      RRD = 1
C j     initial surface storage
      SSI = 0.4
C j     surface storage capacity
      SSMAX = 0.4
C j     initial amount of available water in total rootable
C j     zone (moisture content above wilting point)
      WAV = 40
C j     maximum rooting depth allowed by soil
      RDMSOL = 100
C j     fraction of rainfall not infiltating
      NOTINF = 0.0

      ISTART = IDAYB
      IIWOUT=1
      IPS=ISCR

C 1.6 ************* SIMULATION
C       simulation of potential production
      TDWIL = TDWI(IDAYB)
      CALL APPLEJ (ISTART,0,IDOUT,0,IPS,ISCR,ISPEED,DVRTJ)
C estimate finish day
      IFIN = 199
      IFINDA = IFIN+IDAYB
      IF (IFINDA.GE.366) IFINDA = IFINDA - 365
      TOTB(IFINDA) = TWSO
      TDWI(IFINDA) = TWSU * 0.5
      JDVR(IDAYB+1) = DVRTJ * 1.0
      GOTO 75
90      JDVR(1) = JDVR(366)
```

```
      DO 101 IB = 1,365
      TTOB = TTOB + TOTB(IB)*JDVR(IB)/1.2
      WRITE (IFILE,2200) IB,TOTB(IB),JDVR(IB)
101     CONTINUE
      WRITE (IFILE,2300) TTOB
C 1.8 ************* STOP
999     CLOSE (IFILE)
      STOP

C 1.9 ************* FORMAT STATEMENTS
1000    FORMAT (/,20X,'your choise please: ',$)
1001    FORMAT (/,15X,'bananas is chosen',$)
1002    FORMAT (/,15X,'CLM41J.DAT is chosen as climate',$)
1190    FORMAT (/,40X,' Start date (Daynumber) ',$)
1200    FORMAT(' Output to: 1. Screen'/
     $         '            2. File WOFOST.OUT'/
     $         '            3. Printer'//
     $         '            ---> ',$)
2010    FORMAT(I6)
2200    FORMAT(I3,F8.2,F7.4)
2300    FORMAT(F8.2)
      END

C***********************************************************************
C       Chapter 2 in documentation
      SUBROUTINE APPLEJ(START,IWB,IDOUT,IBAL,IPS,ISCR,ISPEED,DVRTJ)
C***********************************************************************
C       Author: C.A. van Diepen, based on earlier version by
C       C. Rappoldt (1987),
C j     The subroutine has been changed by Jeroen van Velzen to
C j     describe the growth of Bananas
C***********************************************************************
C       In this routine the simulation of the potential and the
C       water-limited crop growth and the soil water balance are
C       performed.
C       Subroutines and functions called: AFGEN, ASTRO, INTRPJ, LIMIT,
C       PAUZE, PENMAN, SWEAF, TEXT, TOTASJ.
C       Called by program WMAIN4J.

C 2.1 ************* COMMON BLOCKS

      IMPLICIT REAL(A-H,J-Z)
      IMPLICIT INTEGER(I)

C     DATA BLOCK WITH SIMULATION RESULTS
      COMMON /OUT/IDANTH,IDHALT,DVSHAL,WLV,WSU,TWLV,TWSU,TWSO,TWRT,TAGP
      COMMON /OUT/MREST,GASST,RATIO,HINDEX
      COMMON /OUT/RAINT,TOTINF,TOTIRR,DRAINT,EVWAT,EVSOL,WUSE
      COMMON /OUT/TSR,CRT,PERCT,MWC,TWE,TRC
      COMMON /OPT/RDMO,LVOPT,SUOPT,SOOPT,HIOPT,RATOPT,DUROPT,WUSEO
      COMMON /WAT/TWLVW,TWSUW,TWSOW,HIWAT,RATIOW

C     PLANT NUTRIENT AND SOIL FERTILITY DATA BLOCK is removed

C     PLANT DATA BLOCK
      INTEGER CROPT,DSL,AIRDUC
      COMMON /PLANT/CROPT,DSL,AIRDUC,SPAN,TBASE,RDMCR,DLO,DLC,EFF
      COMMON /PLANT/CFET,DEPNR
```

```
      COMMON /PLANT/TDWIL,RDI,DVRC1,DVRC2,RRI,KDIF,CVL,CVO,CVR,CVS
      COMMON /PLANT/SPA,SSA,Q10,RML,RMO,RMR,RMS,PERDL,PERRT,PERSU
      COMMON /PLANT/FRTB(30),FLTB(30),FSTB(30),FOTB(30),SLATB(30)
      COMMON /PLANT/DVRETB(30),AMAXTB(30),TMPFTB(30),TMNFTB(30)

C     CLIMATE DATA BLOCK
      COMMON /CLMT/ELEV,GEOP,A,B
      COMMON /CLMT/AVRADJ(366),TMINJ(366),TMAXJ(366),VAPPJ(366)
      COMMON /CLMT/WINDJ(366),RAINJ(366),SSHJ(366)

C     SOIL AND WATER DATA BLOCK
      INTEGER DRAINS
      CHARACTER*1 SOLNAM
      COMMON /SOILS/SOLNAM(30)
      COMMON /SOILS/SOPE,SO,KSUB,SMTAB(30),CONTAB(30),SM0,K0,PFTAB(30)
      COMMON /SOILS/FUNRAI,SSI,SSMAX,WAV,ZTI,DRAINS,DD,RDMSOL,NOTINF
      COMMON /SOILS/SMI,SM,SMFCF,SMW,RDM

C 2.2 ************* DECLARATIONS, RUN CONTROL

      INTEGER HALT,START
      DIMENSION LV(366),SLA(366),LVAGE(366)

C       data for heading of output table for single run
      CHARACTER*8 NTEXT,NTEXT0
      CHARACTER*8 GTEXT(2),GTEXT0(2)
      DATA GTEXT0/' no grou','ndwater '/
      DATA NTEXT0/'   fixed'/


C       extinction coefficient for total global radiation
      KGLOB = 0.75*KDIF

C       run control
      START=1+MOD(START-1,365)
      IDAY=START
      HALT=0
      DELT=1.
      ID=0
      RTDF=0.


C 2.3 ************* FUNCTIONS AND HELP VARIABLES


C 2.3.1 ************* SOIL MOISTURE RETENTION DATA

C       field capacity and wilting point
      SMFCF = AFGEN(SMTAB,ALOG10(200.))
      SMW = AFGEN(SMTAB,ALOG10(16000.))


C 2.3.3 ***********  OTHER DATA

C       initialization 7-day running average of minimum temperatures
      TMINRA = 0.0
      IF (IDAY.GE.7) GOTO 315
C       If IDAY is one of the first seven days of the year
```

```
      DO 310 I = 1,IDAY
      TMINRA = TMINRA + (TMINJ(I)/IDAY)
      IF (TMINJ(I).EQ.-99) TMINRA = TMINJ(I+1)
      IF (TMINJ(I).EQ.-99) GOTO 330
310     CONTINUE
      GOTO 330
315     CONTINUE
      DO 320 I = 0,6
      TMINRA = TMINRA+(TMINJ(IDAY-I)/7)
      IF (TMINJ(IDAY-I).EQ.-99) TMINRA = TMINJ(IDAY-I-1)
      IF (TMINJ(IDAY-I).EQ.-99) GOTO 330
320     CONTINUE
330     CONTINUE
c        TMINRA = TMINJ(IDAY)

C       ibid. when daily weather data are available
C       TMINRA = VMINT(IDAY)

C       maximum rooting depth
      IF (IWB.EQ.0) RDM = AMAX1(RDI,RDMCR)
      IF (IWB.EQ.1) RDM = AMAX1(RDI, AMIN1(RDMSOL,RDMO,RDMCR))


C 2.4   ***********  DRIVING VARIABLES

C       *********** RAINFALL DATA
C j the rainfall data are put together with the rest of the wheather data


C 2.5 *************  INITIAL WATER CONDITIONS


C 2.5.1 ***********  INITIAL STATE VARIABLES OF THE WATER BALANCE


      RD = RDI

C       for potential production (IWB=0) skip to next section
      IF (IWB.EQ.0) GOTO 540

C       without groundwater :
      SS=SSI
C       initial moisture content in rooted zone
      SMLIM = SMFCF
      SMI = LIMIT(SMW,SMLIM,SMW+WAV/RDI)
C       initial amount of moisture in rooted zone
      WI = SMI*RDI
      SM = SMI
      W = WI
C       amount of moisture between rooted zone and max.rooting depth
C j     is 0 because the rooting depth is always egual to the
C j     maximum rooting depth
      WLOWI = 0
C j     WLOWI = LIMIT(0.,SMLIM*(RDM-RDI),WAV+RDM*SMW-WI)
      WLOW = WLOWI
C j     In that case SMLOW is also 0
C j     SMLOW = WLOWI/(RDM-RDI)
      SMLOW = 0
```

```
      [illegible]
      GOTO 540

540    CONTINUE


C 2.5.2 ***********  INITIAL SUMMATION VARIABLES OF THE WATER BALANCE

C        all summation variables are set at zero irrespective of the option
C        for IWB. See section 2.8 'Integrals of the water balance'
C        for their use in relation to these options.
      EVAP=0.
      WUSE=0.
      EVSOL=0.
      EVWAT=0.
      TSR=0.
      CRT=0.
      PERCT=0.
      RAINT=0.
      WDRT=0.
      TOTINF=0.
      TOTIRR=0.
      SUMSM = 0.
      LOSST = 0.
      DRAINT = 0.


C 2.5.3 ***********  INITIAL RATES OF THE WATER BALANCE

C        all rates are set at zero irrespective of the option for IWB
      T=0.
      E=0.
      EL=0.
      RAIN=0.
      RIN=0.
      RIRR=0.
      DW=0.
      PERC=0.
      LOSS=0.
      DWLOW=0.
      CR=0.
      DMAX=0.
      DZ=0.


C 2.6 **********  INITIAL CROP CONDITIONS AT EMERGENCE OR TRANSPLANTING


C 2.6.1 ***********  INITIAL VALUES OF CROP PARAMETERS

      IDANTH=0
C j      DVS is initiated
      DVS=0.8

C j      ILVOLD is initiated
      ILVOLD = 80

C 2.6.2 ***********  INITIAL STATE VARIABLES OF THE CROP
```

```
C j     The root sytem has a constant biomass of 1000, the initial dry
C j     weight of the leaves (TDWIL) is asked by the subroutine CRPRDJ

      TDW = TDWIL + 1000
      WRT = 1000
      TADW = TDWIL
      WLV = TDWIL
      WSU = 0.0
      WSO = 0.0

      LASUM = 0.0
      DO 610 IL=1,40
C j     The leaves of the new motherplant are distributed in age
      LV(IL) = (WLV/52) * (1 - 0.005 * (IL-0.5))
610     CONTINUE
      DO 620 IL=41,80
      LV(IL) = (WLV/52) * (1.6 - 0.02 * (IL-0.5))
620     CONTINUE
      DO 630 IL=1,80
      LVAGE(IL) = IL * 1.0
      DVSV = 0.8 - (IL * 0.01)
      SLA(IL) = AFGEN(SLATB,DVSV)
      LASUM = LASUM + SLA(IL)*LV(IL)
630     CONTINUE


      DWRT=0.
      DWLV=0.
      DWSU=0.
      DWSO=0.


