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USERS GUIDE TO THE CRIES AGRO-ECONOMIC INFORMATION SYSTEM YIELD MODEL

(Version 1.0)

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COMPREHENSIVE RESOURCE INVENTORY AND EVALUATION SYSTEM (CRIES) PROJECT
MICHIGAN STATE UNIVERSITY

In Cooperation with the

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USER'S GUIDE TO THE CRIES AGRO-ECONOMIC INFORMATION SYSTEM - YIELD MODEL

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VERSION 1.0
For IBM-PC, Model XT/AT
(or compatible MSDOS configurations)

Comprehensive Resource Inventory
and Evaluation System (CRIES) Project,
Michigan State University

in Cooperation with the
U.S. Agency for International Development,

1987

USER'S GUIDE TO THE CRIES AGRO-ECONOMIC INFORMATION SYSTEM -YIELD MODEL - VERSION 1.0), 1987. By Ger Schultink, Nilson Amaral and Delbert Mokma. CRIES Project, Michigan State University, East Lansing, Michigan 48824-1222

ABSTRACT

This User's Guide documents the YIELD model - one of the major analytical software modules of the Agro-economic Information System (AIS) of the Comprehensive Resource Inventory and Evaluation System (CRIES) Resource Information System (RIS) - modified for IBM-Model XT or AT or compatible micro-computers using the MS-DOS operating system. YIELD provides the capability to predict yield for thirty food and export crops for user-selected locations and agro-ecological zones. The model may be linked with a national data base containing agro-climatic data to predict yield response for any location, or regional and national aggregates, thereof. If the data base is not established, the user is provided with a data management option facilitating data input and editing for selected locations. Data requirements include: location identification, temperature, precipitation, relative humidity, wind velocity, solar radiation, sowing dates, crop type, length of growing stages, soil texture, relevant water table characteristics on the root zone, and root growth over various growing stages. Optional model inputs include yield adjustments for soil salinity, soil moisture preservation techniques and general fertilizer availability. In combination with other CRIES-RIS modules and the established data base, the YIELD model provides the user with the analytical framework to evaluate physical and socio-economic attributes by location, and determine the comparative advantage of sites or zones for land use alternatives. Farming systems, representing land utilization types and their regional or national aggregates may also be evaluated with regards to their optimum performance characteristics and resulting socio-economic benefits derived under alternative land use and development policy scenarios.

DISCLAIMER

This document and/or portions of the software and data furnished herewith were developed with project funding from the U.S. Agency for International Development, the World Bank and the CRIES Project, Michigan State University. Although every effort has been made to make the described software as useful as possible given existing financial and time constraints, the CRIES Project and Michigan State University will not assume any responsibility for any damages, incurred or generated by the use of this software. Mention of any product, manufacturer, or supplier shall not, nor is intended to, imply approval, disapproval, or fitness for any particular use.

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CRIES - Agro-Economic Information System
Module: YIELD SIMULATOR
Version 1.00
Serial # MSU CRIES

Comprehensive Resource Inventory and Evaluation System (CRIES)
Michigan State University, East Lansing, MI 48824, USA

CRIES - AIS - YIELD User's Guide, Version 1.0, 1987.

PREFACE

The Comprehensive Resource Information and Evaluation System (CRIES) Project encompasses a systematic resource analysis approach to evaluate public and private benefits derived from alternative land use options and policy scenarios. Examples in the developing world include the creation of food self-sufficiency while meeting rural employment requirements or meeting balance of payment goals through the expansion and/or intensification of the production of food and cash crops, resulting in increased exports of agricultural commodities and import substitution.

This User's Guide is part of the CRIES Project's effort to develop, adapt, and document general procedures to inventory, classify and analyze current land use, its distribution, extent, and resource development potential. This work represents a cooperative effort of the CRIES Project and the US Agency for International Development (USAID) missions to Honduras, Jamaica, the Dominican Republic, the Philippines and Haiti. Additional support was received from the USAID Title XII Strengthening Grant, International Development and Food Assistance Act of 1975 and the World Bank.