C 2.6.3 ***********  INITIAL SUMMATION VARIABLES OF THE CROP

      GASST = 0.
      MREST = 0.


C 2.6.4 ***********  INITIAL RATES OF THE CROP

      DVR=0.

      GWRT=0.
      GWLV=0.
      GWSU=0.
      GWSO=0.
      DRRT=0.
      DRLV=0.
      DRSU=0.
      DRSO=0.

      GASS=0.
      MRES=0.


C 2.7 ************* PRINT HEADING OF OUTPUT TABLE

C       skip this section if no output table on single run is required
```

```
      IF (IDOUT.EQ.0) GOTO 730
      IF (IWB.EQ.1) GOTO 710

C       potential production

      WRITE (IPS,9810) START
      WRITE (IPS,9860)
      GOTO 730

710     CONTINUE
C       water limited production
      CALL TEXT(GTEXT,GTEXTO,2)
      CALL TEXT(NTEXT,NTEXTO,1)

C j     WRITE (IPS,9820) START,NTEXT,SOLNAM,RDMSOL,GTEXT,NOTINF


C       without groundwater
      WRITE (IPS,9830) SMO,SMFCF,SMW,RDM,WAV,SSMAX
      WRITE (IPS,9870)
730     CONTINUE


C ***********************  DYNAMIC CALCULATIONS  ***********************
C ***********************  DYNAMIC CALCULATIONS  ***********************
C ***********************  DYNAMIC CALCULATIONS  ***********************


C  *****************  INTEGRALS OF THE WATER BALANCE  *****************
C  *****************  INTEGRALS OF THE WATER BALANCE  *****************

C 2.8 *************** SUMMATION AND STATE VARIABLES

800     CONTINUE

C       total transpiration
      WUSE = WUSE + T*DELT
C       total evaporation from surface water layer and/or soil
      EVWAT = EVWAT + EL*DELT
      EVSOL = EVSOL + E*DELT
C       end of water balance for IWB=0 :
      IF (IWB.EQ.0) GOTO 820

C       totals for rainfall, irrigation and infiltration
      RAINT = RAINT + RAIN*DELT
      TOTINF= TOTINF + RIN*DELT
      TOTIRR= TOTIRR + RIRR*DELT
C       surface storage and runoff
      SSPRE = SS + (RAIN+RIRR-EL-RIN)*DELT
      SS = AMIN1(SSPRE,SSMAX)
      TSR = TSR + (SSPRE-SS)
C       amount of water in rooted zone
      W = W + DW*DELT

C       total percolation and loss of water by deep leaching
      PERCT = PERCT + PERC*DELT
      LOSST = LOSST + LOSS*DELT
C       amount of water in unrooted, lower part of rootable zone
```

```
      WLOW = WLOW + DWLOW*DELT
C         total amount of water in the whole rootable zone
      WWLOW = W + WLOW
C         end of water balance
820       CONTINUE

C 2.9 ********* ROOT GROWTH ; CHANGE OF ROOTZONE SUBSYSTEM BOUNDARY

C         calculation of soil moisture content of new rootzone (W,SM)
C         root growth RR in cm (no rate)
C j       there is no growth of the rootsystem described
      RR = 0.


C 2.10  ******** MEAN SOIL MOISTURE CONTENT IN ROOTED ZONE

      IF (IWB.EQ.0) GOTO 1010
      SM = W/RD
C         calculating mean soil moisture content over growing period
      SUMSM = SUMSM + SM*DELT
1010      CONTINUE


C 2.11  *** FINISH CONDITIONS DUE TO LASTING LACK OF OXYGEN IN ROOT ZONE


C 2.12  **************** INTEGRALS OF THE CROP

C         phenological development stage
      DVS = DVS+DVR*DELT
C         save date of anthesis
      IF (DVS.GE.1. .AND. IDANTH.EQ.0) IDANTH=ID
C         dry weight of living plant organs
C j       the rootsystem has a constant biomass
      WRT = WRT
      WLV = WLV+GWLV*DELT
      WSU = WSU+GWSU*DELT
      WSO = WSO+GWSO*DELT
C         total above ground and total dry weight of crop
      TADW = WLV+WSU+WSO
      TDW = TADW+WRT
C         dry weight of dead plant organs
      DWRT = 0
      DWLV = DWLV+DRLV*DELT
      DWSU = DWSU+DRSU*DELT
      DWSO = DWSO+DRSO*DELT
C         dry weight of dead and living plant organs
      TWRT = WRT+DWRT
      TWLV = WLV+DWLV
      TWSU = WSU+DWSU
      TWSO = WSO+DWSO
      TAGP = TWLV+TWSU+TWSO
C         total gross assimilation and maintenance respiration
      GASST = GASS + GASST
      MREST = MRES + MREST
C         leaf area index
C j       The LAI of mother and sucker are taken together
      LAI = LASUM+SSA*WSU+SPA*WSO
```

```
C 2.13    *************** CROP FINISH CONDITIONS

      IF (DVS.GE.2.) HALT=1
      IF (LAI.LE.0.002.AND.DVS.GT.0.5) GOTO 1310
      GOTO 1320
1310    HALT=1
      IF (IDOUT.GE.1) WRITE(IPS,9920)
1320    CONTINUE


C *************************  DRIVING VARIABLES  *************************
C *************************  DRIVING VARIABLES  *************************

C 2.14   ************* INTAKE AND CONVERSION OF CLIMATE DATA

      CALL INTRPJ (IDAY,DAYL,TMIN,TMAX,AVRAD,VAPOUR,WIND,RAIN,ISCR)
C       conversion of radiation from MJ to Joules per day
      AVRAD = AVRAD * 1000000.
C       conversion of rainfall from mm to cm per day
      IF (IWB.EQ.1) RAIN = RAIN/10.
C       average temperature
      TEMP = (TMIN+TMAX)/2.
C       average daytemperature
      DTEMP = (TMAX + TEMP)/2.
C       calculation of 7-day running average of minimum temperature
      IDOLD = 1 + MOD(IDAY+357,365)
C       minimum temperature 7 days ago, not before start day
      IF (ID.LT.7) TMINOL = TMINJ(START)
      IF (ID.LT.7) GOTO 1410
      IF (IDAY.LT.7) TMINOL = TMINJ(1)
      IF (IDAY.GE.8) TMINOL = TMINJ(IDAY-7)
C       7-day running average of minimum temperature
1410    TMINRA = TMINRA + (TMIN - TMINOL)/7

      IF (MOD(ID,ISPEED) .EQ. 0) CALL PENMAN (IDAY,GEOP,ELEV,A,B,TMIN,
     S                  TMAX,AVRAD,VAPOUR,WIND,EO,ESO,ETO)

C       potential evaporation rates in cm per day
      IF (MOD(ID,ISPEED) .EQ. 0) EO  = EO /10.
      IF (MOD(ID,ISPEED) .EQ. 0) ESO = ESO/10.
      IF (MOD(ID,ISPEED) .EQ. 0) ETO = CFET*ETO/10.
C       maximum transpiration and evaporation rate
      TM = AMAX1(0.0001,ETO*(1.-EXP(-1.*KGLOB*LAI)))
      EM = AMAX1(0.,ESO*EXP(-1.*KGLOB*LAI))

C ********************  RATES OF THE WATER BALANCE  ********************
C ********************  RATES OF THE WATER BALANCE  ********************


C 2.15 ****** RATES OF THE WATER BALANCE FOR POTENTIAL PRODUCTION

C       for water limited production skip to next section
      IF (IWB.EQ.1) GOTO 1600
C       transpiration rate
      T = TM
C       evaporation rate from soil (non-rice) or water surface (rice)
      E = 0.
```

```
      EL = 0.
      E = EM*(SMFCF-SMW/3.)/(SMO-SMW/3.)
      EVAP = E + EL
C       for potential production proceed with crop growth
      GOTO 1900


C 2.16  ****** FIRST PART OF WATER BALANCE FOR WATER LIMITED PRODUCTION
C                FOR SITE WITH OR WITHOUT GROUNDWATER

C       *********** actual transpiration rate
C       calculation critical soil moisture content
1600    SWDEP = SWEAF(ETO,DEPNR)
      SMCR = (1.-SWDEP)*(SMFCF-SMW)+SMW
C       reduced transpiration in case of water shortage
      T = TM * LIMIT(0.,1.,(SM-SMW)/(SMCR-SMW))
C       for non-rice crops reduced transpiration in case of air shortage
      T = T * LIMIT(0.,1.,((SMO-0.05)-SM)/0.05)

C       *********** actual evaporation rates ...
      E = 0.
      EL = 0.
C       ... from surface water if surface storage more than 1 cm, ...
      IF (SS.GT.1.) EL = EO*EXP(-1.*KGLOB*LAI)
C       ... else from soil surface
      IF (SS.LE.1.) E = EM * LIMIT(0.,1.,(SM-SMW/3.)/(SMO-SMW/3.))
C       total evaporation rate, to serve as output variable only
      EVAP = E + EL

C       *********** preliminary infiltration rate
      IF (SS.GT.0.1) GOTO 1610
C       without surface storage
      RINPRE=(1.-NOTINF)*RAIN+RIRR+SS/DELT
      GOTO 1620
1610    CONTINUE
C       with surface storage, infiltration limited by SOPE
      AVAIL = SS+(RAIN+RIRR-EL)*DELT
      RINPRE= AMIN1(SOPE*DELT,AVAIL)/DELT
1620    CONTINUE

C 2.17  ****** SECOND PART OF WATER BALANCE FOR WATER LIMITED PRODUCTION
C                FOR SITE WITHOUT GROUNDWATER

C       ********** percolation
C       equilibrium amount of soil moisture in rooted zone
      WE = SMFCF * RD
C       percolation from rooted zone to subsoil equals amount of
C       excess moisture in rooted zone (not to exceed conductivity)
      PERC1 = LIMIT (0., SOPE, (W - WE)/DELT - T - E)

C       ********** loss of water at the lower end of the maximum root zone
C       equilibrium amount of soil moisture below rooted zone
      WELOW = SMFCF * (RDM - RD)
      LOSS = LIMIT (0., KSUB, (WLOW - WELOW)/DELT + PERC1 )
C       percolation not to exceed uptake capacity of subsoil
      PERC2 = ((RDM -RD) * SMO - WLOW) / DELT + LOSS
      PERC = AMIN1(PERC1,PERC2)
```

```
C       ********** adjustment of infiltration rate
      RIN=AMIN1(RINPRE,(SMO-SM)*RD/DELT + T + E + PERC)

C       ***** rates of change in amounts of moisture W and WLOW
      DW = - T - E - PERC + RIN
      DWLOW = PERC - LOSS


C       *********************** CROP GROWTH ***********************
C       *********** RATES OF CHANGE OF THE CROP VARIABLES ***********
C       *********** RATES OF CHANGE OF THE CROP VARIABLES ***********


C 2.19  ***********  PHENOLOGICAL DEVELOPMENT RATE

1900    IF (MOD(ID,ISPEED) .EQ. 0) CALL ASTRO (IDAY,GEOP,DAYL,
     S                                        DAYLP,SINLD,COSLD)
      DVRED = 1.
      DVRET = 1.
      IF (DVS.GT.1.) GOTO 1910
C       development during vegetative phase
      IF (DSL.GE.1) DVRED = LIMIT(0.,1.,(DAYLP-DLC)/(DLO-DLC))
      IF (DSL.NE.1) DVRET = AFGEN(DVRETB,TEMP)
      DVR = DVRC1*DVRED*DVRET
      IF (ID.EQ.1) DVRTJ = DVR
      GOTO 1920
1910    CONTINUE
C       development during generative phase
      DVRET = AFGEN(DVRETB,TEMP)
      DVR = DVRC2*DVRET
1920    CONTINUE


C 2.20 **************** DAILY DRY MATTER PRODUCTION

C       ********** gross assimilation
      AMAX = AFGEN(AMAXTB,DVS)
C       correction for sub-optimum average day temperature
      AMAX = AMAX * AFGEN(TMPFTB,DTEMP)

      CALL TOTASJ (DVS,IDAY,ID,ISPEED,DAYL,AMAX,EFF,LAI,KDIF,AVRAD,
     1               SINLD,COSLD,DTGA)
C       correction for low minimum temperature
      DTGA = DTGA * AFGEN(TMNFTB,TMINRA)

C       potential assimilation in kg CH2O per ha
      PGASS = DTGA * 30./44.
C       water stress reduction
C j     A factor PERRT is used by the rootsystem
      GASS = PGASS * T/TM * (1-PERRT)

C       ********** partitioning factors
      FR = 0
C j     The part of the assimilates available for the leaves depends on DVR
C j       and the maximum developing rate, because the maximum developing
rate
C j     before and after floral initiation (DVRC1 and DVRC2) is the same
C j     the maximum developing rate = DVRM = DVRC1 = DVRC2
```

```
      DVRM = [illegible]
      FL = ((DVR/DVRM)*0.5+0.5)*AFGEN(FLTB,DVS)
      FO = AFGEN(FOTB,DVS)
      FS = 1 - FL - FO

C         ********** respiration and dry matter increase
C j       The respiration of the roots includes also the compensation for the

C j       dead roots
      RMRES = GASS*0.05+RML*WLV+RMS*WSU+RMO*WSO
      TEFF = Q10**((TEMP-25.)/10.)
      MRES = AMIN1(GASS,RMRES*TEFF)
      CVF  = 1./((FL/CVL+FS/CVS+FO/CVO)*(1.-FR)+FR/CVR)
      ASRC = GASS-MRES
      DMI  = CVF*ASRC

C         ********** check on carbon balance
      CCHECK = (GASS-MRES-(FR+(FL+FS+FO)*(1.-FR))*DMI/CVF)
     $           /AMAX1(0.0001,GASS)
      IF (ABS(CCHECK).LE.0.0001) GOTO 2020
      WRITE (IPS,9911) IDAY,CCHECK,GASS,MRES,FR,FL,FS,FO,DMI,CVF
      FCHECK = FR+(FL+FS+FO)*(1.-FR) - 1.
      IF (ABS(FCHECK).GT.0.0001)
     $         WRITE (IPS,9912) FCHECK,FR,FL,FS,FO
      STOP
2020    CONTINUE


C 2.21  ************* GROWTH RATE BY PLANT ORGAN


C 2.21.1 ************* GROWTH RATE ROOTS AND AERIAL PARTS

      ADMI = DMI
      GWRT = 0

C 2.21.2 **************** GROWTH RATE LEAVES

C         weight of new leaves
      GRLV = FL*ADMI

C         death of leaves due to water stress or high LAI
      DSLV1 = WLV*(1.-T/TM)*PERDL
      LAICR = 3.2/KDIF
      DSLV2 = WLV*LIMIT(0.,0.03,0.03*(LAI-LAICR)/LAICR)
      DSLV = AMAX1(DSLV1,DSLV2) * DELT
      DSLVT = DSLV
C         determination of last remaining class of living leaves
      DO 2120 IK = 1,ILVOLD
      IIK = ILVOLD - IK + 1
      DUM = AMIN1(DSLVT,LV(IIK))
      LV(IIK) = LV(IIK) - DUM
      DSLVT = DSLVT - DUM
      IF (DSLVT.LE.0.) GOTO 2130
2120    CONTINUE
2130    ILVOLD = IIK

C         ********** physiologic ageing of leaves per time step
```

```fortran
      FYSDEL = AMAX1(0.,(TEMP-TBASE)/(35.-TBASE))*DELT
      DO 2140 IK=1,ILVOLD
      IIK = ILVOLD-IK+1
      LV(IIK+1)  = LV(IIK)
      SLA(IIK+1) = SLA(IIK)
      LVAGE(IIK+1) = LVAGE(IIK)+FYSDEL
2140    CONTINUE
      ILVOLD = ILVOLD+1
      IF(ILVOLD.GT.365) GOTO 2150
      GOTO 2160
2150    HALT=1
C       message on output and simulation will be stopped
      IF (IDOUT.GE.1) WRITE (IPS,9913)
2160    CONTINUE

C       ********** new leaves in class 1
      LV(1) = GRLV*DELT
      SLA(1) = AFGEN(SLATB,DVS)
      LVAGE(1) = 0.

C       ********** leaves older than SPAN die
      DALV = 0.
      DO 2170 IK=1,ILVOLD
      IIK = ILVOLD-IK+1
      IF (LVAGE(IIK).LT.SPAN) GOTO 2180
      DALV=DALV+LV(IIK)
      LV(IIK)=0.
2170    CONTINUE
2180    ILVOLD = IIK

C       ********** calculation of new leaf area
      LASUM = 0.
      DO 2190 I=1,ILVOLD
      LASUM = LASUM+LV(I)*SLA(I)
2190    CONTINUE

C       ********** death rate leaves and growth rate living leaves
      DRLV = (DSLV+DALV)/DELT
      GWLV = GRLV-DRLV


C 2.21.3 ******************** GROWTH RATE STEMS

      GRSU = FS*ADMI
      DRSU = 0.
      IF (DVS.GT.1.5) DRSU = PERSU*WSU
      GWSU = GRSU-DRSU


C 2.21.4 ***************** GROWTH RATE STORAGE ORGANS

      GWSO = FO*ADMI


C 2.22 ************ OUTPUT , IF HALT=1 STOP SIMULATION

C       print condition :
      IF (IDOUT.EQ.0) GOTO 2220
```

```
      IF (MOD(ID,IDOUT).EQ.0 .OR. HALT.EQ.1
     S                         .OR. ID.EQ.IDANTH) GOTO 2210
      GOTO 2220
2210    IF (IWB.EQ.0) WRITE (IPS,9889)
     S        IDAY,ID,WLV,WSU,WSO,LAI,DVS,RD,T,GASS,MRES,DMI,TAGP
      IF (IWB.EQ.1) WRITE (IPS,9900)
     S        IDAY,ID,WLV,WSU,WSO,LAI,RD,RAINT,T,EVAP,SM,SS,WWLOW
2220    CONTINUE


C 2.23 *************  DAY COUNTING, NEXT TIME STEP

      IF (HALT .EQ. 1) GOTO 2400
      ID = ID+1
      IDAY = 1+iday
C       MOD(IDAY,365)
      if (iday.ge.366) iday = 1
C       in case of january 1, new year of generated rainfall
C j     When several years are simulated in one run, a new set of data
C j     has to be read
C J        IF (IDAY.EQ.1) CALL CLMRDJ(******)
      GOTO 800



C 2.24 ************ SIMULATION HALTED

C       save final output variables: growth duration and development
C       stage, grain straw ratio, harvest index, transpiration coefficient

2400    IDHALT = ID
      DVSHAL = DVS
      RATIO = TWSO/(TWLV+TWSU)
      HINDEX = TWSO/TAGP
      TRC = 100000.*WUSE/TAGP

C       print summary results on one line of output table
      IF (IDOUT.NE.0) WRITE(IPS,9990)
     S   IDANTH,TWRT,TWLV,TWSU,TWSO,TAGP,GASST,MREST,HINDEX,TRC,
     S   WUSE,IDHALT
      IF (IWB.EQ.1) GOTO 2430
C       saving some simulation results potential production
      RDMO = RD
      LVOPT = TWLV
      SUOPT = TWSU
      SOOPT = TWSO
      HIOPT = HINDEX
      RATOPT = RATIO
      DUROPT = IDHALT*1.
      WUSEO = WUSE
      TRCO = TRC
      RETURN
2430    CONTINUE
C       mean water content rooting zone during crop growth and total
C       water content of the potentially rooted zone at end of simulation
      MWC = SUMSM/IDHALT
      TWE = W+WLOW
```

```
C       checksums waterbalance for system without groundwater
      WBALRT = TOTINF + WI + WDRT - EVSOL - WUSE - PERCT - W
      WBALTT=SSI + RAINT + TOTIRR + WI - W + WLOWI - WLOW - WUSE
     $   - EVWAT - EVSOL - TSR - LOSST - SS


C 2.25 ************ PRINT OUT DESIRED WATER BALANCES

C       for water limited production only
      IF (IWB.EQ.0 .OR. IBAL.EQ.0) GOTO 2520
      IF (IPS.EQ.ISCR) CALL PAUZE(ISCR)
      IF (IBAL.EQ.2) GOTO 2510
      DELSS = SS  -SSI
      DELW  = W   -WI
      DELWLO= WLOW-WLOWI
      WRITE (IPS,9930) TOTIRR,EVWAT,RAINT,EVSOL,WUSE,DELSS,TSR
      WRITE(IPS,9940) DELW,LOSST,WBALTT,DELWLO
2510    CONTINUE
      IF (IBAL.EQ.1) GOTO 2520
      WRITE (IPS,9960) WI,W,TOTINF,EVSOL,WDRT,WUSE
      WRITE(IPS,9970) PERCT,WBALRT
2520    CONTINUE
      RETURN