CRIES has three general objectives:

a) to apply a consistent approach to land resource assessment which is adaptable to many countries and suitable for the transfer of appropriate agrotechnology;

b) to provide assistance in integrated surveys, development of a computer compatible resource data base and computer-aided analysis software suitable for the analysis of development options and policy evaluation; and

c) to provide the training and technical assistance necessary to develop indigenous capabilities to inventory and classify renewable resources, to assess crop production potential, and to systematically evaluate development alternatives and derived public and private benefits.

This evaluative framework is supported by computer-based software designed to systematically delineate agro-ecological production zones, representing areas with physical characteristics considered relatively homogeneous at the level of detail supported by the land evaluation. These zones can be related to existing land uses, associated farming systems and estimated crop production potential based on the land use alternatives and associated enterprises identified.

The difference between current land use and (limited constrained) resource production potential, expressed in crop yields or economic terms, such as "land rent" may be defined as "unrealized production potential". This latter indicator may be considered as a first approximation of the quantitative magnitude of development potential available to meet critical policy goals and objectives over a period of time.

Generally, this type of land evaluation has been associated with aggregate levels of analysis: the administrative district, region or nation. The CRIES Geographic Information System (GIS) described in other user documentation, stores data in a grid-based referencing system which permits the analysis of comparative advantage on a locational basis represented by the data cells composing the integrated spatial data base. This feature ensures that at all stages of analysis the spatial identity is incorporated in the final results and, therefore, reflected in the derived information content on which resource development recommendations and resulting land use policies are based. The location-specific dimension of the information also permits economic feasibility analyses for alternative projects varying in scope and magnitude.

The CRIES-AIS-YIELD model, represented here, was developed to provide agronomists, land use planners, resource managers and policy analysts with a low cost, micro computer-based analysis tool in resource assessment studies.

The YIELD model may be used in combination with other CRIES analysis software to link resource attributes (physical and socio-economic) with performances characteristics (private and public benefits derived). This quantitative assessment is derived from aggregate models incorporating crop requirements, water balance and yield estimators, and enterprise budgets derived f om farming system surveys, to determine socio-economic indicators (e.g., land rent) as a representation of comparative advantage from a public and/or private perspective.

This User's Guide documents the YIELD model - one of the major components of the Agro-economic Information System (AIS) of the Resource Information System (RIS) - of the Comprehensive Resource Inventory and Evaluation System (CRIES) as modified for MSDOS -based micro-computers. YIELD provides the capability to predict yields for a large number of food and export crops for user-selected locations and agro-ecological zones. Data requirements include: location identification, temperature, precipitation, relative humidity, wind velocity, solar radiation, sowing dates, crop type, length of growing stages, predominant soil texture and slope gradient, relevant moisture characteristics in the root zone, and root growth over various growing stages. Optional parameters include farm management/soil moisture preservation techniques and the utilization of salinity factors and general nutrient availability.

In combination with other CRIES-RIS modules and the established data base, the YIELD model provides the user with the analytical framework to evaluate physical and socio-economic attributes by location, and determine the comparative advantage of sites for selected land use alternatives. Farming systems, representing land use options and their regional or national aggregates may also be evaluated with regards to their optimum performance characteristics and resulting socio-economic benefits derived under alternative land use and development policy scenarios.

The microcomputer (MS-DOS) Version 1.0 requires only 256K of RAM, the standard 8088 or 80286 processors with floating point co-processors (8087 or 80285) and is menu-driven. A standard, 132-column or compressed format printer is required to generate the tabular output.

The YIELD model is adapted from "Yield Response to Water" by Doorenbos and Kassam (FAO, 1979). Some model validation was carried out for selected crops in Jamaica and the Dominican Republic for which localized yield were available. User input is solicited to aid in future model validation for additional commodities representing a great variety of agro-ecological conditions. Any additional suggestions and comments are welcome.

The major software development contribution to this version was provided by Nilson Amaral, with assistance from other CRIES staff. Delbert Mokma aided in the adjustment of moisture content values based on the slope gradient and texture characteristics. Scott Witter and others, including Dorothy Dunkley and Sashi Nair aided in selected crop model validation for selected crops in Jamaica and the Dominican Republic. Cheryl Lowe provided typing assistance.