C 2.26 ***************** FORMAT STATEMENTS

9810    FORMAT(//,' POTENTIAL CROP PRODUCTION  Start day',I4)
9820    FORMAT(//,'1WATER LIMITED CROP PRODUCTION, Year',I5,26X,
     $   'Start day',I4,/,1X,29('='),34X,2A8,/,2(1X,30A1),1X,A8,
     $   ' fraction',/,1X,30A1,4X,'RDMso=',F4.0,3X,2A8,5X,
     $   'NOTinf=',F4.2)
9830    FORMAT(3X,'SM0=',F5.3,' SMFC=',F5.3,' SMW=',F5.3,4X,
     $   'RDM=',F4.0,7X,'WAV=',F5.1,9X,'SSmax=',F4.1)
9840    FORMAT(3X,'SM0=',F5.3,' SMFC=',F5.3,' SMW=',F5.3,4X,
     $   'RDM=',F4.0,2X,'ZTI=',F5.0,' no drains',4X,'SSmax=',F4.1)
9850    FORMAT(3X,'SM0=',F5.3,' SMFC=',F5.3,' SMW=',F5.3,4X,
     $   'RDM=',F4.0,2X,'ZTI=',F5.0,'  DD=',F5.0,4X,'SSmax=',F4.1)
9860    FORMAT(/,' DAY  ID   WLV    WSU    WSO    LAI   DVS   RD',
     $   '     T   CASS   MRES    DMI   TAGP')
9870    FORMAT(/,' DAY  ID   WLV    WSU    WSO    LAI   RD',
     $   '     RAIN      T  EVAP     SM    SS W+WLOW')
9880    FORMAT(/,' DAY  ID   WLV    WSU    WSO    LAI   RD',
     $   '     RAIN      T  EVAP     SM    SS     ZT')
9889    FORMAT(1X,I3,I4,3F7.0,2F6.2,F5.0,F5.2,3F7.1,F8.0)
9890    FORMAT(1X,I3,I4,3F7.0,F6.2,F6.0,F7.1,2F6.2,F7.3,F6.1,F6.0)
9900    FORMAT(1X,I3,I4,3F7.0,F6.2,F6.0,F7.1,2F6.2,F7.3,F6.1,F6.1)
9910    FORMAT(' Crop failure due to waterlogging !')
9911    FORMAT(1X,'CARBON FLOWS NOT BALANCED ON DAY',I3,/,
     $  1X,'CCHECK = ',F10.4,' GASS = ',F6.1,' MRES= ',F6.1,' FR,L,S,O= '
     $  ,4F5.2,' DMI= ',F5.1,' CVF= ',F5.2)
9912    FORMAT(1X,'ERROR IN REPARTITION FUNCTIONS',/,
     $  1X,'FCHECK = ',F6.4,', FR =',F5.2,', FL =',F5.2,', FS =',
     $  F5.2,', FSO =',F5.2)
9913    FORMAT(' number of leaf classes exceeds 365 !')
9920    FORMAT(' no living leaves (anymore)')
```

```
9930    FORMAT(/,16X,'WATER BALANCE WHOLE SYSTEM',/,
     $   12X,'irrigation',F6.1,5X,'evap. water surface',F6.1,/,
     $   14X,'rainfall',F6.1,6X,'evap. soil surface',F6.1,/,
     $   ' final minus initial:',18X,'transpiration',F6.1,/,
     $   6X,'-surface storage',F6.1,10X,'surface runoff',F6.1)
9940    FORMAT(4X,'-water in rootzone',F6.1,7X,'lost to deep soil',
     $   F6.1,'  checksum:',F4.1,/,'  -water in lower zone',F6.1)
9950    FORMAT(4X,'-water in rootzone',F6.1,4X,'lost through drains',
     $   F6.1,'  checksum:',F4.1,/,' -water below rootzone',F6.1)
9960    FORMAT(/,18X,'WATER BALANCE ROOT ZONE',/,1X,
     $   'initial water content',F6.1,5X,'final water content',F6.1,/,
     $   10X,'infiltration',F6.1,6X,'evap. soil surface',F6.1,/,
     $   '   added by root growth',F6.1,11X,'transpiration',F6.1)
9970    FORMAT(41X,'percolation',F6.1,'  checksum:',F4.1)
9980    FORMAT(8X,'capillary rise',F6.1,13X,'percolation',F6.1,
     $   '   checksum:',F4.1)
9990    FORMAT (/,1X,'SUMMARY :',
     $    /,1X,'DAYS   TWRT    TWLV    TWSU   ',
     $   ' TWSO    TAGP   GASST   MREST  HINDEX TRC   WUSE',
     $    /,1X,I4,7F8.0,F7.2,F5.0,F6.1,/,1X,I4)
      END

C***********************************************************************
C       Chapter 5 in documentation
      SUBROUTINE CRPRDJ(ISCR)
C***********************************************************************
C       Author: C.A. van Diepen
C j   This subroutine has been changed by Jeroen van Velzen
C***********************************************************************
C       This routine reads crop data from file CROP41.DAT.
C       Subroutines and functions called: SKIP, TABRD.
C       Called by program WMAIN4J

C 5.1 ************* COMMON blocks
      IMPLICIT REAL(A-H,J-Z)
      IMPLICIT INTEGER(I)

C     PLANT DATA BLOCK
      INTEGER CROPT,DSL,AIRDUC
      COMMON /PLANT/CROPT,DSL,AIRDUC,SPAN,TBASE,RDMCR,DLO,DLC,EFF
      COMMON /PLANT/CFET,DEPNR
      COMMON /PLANT/TDWIL,RDI,DVRC1,DVRC2,RRI,KDIF,CVL,CVO,CVR,CVS
      COMMON /PLANT/SPA,SSA,Q10,RML,RMO,RMR,RMS,PERDL,PERRT,PERST
      COMMON /PLANT/FRTB(30),FLTB(30),FSTB(30),FOTB(30),SLATB(30)
      COMMON /PLANT/DVRETB(30),AMAXTB(30),TMPFTB(30),TMNFTB(30)

C     PLANT NUTRIENT AND SOIL FERTILITY DATA BLOCK
      COMMON /NUTRI/NBASE,PBASE,KBASE,NREC,PREC,KREC
      COMMON /NUTRI/NMINSO,NMINVE,NMAXSO,NMAXVE
      COMMON /NUTRI/PMINSO,PMINVE,PMAXSO,PMAXVE
      COMMON /NUTRI/KMINSO,KMINVE,KMAXSO,KMAXVE,YZERO,NFIX

C 5.2 ************* declarations
      INTEGER L1,L2,L3,L4,L5,L6,L7,L8,L9


C 5.4 ************* reading from file
```

```
      READ (8,2000,ERR=9991) CRPNAM
      ILINE = 2
      READ (8,2010,ERR=9992) CROPT,DSL,AIRDUC,SPAN,TBASE,RDMCR,DLO,
     S     DLC,EFF,CFET,DEPNR
      ILINE = 3
      READ (8,2020,ERR=9992) TDWIL,RDI,DVRC1,DVRC2,RRI,KDIF,
     S     CVL,CVO,CVR,CVS
      ILINE = 4
      READ (8,2020,ERR=9992) SPA,SSA,Q10,RML,RMO,RMR,RMS,
     S     PERDL,PERRT,PERST
      ILINE = 5
      READ (8,2035,ERR=9992)
     S              NMINSO,NMINVE,NMAXSO,NMAXVE,
     S              PMINSO,PMINVE,PMAXSO,PMAXVE,
     S              KMINSO,KMINVE,KMAXSO,KMAXVE,YZERO,NFIX
      ILINE = 7
      READ (8,2040,ERR=9992) L1,L2,L3,L4,L5,L6,L7,L8,L9
      CALL TABRD (8,ISCR,ICROP,CRPNAM,8,3,L1,FRTB)
      CALL TABRD (8,ISCR,ICROP,CRPNAM,11,3,L2,FLTB)
      CALL TABRD (8,ISCR,ICROP,CRPNAM,14,3,L3,FSTB)
      CALL TABRD (8,ISCR,ICROP,CRPNAM,17,2,L4,FOTB)
      CALL TABRD (8,ISCR,ICROP,CRPNAM,19,2,L5,SLATB)
      CALL TABRD (8,ISCR,ICROP,CRPNAM,21,2,L6,DVRETB)
      CALL TABRD (8,ISCR,ICROP,CRPNAM,23,2,L7,AMAXTB)
      CALL TABRD (8,ISCR,ICROP,CRPNAM,25,2,L8,TMPFTB)
      CALL TABRD (8,ISCR,ICROP,CRPNAM,27,1,L9,TMNFTB)
      REWIND 8
      WRITE (ISCR,1003)
      READ (ISCR,2050) TDWIL
      IF(TDWIL.LE.0) TDWIL = 1000
      RETURN

C 5.5 ************* error messages
9991    WRITE (ISCR,1001) ICROP,ILINE
      GOTO 9999
9992    WRITE (ISCR,1002) ICROP,CRPNAM,ILINE
9999    STOP

C 5.6 ************* format statements
1001    FORMAT(' Reading error in SUBROUTINE CROPRD for crop :',I3,
     S             ' line nr.',I2)
1002    FORMAT(' Reading error in SUBROUTINE CROPRD for crop :',I3,
     S              /,1X,30A1,' line nr.',I2)
1003    FORMAT(/' What is the initial total dry weight of leaves ?')
2000    FORMAT(30A1)
2010    FORMAT(3I2,F8.0,7F7.0)
2020    FORMAT(10F7.0)
2035    FORMAT(8F7.0,/,6F7.0)
2040    FORMAT(9I3)
2050    FORMAT(F7.0)
      END

C************************************************************************
C       Chapter 6 in documentation
      SUBROUTINE CLMRDJ(ISCR)
C************************************************************************
C       Author: C. Rappoldt
C j   This subroutine has been changed by Jeroen van Velzen
```

```
C***********************************************************************
C       This routine reads weather data from file CLIM41.DAT.
C       Called by program WMAIN4J.

C 6.1 ************* COMMON block
      IMPLICIT REAL(A-H,J-Z)
      IMPLICIT INTEGER(I)

C     CLIMATE DATA BLOCK
      COMMON /CLMT/ELEV,GEOP,A,B
      COMMON /CLMT/AVRADJ(366),TMINJ(366),TMAXJ(366),VAPPJ(366)
      COMMON /CLMT/RAINJ(366),WINDJ(366),SSHJ(366)


C 6.4 ************* reading from file
C j     The data which are not used are called NEPJ
C j     SSH = hours of sunshine

      READ (10,2000,ERR=999) ELEV,GEOP,A,B
      DO 20 I=1,365
      READ (10,2010,ERR=999) NEPJ,NEPJ2,NEPJ3,NEPJ4,NEP5,
     $      AVRADJ(I),TMINJ(I),TMAXJ(I),VAPP1,VAPP2,
     $      VAPP3,RAINJ(I),WINDJ(I),SSHJ(I)
C j     VAPPJ = mean value of VAPP1, VAPP2 en VAPP3
      VAPPJ(I) = (VAPP1+VAPP2+VAPP3)/3
C j   The radiation is in cal/cm²/d and have to be in MJ/m²/d
      AVRADJ(I) = 0.042*AVRADJ(I)
20      CONTINUE
      RETURN

C 6.6 ************* error message
999     WRITE (ISCR,1000)
      STOP

C 6.7 ************* format statements
1000    FORMAT(' CANNOT READ DATA FOR CLIMATE')
2000    FORMAT(2F7.2,F5.4,F7.5)
2010  FORMAT(F2.0,F6.0,3F3.0,F7.0,F6.0,8F6.1)
      END

C***********************************************************************
C       Chapter 7 in documentation
      SUBROUTINE INTRPJ(IDAY,DAYL,TMIN,TMAX,AVRAD,VAPOUR,WIND,RAIN,ISCR)
C***********************************************************************
C       Author: Jeroen van Velzen
C***********************************************************************
C       This routine is based on INTERP (C. Rappoldt) and is used
C       instead. tHe values are read in the subroutine CLMRDJ and are
c     checked on missing values.
C       Called by routine APPLEJ.