The permission granted by the Food and Agricultural Organization of the United Nations (FAO) to reproduce selected tables and figures from " Yield Response to Water" (FAO, 1979), is gratefully acknowledged.

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1. INTRODUCTION TO THE CRIES- AIS - YIELD MODEL

The major objective of the CRIES Resource Information System (RIS) is to support the decision making and policy analysis process in resource development and management. This decision process involves primarily the allocation of scarce production factors by type and location to maximize private and public benefits derived from land use alternatives. Within this larger land evaluation framework, the CRIES - Geographic Information System (GIS) permits the assessment of physical resource attributes by location, while the Ago-economic Information System (AIS) permits the systematic analysis of quantitative performance characteristic in socio-economic terms, resulting from land use alternatives. The YIELD model, as described in this documentation, is one of the key components of the CRIES-RIS permitting quantitative assessment of production potential and anticipated revenues, via enterprise analysis.

1.1 Role and Linkages of the CRIES-RIS components in Resource Evaluation.

The CRIES resource inventory and analysis approach to integrated rural development planning and agricultural sector analysis can be illustrated by the following major components: the CRIES-GIS and the CRIES-AIS (Figure 1).

As indicated in the figure, the linkage between the GIS and AIS constitutes, in essence, the CRIES approach in resource inventory and evaluation. The specific interactions as represented involve a set of software modules used to systematically evaluate land use options given a complex set of physical and socio-economic data, resource management objectives, carrying capacity considerations, and policy concerns.

CRIES
Resource Information System (RIS)

consists of

CRIES Geographic Information System (GIS)	(and)	CRIES Agro-economic Information System (AIS)
CRIES - GIS: (handles data with an intrinsic spatial component) Information Unit: Grid Cell (e.g. 1, 4, 100 hectares)		CRIES - AIS: (handles data of an aggregate nature) Information Unit: Planning Unit (e.g. district, agro-eco. zone)
RESOURCE PRODUCTION BASE and PHYSICAL PRODUCTION POTENTIAL		PERFORMANCE DYNAMICS - BENEFITS/ ALTERNATIVE USE/INPUT SCENARIOS
data examples: soils, precipitation, temperature, bio-climatic zones, elevation, population density, administrative districts		data examples: crop requirements, availability and cost of inputs,food requirements, enterprise budgets
MAJOR SOFTWARE MODULES: * GIS-INPUT * GIS-STATISTICS * GIS-ANALYSIS * GIS-TERRAIN * GIS-DISPLAY * GIS-CHOROLINE * GIS-UTILITIES		MAJOR SOFTWARE MODULES: * AIS-WATBUG * AIS-YIELD * AIS-MULBUD 1) * AIS-ENTERPRI 1) * AIS-LINPROG 1) * AIS-MSTAT 2) * AIS-IN/OUT 3)

Notes: 1) Includes other non-CRIES Licenced software 2) MSU licenced Software. 3) Under development.

Figure 1. - Role and Linkage of Major Software Modules used in the CRIES Land Resource Assessment Approach for Integrated Rural Development Planning.

This manual provides the documentation necessary to use the AIS - YIELD module to assess comparative production potential for selected food and export crops by user defined location or agro-ecological zones.

The GIS permits the initial compilation and spatial analysis of physical resource attributes (e.g. soil and climate parameters) to permit a systematic assessment of the (unrealized) production potential of the resource base. Subsequently, this information can be linked with selected AIS modules (such as YIELD) to provide qualitative and quantitative estimates of the performance characteristics (derived socio-economic benefits) of single or multiple enterprise options for a specific location or an aggregate, thereof, such as a community and its surrounding supply area, i.e., a (sub)region, administrative district, national aggregates or even multi-national regions (e.g., Central America).

To provide users with an initial orientation toward the functions of the main GIS and AIS modules, the main menu of both systems is provided (Figures 2 and 3), containing short function descriptions.