C 7.1 ************* COMMON block
      IMPLICIT REAL(A-H,J-Z)
      IMPLICIT INTEGER(I)

C     CLIMATE DATA BLOCK
      COMMON /CLMT/ELEV,GEOP,A,B
      COMMON /CLMT/AVRADJ(366),TMINJ(366),TMAXJ(366),VAPPJ(366)
```

```
      COMMON /CLMT/WINDJ(366),RAINJ(366),SSHJ(366)

C 7.2 ******* fill in missing values
      IF (TMINJ(IDAY).GE.0) GOTO 20
      ITEL = 0
      IL = 0
      IH = 0
12      IL = IL + 1
      ITEL = ITEL + 1
      IF (ITEL.GE.366) GOTO 120
      IF (IL.EQ.IDAY) IL = IL - 365
      IF (TMINJ(IDAY-IL).GE.0) GOTO 15
      GOTO 12
15      IH = IH + 1
      IF ((IH+IDAY).GE.366) IH = IH - 365
      IF (TMINJ(IDAY+IH).GE.0) GOTO 18
      GOTO 15
18      TMINJ(IDAY) = (TMINJ(IDAY-IL)+TMINJ(IDAY+IH))/2
20      TMIN = TMINJ(IDAY)

      IF (TMAXJ(IDAY).GE.0) GOTO 30
      ITEL = 0
      IL = 0
      IH = 0
22      IL = IL + 1
      ITEL = ITEL + 1
      IF (ITEL.GE.366) GOTO 130
      IF (IL.EQ.IDAY) IL = IL - 365
      IF (TMAXJ(IDAY-IL).GE.0) GOTO 25
      GOTO 22
25      IH = IH + 1
      IF ((IH+IDAY).GE.366) IH = IH - 365
      IF (TMAXJ(IDAY+IH).GE.0) GOTO 28
      GOTO 25
28      TMAXJ(IDAY) = (TMAXJ(IDAY-IL)+TMAXJ(IDAY+IH))/2
30      TMAX = TMAXJ(IDAY)

      IF (AVRADJ(IDAY).GE.0) GOTO 40
      ITEL = 0
      IL = 0
      IH = 0
32      IL = IL + 1
      ITEL = ITEL + 1
      IF (ITEL.GE.3) GOTO 140
c       IS EIGENLIJK GE.366
      IF (IL.EQ.IDAY) IL = IL - 365
      IF (AVRADJ(IDAY-IL).GE.0) GOTO 35
      GOTO 32
35      IH = IH + 1
      IF ((IH+IDAY).GE.366) IH = IH - 365
      IF (AVRADJ(IDAY+IH).GE.0) GOTO 38
      GOTO 35
38      AVRADJ(IDAY) = (AVRADJ(IDAY-IL)+AVRADJ(IDAY+IH))/2
40      AVRAD = AVRADJ(IDAY)


C j     when one of the vapp* values is -99 vappj < 0
      IF (VAPPJ(IDAY).GE.0) GOTO 50
```

```
      ITEL = 0
      IL = 0
      IH = 0
42      IL = IL + 1
      ITEL = ITEL + 1
      IF (ITEL.GE.366) GOTO 150
      IF (IL.EQ.IDAY) IL = IL - 365
      IF (VAPPJ(IDAY-IL).GE.0) GOTO 45
      GOTO 42
45      IH = IH + 1
      IF ((IH+IDAY).GE.366) IH = IH - 365
      IF (VAPPJ(IDAY+IH).GE.0) GOTO 48
      GOTO 45
48      VAPPJ(IDAY) = (VAPPJ(IDAY-IL)+VAPPJ(IDAY+IH))/2
50      VAPOUR = VAPPJ(IDAY)

      IF (WINDJ(IDAY).GE.0) GOTO 60
      ITEL = 0
      IL = 0
      IH = 0
52      IL = IL + 1
      ITEL = ITEL + 1
      IF (ITEL.GE.366) GOTO 160
      IF (IL.EQ.IDAY) IL = IL - 365
      IF (WINDJ(IDAY-IL).GE.0) GOTO 55
      GOTO 52
55      IH = IH + 1
      IF((IH+IDAY).GE.366) IH = IH - 365
      IF (WINDJ(IDAY+IH).GE.0) GOTO 58
      GOTO 55
58      WINDJ(IDAY) = (WINDJ(IDAY-IL)+WINDJ(IDAY+IH))/2
60      WIND = WINDJ(IDAY)

      IF(RAINJ(IDAY).GE.0) GOTO 70
      ITEL = 0
      IL = 0
      IH = 0
62      IL = IL + 1
      IF (ITEL.GE.366) GOTO 170
      IF (IL.EQ.IDAY) IL = IL - 365
      IF (RAINJ(IDAY-IL).GE.0) GOTO 65
      GOTO 62
65      IH = IH + 1
      IF((IH+IDAY).GE.366) IH = IH - 365
      IF (RAINJ(IDAY+IH).GE.0) GOTO 68
      GOTO 65
68      RAINJ(IDAY) = (RAINJ(IDAY-IL)+RAINJ(IDAY+IH))/2
70      RAIN = RAINJ(IDAY)

C 7.3 ******** when there are no dat at all

      GOTO 200
120     TMINJ(IDAY) = 15.0
      WRITE(ISCR,1000)
      GOTO 20
130     TMAXJ(IDAY) = 28.0
      WRITE(ISCR,1000)
      GOTO 30
```

```
140     IF(SSHJ(IDAY).GE.0) GOTO 149
      IL = 0
      IH = 0
      ITEL = 0
142     IL = IL + 1
      ITEL = ITEL + 1
      IF (ITEL.GE.366) GOTO 180
      IF (IL.GE.IDAY) IL = IL - 365
      IF (SSHJ(IDAY-IL).GE.0) GOTO 145
      GOTO 142
145     IH = IH + 1
      IF ((IH+IDAY).GE.366) IH = IH - 365
      IF (SSHJ(IDAY).GE.0) GOTO 148
      GOTO 145
148     SSHJ(IDAY) = (SSHJ(IDAY-IL)+SSHJ(IDAY+IH))/2
      IF (A.LE.0) GOTO 180
      IF (B.LE.0) GOTO 180
C j   AVRADJ(IDAY) = (A + B SSHJ(IDAY)/DAYL) *
149     AVRADJ(IDAY) = 16
      WRITE(ISCR,1000)
      GOTO 40
150     VAPPJ(IDAY) = 25.0
      WRITE(ISCR,1000)
      GOTO 50
160     WINDJ(IDAY) = 5.0
      WRITE(ISCR,1000)
      GOTO 60
170     RAINJ(IDAY) = 1.0
      WRITE(ISCR,1000)
      GOTO 70
180         AVRADJ(IDAY) = 16
      WRITE(ISCR,1000)
      GOTO 149
200     CONTINUE

      RETURN

C 7.4 **** Format statments
1000    FORMAT('  WARNING: There is a lack of climate data')

      END

C***********************************************************************
C       Chapter 11 in documentation
      SUBROUTINE TOTASJ(DVS,IDAY,ID,ISPEED,DAYL,AMAX,EFF,LAI,KDIF,AVRAD,
     $                    SINLD,COSLD,DTGA)
C***********************************************************************
C        Author: D.W.G. van Kraalingen, 1986
C j      Changed by Jeroen van Velzen (1993) to describe bananas
C***********************************************************************
C       This routine calculates the daily total gross CO2 assimilation
C       (DTGA) by performing a Gaussian integration over time. At
C       three different times of the day, irradiance is computed and
C       used to calculate the instantaneous canopy assimilation,
C       whereafter integration takes place. More information on this
C       routine is given by Spitters et al. (1988).
C       Subroutines and functions called: ASSIM, RADIAJ.
C       Called by routine APPLEJ.
```

```
C 11.1 ************* declarations
      IMPLICIT REAL(A-H,J-Z)
      IMPLICIT INTEGER(I)
      DIMENSION SINBT(3),PDIRT(3),PDIFT(3)
      DATA GAUSR/0.3872983/

C 11.2 ************* three-point Gaussian integration over day
      DTGA  = 0.
      IF(AMAX.EQ.0.) GOTO 20
      DO 10 I=1,3
      HOUR = 12.0+DAYL*0.5*(0.5+(I-2)*GAUSR)
C       at a specified hour, diffuse and direct irradiance is computed
      IF (MOD(ID,ISPEED) .EQ. 0) CALL RADIAJ(DVS,IDAY,HOUR,DAYL,SINLD,
     1                                COSLD,AVRAD,SINB,PARDIR,PARDIF)
      IF (MOD(ID,ISPEED) .EQ. 0) SINBT(I)=SINB
      IF (MOD(ID,ISPEED) .EQ. 0) PDIRT(I)=PARDIR
      IF (MOD(ID,ISPEED) .EQ. 0) PDIFT(I)=PARDIF
      SINB= SINBT(I)
      PARDIR= PDIRT(I)
      PARDIF= PDIFT(I)
C       irradiance and crop properties determine assimilation
      CALL ASSIM (AMAX,EFF,LAI,KDIF,SINB,PARDIR,PARDIF,FGROS)
      IF(I.EQ.2) FGROS=FGROS*1.6
      DTGA = DTGA+FGROS
10      CONTINUE
      DTGA  =DTGA*DAYL/3.6
20      RETURN
      END

C***********************************************************************
C        Chapter 12 in documentation
      SUBROUTINE RADIAJ(DVS,IDAY,HOUR,DAYL,SINLD,COSLD,AVRAD,SINB,
     $                  PARDIR,PARDIF)
C***********************************************************************
C         Author: D.W.G. van Kraalingen, 1986
C J   changed by Jeroen van Velzen (1992), to describe bananas
C***********************************************************************
C        This routine calculates the fluxes of diffuse and direct
C        photosynthetically active radiation from the total daily
C        shortwave radiation actually received (AVRAD) for a given
C        day of the year and hour of the day. The input variables
C        DAYL, SINLD and COSLD are calculated in routine ASTRO. More
C        information on this routine is given by Spitters et al. (1988).
C        Subroutines and functions called: none.
C        Called by routine TOTASJ.