1.2 Basic Operational Considerations in the CRIES-AIS-YIELD model.

One of the basic capabilities of a YIELD model is to calculate the maximum crop yield, based on the genetic potential of a standard crop. Local potential crop yield is predicted on an incremental basis during the major growing stages of the crop, based on yield response

CRIES - GEOGRAPHIC INFORMATION SYSTEM
(CRIES - GIS) - Version 6.00

MAIN MENU

PLEASE SELECT GIS MODULE :

[F1] GIS-INPUT	these phases are used for primary data entry
[F2] GIS-STATISTICS	these phases provide statistical summaries
[F3] GIS-ANALYSIS	these phases analyze and create raster files
[F4] GIS-TERRAIN	these phases support 3 - D modeling
[F5] GIS-DISPLAY	these phases display the contents of a raster file
[F6] GIS-CHOROLINE	these phases produce dot matrix printer maps
[F7] GIS-UTILITIES	these phases create, edit and reformat files

Figure 2. - Main Menu CRIES - Geographic Information System

to moisture availability determined by climate and soil variables, and plant requirements. Therefore, yield prediction levels may be calculated for point locations as defined from climate time series data or for the agro-ecological profiles present in the national data base. The user is provided with the option to evaluate crop response under "irrigated conditions" by increasing water availability or even by bringing moisture levels up to field capacity througout the growing season and to determine crop response without water deficits. This option does not necessarily represent the optimum yield response and irrigation efficiency scenario, since plant requirements and stress tolerances with respect to water deficit or surplus may vary. Even without considering temperature contraints in the (sub)tropical regions, crop production and final yield is affected by a great

CRIES - AGRO-ECONOMIC INFORMATION SYSTEM
(CRIES - AIS) VERSION 1.0

MAIN MENU

PLEASE SELECT AIS MODULE :

[F1] AIS-WATBUG	provides water balance analysis with minimal data requirements (*)
[F2] AIS-WATER	provides water balance modeling (**)
[F3] AIS-YIELD	provides yield prediction for selected locations or agro-ecological zones
[F4] AIS-ENTERPRI	conducts single enterprise analysis
[F5] AIS-MULBUD	conducts multiple enterprise analysis for multiple time periods
[F6] AIS-LINPROG	optimizes objective function using linear programming
[F7] AIS-IN/OUT	supports economic input/output analysis (**)
[F8] AIS-MSTAT	provides experimental design, data analysis and data management for agronomic research experiments

Figure 3. - Main Menu CRIES - Agro-economic Information System

number of variables relating to bio-chemical, physiological and physical processes. In addition, farm management practices, cropping systems and input constraints introduce variability in crop response within the same agro-ecological zone. This is especially true for small scale farming systems with an emphasis on food crop production, high labor inputs and limited marketing orientation, where farm management practices affecting moisture availability under rain-fed conditions may play a major role in increasing crop productivity. In contrast, large scale, more capital intensive, mono cropping operations with an emphasis on export crop production represent less temporal and spatial variability in crop response and are more realistically represented in yield modeling efforts, such as represented in YIELD. This means that the YIELD model is more appropriately used in the regional allocation of production options then the prediction of detailed and site-specific yield response.

To effectively support rural development planning in tropical regions, it is necessary to provide a general quantitative assessment of production potential. With this broad objective in mind, it is accurate to state that most yield response variations are closely linked with moisture availability throughout the growing season. The significance of the YIELD model is that it permits a systematic analysis of comparative advantage of production potential of selected crops by assessing the impact of the major variables affecting crop moisture availability and yield. As such, it provides a powerful tool in optimizing development decisions by type and location over time.

2. THEORETICAL FRAMEWORK OF THE YIELD MODEL

The YIELD model is primarily based on the crop yield response to water supply, with optional yield adjustments based on salinity and composite nutrient availability. The primary yield response is a function of crop water requirements and water deficits experienced during the critical phases of the growing period. The quantification of this relationship is possible when empirical data on crop moisture requirements, maximum yield, moisture deficits and resulting actual yield are available. Plant stress resulting from moisture deficits is determined by a number of variables, including precipitation and actual evapotranspiration. Plant moisture stress can be quantified by the rate of actual evapotranspiration (ETa) in relation to the maximum evapotranspiration (ETm). ETm and ETa can be quantified for most crops and most climatic zones. If ETa equals ETm, crop moisture requirements are fully met. If ETa < ETm, water supply is insufficient and crop yield will be reduced in most crops.

The extent to which moisture deficit will reduce crop yield is largely determined by the crop species and the length and timing of the period in the growing season. Experimental research has shown that it is possible to quantify the relationship between maximum crop yield (Ym) and actual yield (Ya) under different moisture supply regimes as defined by the relative evapotranspiration ratio (ETa/ETm). Subject to the farm management constraints identified above, Ya = Ym when crop water requirements are fully met, and Ya < Ym if water deficits conditions exist.

Doorenbos and Kassam (FAO, 1979) quantified the effect of moisture stress on yield by defining the relationship between relative yield and relative evapotranspiration deficit using the empirically-derived yield factor (ky), as follows:

$$\left(1 - \frac{Ya}{Ym}\right) = ky \left(1 - \frac{ETa}{ETm}\right)$$

where: Ya = actual harvested yield
Ym = maximum harvested yield
ky = yield response factor
ETa = actual evapotranspiration
ETm = maximum evapotranspiration

The yield response factor used in the equation is based on extensive research covering a variety of soil and growing conditions. The factors selected, represent high yielding varieties, well adapted to local agro-ecological conditions, under optimum agronomic practices and inputs.

This equation and the methodology referenced in Doorenbos and Kassam (1979) form the basis for the development of the CRIES - AIS - YIELD model. The model uses four simulation phases in deriving estimates of crop yield. They are:

Phase I - Calculation of Maximum Yield of a Standard Crop;
Phase II - Determination of Maximum Evapotranspiration;
Phase III - Determination of Actual Evapotranspiration; and
Phase IV - Calculation of Estimated Yield.

2.1 Phase I - Calculation of Maximum Yield of a Standard Crop.

Maximum yield (Ym) is determined by genetic potential and adaptability to local agro-ecological conditions. Adaptability can be evaluated by comparing crop requirements and tolerances for prevailing conditions with in situ conditions. Experimental research should indicate which crop species and varieties should be considered to maximize productivity and revenues derived (*). Maximum yield, therefore, is defined as harvested yield (expressed in biomass or dry matter) of well adapted, high-producing varieties at the end of the required growing period without stress inducing constraints (water, nutrients, pests and diseases) under good farm management. Examples of reported yields of varieties adapted to prevailing climatic conditions are provided (Table 1, from FAO, 1979). Climatic factors affecting maximum yield are temperature, precipitation, solar radiation and length of growing season. Special requirements may exist in relation to specific temperatures and daylength during certain stages of crop development. Doorenbos and Kassam (1979) provide a summary of major crop requirements (Table 2).

Water availability and temperature affects the length of the growing season, while variations in moisture supply within the season affect actual crop yield during critical stages in development. Some crops require a periodic deficit to aid flowering or fruit development. The crop requirement summary provided includes the water utilization efficiency (Ey) or harvested yield per unit of water and the sensitivity of yield to water deficit.

The calculation of maximum yield can be carried out for different climatic conditions. Two selected methods are provided:

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* This research can be accommodated by MSTAT, a software program for the design, management and analysis of agronomic research experiments, developed at Michigan State University (MSTAT, Version 3.0, 1985).

Table 1 Good Yields of High-producing Varieties adapted to the Climatic Conditions of the Available Growing Season under Adequate Water Supply and High Level of Agricultural Inputs under Irrigated Farming Conditions (tons/hectare) (from FAO, 1979)