C 12.1 ************* declarations
      IMPLICIT REAL(A-H,J-Z)
      IMPLICIT INTEGER(I)
C j      FRERA = fraction of radiation available for the plant depending of
DVS
      DIMENSION FRERA(10)
      DATA FRERA/0.7,0.45, 0.9,0.75, 1.15,0.95, 1.25,1.0, 2.0,1.0/
      DATA PI/3.1415926/

C 12.2 ************* calculations on solar elevation
C       sine of solar elevation SINB
      AOB    = SINLD/COSLD
```

```
      SINB   = AMAX1(0.,SINLD+COSLD*COS(2.*PI*(HOUR+12.)/24.))
C       integral of SINB
      DSINB  = 3600.*(DAYL*SINLD+24.*COSLD*SQRT(1.-AOB*AOB)/PI)
C       integral of SINB, corrected for lower atmospheric transmission
C       at low solar elevations
      DSINBE = 3600.*(DAYL*(SINLD+0.4*(SINLD*SINLD+COSLD*COSLD*0.5))+
     $         12.0*COSLD*(2.0+3.0*0.4*SINLD)*SQRT(1.-AOB*AOB)/PI)

C 12.3 ************* solar constant and daily extraterrestrial radiation
      SC     = 1370.*(1.+0.033*COS(2.*PI*IDAY/365.))
      DSO    = SC*DSINB

C 12.4 ************* diffuse light fraction from atmospheric transmission
      ATMTR  = AVRAD/DSO
      IF(ATMTR.GT.0.75) FRDIF = 0.23
      IF(ATMTR.LE.0.75.AND.ATMTR.GT.0.35) FRDIF = 1.33-1.46*ATMTR
      IF(ATMTR.LE.0.35.AND.ATMTR.GT.0.07)
     $                       FRDIF = 1.-2.3*(ATMTR-0.07)**2
      IF(ATMTR.LE.0.07) FRDIF = 1.

C 12.5 *********** photosynthetically active radiation, diffuse and direct
      PAR    = 0.5*AVRAD*SINB*(1.+0.4*SINB)/DSINBE
C j   available part of the radiation = PARA
      PARA = PAR *AFGEN(FRERA,DVS)
      PARDIF = AMIN1(PARA,SINB*FRDIF*ATMTR*0.5*SC)
      PARDIR = PARA-PARDIF
      RETURN
      END
```

APPENDIX II

Crop41.dat, the data file as used.

```
 Bananas
  3 0 0     125.     10.  100.0     1.0      0.    0.33   1.00     1.0
  1800.0  100.0 0.0083 0.0083     0.0  0.700  0.680  0.680  0.680  0.680
  0.0000 0.0010     2.0  0.025  0.010  0.000  0.012  0.030  0.100  0.000
  0.0070 0.0025 0.0100 0.0035 0.0008 0.0080 0.0012 0.0003
  0.0200 0.0250 0.0400 0.0453      0.   0.00
   8 10 12 10 10 12  6 10  4
     0.00    0.00    0.01    0.00    1.10    0.00    2.00    0.00
     -.--
     -.--
     0.00    1.00    0.80    1.00    1.00    0.60    1.10    0.15    2.00    0.00
     -.--
     -.--
     0.00    0.00    1.00    0.40    1.10    0.40    1.20    0.40    1.25    0.40
     2.00    0.40
     -.--
     0.00    0.00    0.80    0.00    1.00    0.00    1.10    0.45    2.00    0.60
     -.--
     0.00  0.0025    0.25  0.0025    0.50  0.0025    0.75  0.0025    2.00  0.0025
     -.--
    15.00    0.00   19.00    0.65   26.00    1.00   33.00    0.90   35.00    0.70
    40.00    0.00
     0.00   40.00    1.00   40.00    2.00   40.00
     -.--
     0.00    0.00   10.00    0.50   20.00    0.80   28.00    1.00   40.00    0.50