<table>
<tr><th rowspan="3" colspan="2">CROP</th><th colspan="6">Climatic Regions</th></tr>
<tr><th colspan="2">Tropics [1]</th><th colspan="2">Subtropics [2]</th><th colspan="2">Temperate [3]</th></tr>
<tr><th><20°C [4]</th><th>>20°C</th><th><20°C</th><th>>20°C</th><th><20°C</th><th>>20°C</th></tr>
<tr><td>Alfalfa</td><td>hay</td><td colspan="2">15</td><td colspan="2">25</td><td colspan="2">10</td></tr>
<tr><td>Banana</td><td>fruit</td><td></td><td>40-60</td><td></td><td>30-40</td><td></td><td></td></tr>
<tr><td>Bean: fresh</td><td>pod</td><td>6-8</td><td></td><td>6-8</td><td></td><td>6-8</td><td></td></tr>
<tr><td>dry</td><td>grain</td><td>1.5-2.5</td><td></td><td>1.5-2.5</td><td></td><td>1.5-2.5</td><td></td></tr>
<tr><td>Cabbage</td><td>head</td><td>40-60</td><td></td><td>40-60</td><td></td><td>40-60</td><td></td></tr>
<tr><td>Citrus:</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>grapefruit</td><td>fruit</td><td></td><td>35-50</td><td></td><td>40-60</td><td></td><td></td></tr>
<tr><td>lemon</td><td>fruit</td><td></td><td>25-30</td><td></td><td>30-45</td><td></td><td></td></tr>
<tr><td>orange</td><td>fruit</td><td></td><td>20-35</td><td></td><td>25-40</td><td></td><td></td></tr>
<tr><td>Cotton</td><td>seed cotton</td><td></td><td>3-4</td><td></td><td>3-4.5</td><td></td><td></td></tr>
<tr><td>Grape</td><td>fruit</td><td colspan="2">5-10</td><td colspan="2">15-30</td><td colspan="2">15-25</td></tr>
<tr><td>Groundnut</td><td>nut</td><td></td><td>3-4</td><td></td><td>3.5-4.5</td><td></td><td>1.5-2</td></tr>
<tr><td>Maize</td><td>grain</td><td>7-9</td><td>6-8</td><td>9-10</td><td>7-9</td><td></td><td>4-6</td></tr>
<tr><td>Olive</td><td>fruit</td><td></td><td></td><td colspan="2">7-10</td><td></td><td></td></tr>
<tr><td>Onion</td><td>bulb</td><td>35-45</td><td></td><td>35-45</td><td></td><td>35-45</td><td></td></tr>
<tr><td>Pea: fresh</td><td>pod</td><td>2-3</td><td></td><td>2-3</td><td></td><td>2-3</td><td></td></tr>
<tr><td>dry</td><td>grain</td><td>0.6-0.8</td><td></td><td>0.6-0.8</td><td></td><td>0.6-0.8</td><td></td></tr>
<tr><td>Fresh pepper</td><td>fruit</td><td colspan="2">15-20</td><td colspan="2">15-25</td><td colspan="2">15-20</td></tr>
<tr><td>Pineapple</td><td>fruit</td><td></td><td>75-90</td><td></td><td>65-75</td><td></td><td></td></tr>
<tr><td>Potato</td><td>tuber</td><td>15-20</td><td></td><td>25-35</td><td></td><td>30-40</td><td></td></tr>
<tr><td>Rice</td><td>paddy</td><td></td><td>6-8</td><td></td><td>5-7</td><td></td><td>4-6</td></tr>
<tr><td>Safflower</td><td>seed</td><td></td><td></td><td colspan="2">2-4</td><td></td><td></td></tr>
<tr><td>Sorghum</td><td>grain</td><td>3-4</td><td>3.5-5</td><td>3-4</td><td>3.5-5</td><td></td><td>2-3</td></tr>
<tr><td>Soybean</td><td>grain</td><td colspan="2">2.5-3.5</td><td colspan="2">2.5-3.5</td><td></td><td></td></tr>
<tr><td>Sugarbeet</td><td>beet</td><td></td><td></td><td colspan="2">40-60</td><td colspan="2">35-55</td></tr>
<tr><td>Sugarcane</td><td>cane</td><td></td><td>110-150</td><td></td><td>100-140</td><td></td><td></td></tr>
<tr><td>Sunflower</td><td>seed</td><td colspan="2">2.5-3.5</td><td colspan="2">2.5-3.5</td><td colspan="2">2-2.5</td></tr>
<tr><td>Tobacco</td><td>leaf</td><td></td><td>2-2.5</td><td></td><td>2-2.5</td><td></td><td>1.5-2</td></tr>
<tr><td>Tomato</td><td>fruit</td><td colspan="2">45-65</td><td colspan="2">55-75</td><td colspan="2">45-65</td></tr>
<tr><td>Water melon</td><td>fruit</td><td></td><td>25-35</td><td></td><td>25-35</td><td></td><td></td></tr>
<tr><td>Wheat</td><td>grain</td><td>4-6</td><td></td><td>4-6</td><td></td><td>4-6</td><td></td></tr>
</table>