     -.--
     0.00    0.00    3.00    1.00
```

APPENDIX III

The simulation results for plants which are initialized at three different days at Cobal, where the weather is assumed to be as in 1976.

The described variables are: Day = julian date, ID = days after initiation, WLV = biomass of the leaves, pseudostem and rhizome (kg ha^{-1}), WSU = biomass of the suckers (kg ha^{-1}), WSO = biomass of the storage organs (kg ha^{-1}), LAI = leaf area index (m^2 m^{-2}), DVS = development stage, RD = root depth (cm), T = actual transpiration rate (cm d^{-1}), GASS = actual gross assimulation rate of the canopy, expressed in carbohydrates (kg ha^{-1} d^{-1}), MRES = maintenance respiration rate depending on average are temperature (kg ha^{-1} d^{-1}), DMI = rate of dry-matter increase of the crop (kg ha^{-1} d^{-1}), TAGP = Total above-ground dry weight of dead and living plant organs (kg ha^{-1}), TWRT = total dry weight of roots (dead and living) (kg ha^{-1}), TWLV = total dry weight of leaves, pseudostem and rhizome (kg ha^{-1}), TWSU = total dry weight of the suckers (kg ha^{-1}), total dry weight of the storage organs (kg ha^{-1}), GASST = total gross assimilation,in carbohydrates (kg ha^{-1}), MREST = total maintenance respiration (kg ha^{-1}), HINDEX = harvest index (kg kg^{-1}), TRC = transpiration coefficient (kg kg^{-1}), WUSE = total transpiration during crop growth (cm).

POTENTIAL CROP PRODUCTION Start day: 1th January

Y	ID	WLV	WSU	WSO	LAI	DVS	RD	T	GASS	MRES	DMI	TAGP
1	0	1800.	0.	0.	4.50	.80	100.	.19	153.6	46.2	73.1	1800.
1	10	2195.	226.	0.	5.71	.83	100.	.28	173.9	60.2	77.4	2494.
1	20	2366.	391.	0.	6.31	.88	100.	.43	242.9	71.6	116.4	3056.
1	30	2601.	714.	0.	7.22	.93	100.	.31	212.8	87.5	85.2	3977.
1	40	2610.	1104.	0.	7.63	.98	100.	.18	25.5	25.5	.0	4877.
8	47	2491.	1342.	0.	7.57	1.00	100.	.48	286.1	88.6	134.3	5333.
1	50	2503.	1548.	12.	7.81	1.02	100.	.50	284.3	93.5	129.7	5716.
1	60	2358.	2128.	208.	8.02	1.06	100.	.48	293.6	96.1	134.3	6904.
1	70	2094.	2748.	759.	7.98	1.12	100.	.48	300.8	117.7	124.5	8324.
1	80	1793.	3149.	1191.	7.63	1.17	100.	.51	324.7	118.7	140.1	9267.
1	90	1604.	3754.	1862.	7.76	1.23	100.	[illegible]	[illegible]46.4	130.2	147.0	10707.
1	100	1413.	4224.	2407.	7.76	1.30	100.	.22	191.1	133.2	39.3	11851.
1	110	1251.	4692.	2968.	7.82	1.37	100.	.26	269.5	136.8	90.3	12999.
1	120	1075.	5000.	3347.	7.69	1.44	100.	.40	319.5	138.8	109.3	13758.
1	130	941.	5357.	3799.	7.71	1.51	100.	.36	296.4	152.8	97.6	14639.
41	140	817.	5677.	4216.	7.72	1.59	100.	.27	267.6	166.7	68.7	15435.
51	150	707.	5990.	4635.	7.76	1.67	100.	.28	286.6	169.6	79.6	16214.
61	160	601.	6263.	5007.	7.77	1.74	100.	.27	265.1	177.6	59.5	16891.
71	170	511.	6582.	5455.	7.86	1.82	100.	.40	314.6	194.0	82.0	17687.
81	180	421.	6765.	5717.	7.82	1.89	100.	.39	313.2	190.3	83.5	18143.
1	190	346.	7052.	6140.	7.92	1.97	100.	.14	175.1	169.2	4.0	18862.

TENTIAL CROP PRODUCTION Start day 120

Y	ID	WLV	WSU	WSO	LAI	DVS	RD	T	GASS	MRES	DMI	TAGP
0	0	1800.	0.	0.	4.50	.80	100.	.15	78.3	51.5	18.2	1800.
0	10	2380.	97.	0.	6.05	.87	100.	.48	248.4	86.9	109.8	2567.
0	20	2706.	303.	0.	7.07	.95	100.	.50	315.6	105.0	143.2	3433.
9	28	2801.	595.	0.	7.60	1.01	100.	.26	230.0	103.6	85.9	4222.
0	30	2785.	668.	8.	7.63	1.02	100.	.50	334.0	108.5	153.4	4399.
0	40	2576.	1082.	242.	7.52	1.10	100.	.41	295.2	110.9	125.3	5404.
0	50	2291.	1564.	784.	7.29	1.18	100.	.42	313.1	118.4	132.4	6595.
0	60	2038.	1954.	1233.	7.05	1.25	100.	.13	180.9	97.5	56.8	7556.
0	70	1855.	2391.	1754.	7.03	1.32	100.	.55	357.5	135.6	150.9	8638.
0	80	1685.	2849.	2310.	7.06	1.40	100.	.19	230.1	110.5	81.3	9766.
0	90	1484.	3093.	2608.	6.80	1.45	100.	.13	190.5	112.5	53.0	10359.
0	100	1320.	3267.	2826.	6.57	1.51	100.	.43	319.8	131.5	128.1	10785.
0	110	1204.	3570.	3215.	6.58	1.57	100.	.38	321.4	134.4	127.1	11531.
0	120	1116.	4053.	3854.	6.84	1.64	100.	.13	181.1	119.9	41.6	12728.
0	130	995.	4345.	4250.	6.83	1.71	100.	.28	272.0	145.7	85.9	13454.
0	140	876.	4546.	4526.	6.74	1.77	100.	.15	190.1	138.2	35.3	13949.
0	150	780.	4864.	4974.	6.81	1.84	100.	.28	294.4	152.5	96.4	14740.
0	160	685.	5196.	5454.	6.91	1.92	100.	.53	358.9	182.0	120.3	15568.
0	170	591.	5424.	5791.	6.90	1.99	100.	.25	243.3	166.4	52.3	16139.
2	172	573.	5485.	5881.	6.92	2.01	100.	.30	284.5	174.1	75.0	16289.

ITENTIAL CROP PRODUCTION Start day 244

Y	ID	WLV	WSU	WSO	LAI	DVS	RD	T	GASS	MRES	DMI	TAGP
14	0	1800.	0.	0.	4.50	.80	100.	.35	211.0	61.0	102.0	1800.
4	10	2271.	95.	0.	5.77	.86	100.	.18	166.8	68.6	66.8	2445.
4	20	2560.	281.	0.	6.68	.93	100.	.20	184.4	83.5	68.6	3154.
4	30	2700.	617.	0.	7.37	1.00	100.	.39	281.9	102.6	121.9	4041.
5	31	2724.	666.	0.	7.48	1.01	100.	.33	275.0	105.0	115.6	4163.
4	40	2633.	1055.	155.	7.64	1.08	100.	.21	202.7	103.6	67.4	5111.
4	50	2318.	1426.	551.	7.22	1.15	100.	.26	247.7	104.6	97.3	6023.
4	60	2080.	1838.	1019.	7.04	1.22	100.	.25	259.8	108.3	103.0	7033.
4	70	1840.	2080.	1297.	6.68	1.27	100.	.14	50.7	50.7	.0	7619.
4	80	1703.	2492.	1783.	6.75	1.33	100.	.31	269.5	123.0	99.6	8624.
4	90	1564.	2874.	2251.	6.78	1.41	100.	.10	181.7	108.1	50.0	9570.
4	100	1419.	3243.	2705.	6.79	1.47	100.	.14	178.6	106.3	49.2	10467.
4	110	1276.	3504.	3035.	6.69	1.54	100.	.32	254.7	114.6	95.3	11104.
4	120	1158.	3903.	3542.	6.80	1.59	100.	.27	249.0	112.2	93.0	12065.
9	130	1036.	4251.	3986.	6.84	1.62	100.	.09	179.1	102.5	52.1	12896.
9	140	913.	4461.	4257.	6.74	1.66	100.	.24	195.9	116.0	54.3	13400.
9	150	822.	4822.	4738.	6.88	1.71	100.	.38	297.9	135.9	110.1	14281.
9	160	730.	5171.	5212.	7.00	1.76	100.	.29	231.8	142.0	61.0	15133.
9	170	640.	5429.	5569.	7.03	1.80	100.	.47	315.3	141.9	117.9	15766.
9	180	563.	5869.	6186.	7.28	1.85	100.	.25	225.3	157.6	46.0	16848.
9	190	484.	6287.	6786.	7.50	1.90	100.	.44	328.5	171.8	106.6	17883.

APPENDIX IV

The yearly avarage weather data per plantations used in the multiple regression. The yield is described in 1000 boxes of 18.14 kg per hectare per year.
The plantations Carmen (10), La Estrella (11), Bananera Monte Blaco (12), La Laureles (13) and Tropico (14) are assumped to have the weather conditions as described by the weather station Carmen. The plantations Los Diamantos (30) is assumed to have the weather conditions of the weather station Los diamantos. The plantation Coopebataan R.L. (43) is assumped to have the weather conditions as described by the weather station Lola. The plantations Mola (60), Perdiz (61), Bananera Toruguero (62), Bananera Fromosa (63), San Alberto (65) and Productora Tropical (66) are assumped to have the weather conditions as described by the weather station Mola.

year	tmin	tmax	rain	hour sun	planta.	yield/ha
84	20.67	30.68	8.99	4.40	10	2.61
85	20.13	30.75	7.70	4.85	10	2.76
86	21.35	30.61	9.72	4.47	10	2.80
87	21.97	30.96	9.73	3.99	10	2.82
88	22.09	30.90	9.84	4.77	10	2.58
89	21.60	30.62	8.81	4.68	10	2.93
90	22.14	30.96	12.07	4.58	10	2.76
91	21.54	30.78	11.17	4.28	10	2.63
83	21.32	31.18	9.20	4.10	11	2.98
84	20.67	30.68	8.99	4.40	11	2.88
85	20.13	30.75	7.70	4.85	11	3.42
86	21.35	30.61	9.72	4.47	11	2.98
87	21.97	30.96	9.73	3.99	11	2.71
88	22.09	30.90	9.84	4.77	11	3.20
89	21.60	30.62	8.81	4.68	11	3.55
90	22.14	30.96	12.07	4.58	11	3.72
91	21.54	30.78	11.17	4.28	11	3.16
83	21.32	31.18	9.20	4.10	12	2.82
84	20.67	30.68	8.99	4.40	12	2.79
85	20.13	30.75	7.70	4.85	12	3.31
86	21.35	30.61	9.72	4.47	12	2.92
87	21.97	30.96	9.73	3.99	12	2.77
88	22.09	30.90	9.84	4.77	12	3.01
89	21.60	30.62	8.81	4.68	12	3.30
90	22.14	30.96	12.07	4.58	12	2.91
91	21.54	30.78	11.17	4.28	12	3.03
85	20.13	30.75	7.70	4.85	13	3.66
86	21.35	30.61	9.72	4.47	13	2.98
87	21.97	30.96	9.73	3.99	13	2.91
88	22.09	30.90	9.84	4.77	13	3.09
89	21.60	30.62	8.81	4.68	13	3.31
90	22.14	30.96	12.07	4.58	13	3.07
91	21.54	30.78	11.17	4.28	13	2.85
85	20.13	30.75	7.70	4.85	14	3.91
86	21.35	30.61	9.72	4.47	14	3.20
87	21.97	30.96	9.73	3.99	14	2.91
88	22.09	30.90	9.84	4.77	14	3.15
89	21.60	30.62	8.81	4.68	14	3.48
90	22.14	30.96	12.07	4.58	14	3.41

91	21.54	30.78	11.17	4.28	14	2.89
77	19.35	29.00	11.61	4.55	30	1.75
78	19.82	29.06	13.49	4.56	30	1.70
79	20.24	29.02	11.44	4.24	30	1.87
80	20.56	28.48	12.18	4.28	30	1.42
81	20.44	28.45	15.46	4.07	30	1.47
82	20.14	28.80	12.28	4.41	30	1.48
83	20.83	29.08	11.78	3.77	30	1.50
84	19.79	28.37	11.03	3.48	30	1.41
85	19.57	28.23	9.41	3.87	30	1.34
86	19.94	27.99	10.74	3.49	30	1.48
87	20.81	28.48	11.63	3.34	30	1.39
88	20.36	28.40	11.61	4.10	30	1.79
89	19.96	28.17	12.43	3.84	30	2.06
90	20.47	28.37	12.69	3.79	30	1.66
91	20.51	28.31	12.20	3.33	30	1.65
77	20.60	30.07	10.60	4.62	43	2.06
78	20.59	30.62	8.14	4.47	43	2.13
79	20.43	30.87	9.14	4.46	43	1.95
80	20.87	30.31	9.05	4.18	43	1.88
81	19.62	29.49	10.39	3.90	43	1.84
82	19.88	30.42	9.28	4.02	43	1.98
83	21.49	30.75	7.66	4.11	43	1.74
84	19.97	30.51	9.05	4.74	43	1.92
85	19.64	30.07	7.03	4.55	43	1.76
86	20.59	30.09	9.07	3.90	43	1.98
87	21.30	29.86	11.03	3.79	43	1.99
88	20.79	30.19	9.38	4.51	43	1.85
89	20.39	29.87	8.51	4.49	43	2.29
90	20.78	30.11	11.24	4.26	43	2.30
90	21.64	30.35	missing	4.50	61	2.50
91	22.01	30.31	missing	4.18	61	2.65
80	21.79	30.41	10.75	4.68	62	1.35
81	21.26	30.22	11.80	4.28	62	1.92
82	20.60	30.73	12.09	4.41	62	1.24
83	21.48	31.27	8.14	4.09	62	1.43
84	20.42	30.96	10.11	4.50	62	2.21
85	20.13	30.97	7.44	4.70	62	1.34
86	21.06	30.98	10.93	3.99	62	2.24
87	22.14	31.12	9.46	3.96	62	2.46
88	21.64	30.68	11.80	4.44	62	2.65
89	21.20	30.15	9.75	4.82	62	2.71
90	21.64	30.35	missing	4.50	62	2.48
91	22.01	30.31	missing	4.18	62	2.51
80	21.79	30.41	10.75	4.63	63	2.21
81	21.26	30.22	11.80	4.28	63	2.11
82	20.60	30.73	12.09	4.41	63	1.93
83	21.48	31.27	8.14	4.09	63	2.19
84	20.42	30.96	10.11	4.50	63	2.43
85	20.13	30.97	7.44	4.70	63	1.44
86	21.06	30.98	10.93	3.99	63	2.77
87	22.14	31.12	9.46	3.96	63	2.46
88	21.64	30.68	11.80	4.44	63	2.48
89	21.20	30.15	9.75	4.82	63	2.63
90	21.64	30.35	missing	4.50	63	2.46
91	22.01	30.31	missing	4.18	63	2.44
80	21.79	30.41	10.75	4.68	60	2.18
81	21.26	30.22	11.80	4.28	60	2.53

82	20.60	30.73	12.09	4.41	60	2.54
83	21.48	31.27	8.14	4.09	60	2.67
84	20.42	30.96	10.11	4.50	60	2.80
85	20.13	30.97	7.44	4.70	60	1.93
86	21.06	30.98	10.93	3.99	60	2.78
87	22.14	31.12	9.46	3.96	60	2.98
88	21.64	30.68	11.80	4.44	60	2.87
89	21.20	30.15	9.75	4.82	60	2.91
90	21.64	30.35	missing	4.50	60	2.63
91	22.01	30.31	missing	4.18	60	2.42
80	21.79	30.41	10.75	4.68	64	1.84
81	21.26	30.22	11.80	4.28	64	1.89
82	20.60	30.73	12.09	4.41	64	1.48
83	21.48	31.27	8.14	4.09	64	1.87
84	20.42	30.96	10.11	4.50	64	1.86
85	20.13	30.97	7.44	4.70	64	1.35
86	21.06	30.98	10.93	3.99	64	2.24
87	22.14	31.12	9.46	3.96	64	2.75
88	21.64	30.68	11.80	4.44	64	2.78
89	21.20	30.15	9.75	4.82	64	2.59
90	21.64	30.35	missing	4.50	64	2.55
91	22.01	30.31	missing	4.18	64	2.33
80	21.79	30.41	10.75	4.68	65	1.46
81	21.26	30.22	11.80	4.28	65	1.39
82	20.60	30.73	12.09	4.41	65	1.62
83	21.48	31.27	8.14	4.09	65	2.07
84	20.42	30.96	10.11	4.50	65	1.92
85	20.13	30.97	7.44	4.70	65	1.47
86	21.06	30.98	10.93	3.99	65	2.24
87	22.14	31.12	9.46	3.96	65	1.74
88	21.64	30.68	11.80	4.44	65	2.48
89	21.20	30.15	9.75	4.82	65	2.24
90	21.64	30.35	missing	4.50	65	1.96
91	22.01	30.31	missing	4.18	65	2.08
80	21.79	30.41	10.75	4.68	66	1.64
81	21.26	30.22	11.80	4.28	66	1.58
82	20.60	30.73	12.09	4.41	66	1.82
83	21.48	31.27	8.14	4.09	66	1.61
84	20.42	30.96	10.11	4.50	66	1.07
85	20.13	30.97	7.44	4.70	66	0.48
86	21.06	30.98	10.93	3.99	66	1.57
87	22.14	31.12	9.46	3.96	66	1.73
88	21.64	30.68	11.80	4.44	66	1.98
89	21.20	30.15	9.75	4.82	66	2.24
90	21.64	30.35	missing	4.50	66	2.35
91	22.01	30.31	missing	4.18	66	1.91

APPENDIX V

The program made in Genstat 5.0 to preform a multiple regression analysis of yield, year of production and enviromental conditions.

```
Genstat 5  Release 2.1  (Vax/VMS5)               9-NOV-1993 15:59:50.89
Copyright 1990, Lawes Agricultural Trust (Rothamsted Experimental Station)

   1  "multiple regression analyses of climate on yield"
   2  UNIT [NVALUES=140]
   3  "FACTOR [LEVELS = !(77,78,79,80,81,82,83.84,85,86,87,88,89,90,91)] YEAR"
   4  FACTOR [LEVELS = !(10.11,12,13,14,30.43,60,61,62,63,64,65,66)] FINCA
   5  OPEN 'total.dat'; CHANNEL = 2
   6  READ [CHANNEL = 2] YEAR,TMIN,TMAX,RAIN,SSH,FINCA,YIELD,SUR

    Identifier   Minimum     Mean   Maximum    Values   Missing
          YEAR     77.00    85.78     91.00       140         0
          TMIN     16.54    21.15     22.14       140         0   Skew
          TMAX     27.99    30.44     31.27       140         0
          RAIN      3.82    10.20     15.46       140        14
           SSH     3.330    4.356     5.590       140         0
         YIELD     1.070    2.303     3.720       140         0
           SUR     143.0    241.9     551.0       140         0   Skew
   7  CALC ITITA = TMIN*TMAX
   8  CALC ITIRA = TMIN*RAIN
   9  CALC ITISS = TMIN*SSH
  10  CALC ITARA = TMAX*RAIN
  11  CALC ITASS = TMAX*SSH
  12  CALC IRASS = RAIN*SSH
  13  MODEL YIELD
  14  TERMS YEAR,TMIN,TMAX,RAIN,SSH,ITITA,ITIRA,ITISS,ITARA,ITASS,IRASS
  15  FIT YEAR,TMIN,TMAX,RAIN,SSH,ITITA,ITIRA,ITISS,ITARA,ITASS,IRASS

15..........................................................................................

***** Regression Analysis *****

 Response variate: YIELD
     Fitted terms: Constant, YEAR, TMIN, TMAX, RAIN, SSH, ITITA, ITIRA, ITISS, ITARA, ITASS, IRASS


*** Summary of analysis ***

               d.f.        s.s.       m.s.     v.r.
Regression       11       26.66     2.4239    11.92
Residual        114       23.18     0.2034
Total           125       49.85     0.3988

Change          -11      -26.66     2.4239    11.92

Percentage variance accounted for 49.0
```

```
* MESSAGE: The following units have high leverage:
              39       0.330
              40       0.292
              43       0.512
              47       0.357
              48       0.272
              49       0.321
              53       0.257
              59       0.928
```

*** Estimates of regression coefficients ***

	estimate	s.e.	t
Constant	148.7	70.9	2.10
YEAR	0.0580	0.0156	3.72
TMIN	-9.01	3.73	-2.41
TMAX	-6.32	2.61	-2.42
RAIN	0.46	1.16	0.40
SSH	13.68	6.20	2.21
ITITA	0.324	0.114	2.83
ITIRA	-0.0585	0.0458	-1.28
ITISS	-0.001	0.233	0.00
ITARA	0.0933	0.0481	1.94
ITASS	-0.274	0.241	-1.13
IRASS	-0.474	0.177	-2.68

```
16  RSELECT [NUMBERBEST=10; CRITERION=cp;TOLERANCE = 0.01] \
17  !P(YEAR,TMIN,TMAX,RAIN,SSH,ITITA,ITIRA,ITISS,ITARA,ITASS,IRASS)
```

***** All Possible Subsets Regression *****

Response variate: YIELD

Free explanatory variables are coded by

1	YEAR
2	TMIN
3	TMAX
4	RAIN
5	SSH
6	ITITA
7	ITIRA
8	ITISS
9	ITARA
10	ITASS
11	IRASS

For each selected subset, the criteria, minimum tolerance and t-statistics of included variables are printed. t-statistics are truncated at 99.99 .

Subsets with 3 explanatory variables

R2	Adj	Cp	MinTol	1	2	3	4	5	6	7	8	9	10	11
49.06	47.81	6.66	0.8892	6.31	-	-	-	3.97	5.30	-	-	-	-	-
48.85	47.59	7.38	0.8309	6.37	-	-	-	-	4.42	-	-	-	3.89	-
48.55	47.29	8.11	0.6881	6.11	-	-	-	-	3.14	-	3.79	-	-	-

48.46	47.19	9.33	0.8615	6.08	4.29	-	-	-	-	-	-	-	5.26	-

Subsets with 4 explanatory variables

R2	Adj	Cp	MinTol	1	2	3	4	5	6	7	8	9	10	11
49.11	47.42	8.75	0.8868	6.27	-	-	-	3.95	5.29	-	-	-	-	-0.33
49.10	47.42	8.75	0.8651	6.29	-	-	-	3.66	5.26	-0.32	-	-	-	-
49.10	47.42	8.76	0.8758	6.28	-	-	-	3.71	5.28	-	-	-0.31	-	-
49.10	47.42	8.77	0.8887	6.29	-	-	-0.30	3.66	5.27	-	-	-	-	-
49.07	47.38	8.84	0.0460	6.22	-	-	-	1.11	2.63	-	-0.13	-	-	-
49.06	47.38	8.55	0.1356	6.18	-0.09	-	-	3.53	2.19	-	-	-	-	-

Subsets with tolerances less than 0.0100 have been encountered and omitted

Largest discrepancy observed for selection criterion is 0

18 FIT YEAR,TMIN,TMAX,RAIN,SSH

18..

***** Regression Analysis *****

Response variate: YIELD
Fitted terms: Constant, YEAR, TMIN, TMAX, RAIN, SSH

*** Summary of analysis ***

	d.f.	s.s.	m.s.	v.r.
Regression	5	24.43	4.8865	23.07
Residual	120	25.41	0.2118	
Total	125	49.85	0.3988	
Change	-5	-24.43	4.8865	23.07

Percentage variance accounted for 46.9

* MESSAGE: The following units have high leverage:

53	0.132
59	0.385

*** Estimates of regression coefficients ***

	estimate	s.e.	t
Constant	-14.24	2.11	-6.75
YEAR	0.0777	0.0129	6.03
TMIN	0.2087	0.0693	3.01
TMAX	0.1207	0.0758	1.59
RAIN	-0.0113	0.0325	-0.35
SSH	0.449	0.129	3.46

```
19 RSELECT [NUMBERBEST=10; CRITERION=cp;TOLERANCE = 0.01] \
20 !P(YEAR,TMIN,TMAX,RAIN,SSH)
```

***** All Possible Subsets Regression *****

Response variate: YIELD

For each selected subset, the criteria, minimum tolerance and t-statistics of included variables are printed. t-statistics are truncated at 99999.99.

Subsets with 2 explanatory variables

R2	Adj	Cp	MinTol	YEAR	TMIN	TMAX	RAIN	SSH
41.50	40.55	17.68	0.9871	7.16	-	5.14	-	-

Subsets with 3 explanatory variables

R2	Adj	Cp	MinTol	YEAR	TMIN	TMAX	RAIN	SSH
47.05	45.75	6.63	0.8526	5.99	4.73	-	-	4.86
44.55	43.18	12.52	0.8598	7.52	-	3.98	-	2.59
43.80	42.42	14.28	0.7242	5.99	2.23	3.90	-	-
41.70	40.27	19.21	0.7934	7.11	-	4.89	0.65	-

Subsets with 4 explanatory variables

R2	Adj	Cp	MinTol	YEAR	TMIN	TMAX	RAIN	SSH
48.96	47.28	4.12	0.6649	6.18	3.24	2.13	-	3.50
47.94	46.22	6.53	0.8156	5.85	4.95	-	-1.44	4.23
45.16	43.35	13.08	0.7402	7.49	-	4.13	1.16	2.76
43.92	42.06	16.00	0.5325	5.83	2.19	2.81	-0.51	-

Subsets with 5 explanatory variables

R2	Adj	Cp	MinTol	YEAR	TMIN	TMAX	RAIN	SSH
49.02	46.89	6.00	0.4715	6.03	3.01	1.59	-0.35	3.46

Largest discrepancy observed for selection criterion is 0

```
21 FIT TMIN,TMAX,RAIN,SSH,ITITA,ITIRA,ITISS,ITARA,ITASS,IRASS
```

21..

***** Regression Analysis *****

Response variate: YIELD
Fitted terms: Constant, TMIN, TMAX, RAIN, SSH, ITITA, ITIRA, ITISS, ITARA, ITASS, IRASS

*** Summary of analysis ***

	d.f.	s.s.	m.s.	v.r.
Regression	10	23.84	2.3843	10.54
Residual	115	26.00	0.2261	
Total	125	49.85	0.3988	
Change	-10	-23.84	2.3843	10.54

Percentage variance accounted for 43.3

* MESSAGE: The following units have high leverage:

39	0.309
40	0.290
43	0.512
47	0.356
48	0.271
49	0.321
53	0.265
59	0.925

*** Estimates of regression coefficients ***

	estimate	s.e.	t
Constant	242.4	69.9	3.47
TMIN	-13.11	3.76	-3.49
TMAX	-9.74	2.58	-3.78
RAIN	0.31	1.22	0.25
SSH	15.78	6.51	2.42
ITITA	0.462	0.114	4.04
ITIRA	-0.0797	0.0479	-1.66
ITISS	0.062	0.246	0.25
ITARA	0.1555	0.0476	3.27
ITASS	-0.287	0.255	-1.13
IRASS	-0.771	0.166	-4.64

```
22 RSELECT [NUMBERBEST=10; CRITERION=cp;TOLERANCE = 0.01] \
23 !P(TMIN,TMAX,RAIN,SSH,ITITA,ITIRA,ITISS,ITARA,ITASS,IRASS)
```

***** All Possible Subsets Regression *****

Response variate: YIELD

Free explanatory variables are coded by

1	TMIN
2	TMAX
3	RAIN
4	SSH
5	ITITA
6	ITIRA
7	ITISS
8	ITARA
9	ITASS
10	IRASS

For each selected subset, the criteria, minimum tolerance and t-statistics of included variables are printed. t-statistics are truncated at 999.99 .

Subsets with 3 explanatory variables

R2	Adj	Cp	MinTol	1	2	3	4	5	6	7	8	9	10
36.24	34.58	22.55	0.0591	-	-	-	-	-	-	8.02	5.05	-	-5.28
35.82	34.24	23.48	0.0324	-	-	4.95	-	-	-	7.10	-	-	-5.15
35.47	33.88	24.26	0.1181	-	-	-	-	-	4.87	8.13	-	-	-5.10

Subsets with 4 explanatory variables

R2	Adj	Cp	MinTol	1	2	3	4	5	6	7	8	9	10
37.49	35.42	21.80	0.0295	-	-1.55	-	-	-	-	5.86	4.70	-	-4.65
36.71	34.61	23.53	0.0290	-	1.30	4.51	-	-	-	5.66	-	-	-4.46
36.62	34.53	23.72	0.0123	-	-	3.95	-	-	-	6.70	-	1.24	-4.29
36.59	34.49	23.80	0.0141	-	-	-	-	-	0.80	7.28	1.46	-	-4.70
36.51	34.41	23.96	0.0546	-	-	-	-	-	-	5.86	3.92	-0.71	-4.54
36.26	34.15	24.52	0.0220	-	-	-	-0.17	-	-	6.34	2.58	-	-2.92
36.25	34.14	24.54	0.0171	0.09	-	-	-	-	-	3.61	2.32	-	-2.59

Subsets with tolerances less than 0.0100 have been encountered and omitted

Largest discrepancy observed for selection criterion is 0

24 STOP

******** End of job. Maximum of 27786 data units used at line 23 (153000 left)