[1] Semi-arid and arid areas only
[2] Summer and winter rainfall areas
[3] Oceanic and continental areas
[4] Mean temperature

Table 2 Climatic, Soil and Water Requirements for Selected Crops (from FAO, 1979)

Crop	Total growing period (days)	Temperature requirements for growth, °C optimum[1] (range)	Daylength requirements for flowering	Specific climatic constraints/ requirements	Soil requirements
Alfalfa	100-365	24-26 (10-30)	Day neutral	Sensitive to frost; cutting interval related to temp.; requires low RH in warm climates	Deep, medium-textured, well-drained, pH = 6.5-7.5
Banana	300-365	25-30 (15-35)	Day neutral	Sensitive to frost; temp. <8°C for longer periods causes serious damage; requires high RH, wind < 4 m/sec	Deep, well-drained loam without stagnant water: pH = 5-7
Bean	fresh: 60-90 dry : 90-120	15-20 (10-27)	Short day/ day neutral	Sensitive to frost; excessive rain, hot weather	Deep, friable soil, well-drained and aerated; opt. pH = 5.5-6.0
Cabbage	100-150+	15-20 (10-24)	Long day	Short periods of frost (-6 to -10°C) are not harmful; opt. RH = 60-90%	Well-drained; opt. pH = 6.0-6.5
Citrus	240-365	23-30 (13-35)	Day neutral	Sensitive to frost (dormant trees less), strong wind, high humidity; cool winter or short dry period preferred	Deep, well-aerated, light to medium-textured soils, free from stagnant water; pH = 5-8
Cotton	150-180	20-30 (16-35)	Short day/ day neutral	Sensitive to frost; strong or cold winds; temp. req. for boll development: 27-32°C (18-38); dry ripening period required	Deep, medium to heavy-textured soils; pH = 5.5-8.0 with opt. pH = 7.0-8.0
Grape	180-270	20-25 (15-30)		Resistant to frost during dormancy (down to -18°C) but sensitive during growth; long, warm to hot, dry summer and cool winter preferred/ required	Well-drained, light soils are preferred
Groundnut	90-140	22-28 (18-33)	Day neutral	Sensitive to frost; for germination temp. >20°C	Well-drained, friable, medium-textured soil with loose top soil: pH = 5.5-7.0
Maize	100-140+	24-30 (15-35)	Day neutral/ short day	Sensitive to frost; for germination temp. > 10°C; cool temp. causes problem for ripening	Well-drained and aerated soils with deep water table and without waterlogging; opt. pH = 5.0-7.0
Olive	210-300	20-25 (15-35)		Sensitive to frost (dormant trees less); low winter temp. required (< 10°C) for flower bud initiation	Deep, well-drained soils free from waterlogging
Onion	100-140 (+30-35 in nursery)	15-20 (10-25)	Long day/ day neutral	Tolerant to frost; low temp. (< 14-16°C) required for flower initiation; no extreme temp. or excessive rain	Medium-textured soil; pH = 6.0-7.0
Pea	fresh: 65-100 dry : 85-120	15-18 (10-23)	Day neutral	Slight frost tolerance when young	Well-drained and aerated soils; pH = 5.5-6.5
Pepper	120-150	18-23 (15-27)	Short day/ day neutral	Sensitive to frost	Light to medium-textured soils; pH = 5.5-7.0
Pineapple	365	22-26 (18-30)	Short day	Sensitive to frost; requires high RH; quality affected by temperature	Sandy loam with low lime content; pH = 4.5-6.5
Potato	100-150	15-20 (10-25)	Long day/ day neutral	Sensitive to frost; night temp. < 15°C required for good tuber initiation	Well-drained, aerated and porous soils; pH = 5-6
Rice	90-150	22-30 (18-35)	Short day/ day neutral	Sensitive to frost, cool temp. causes head sterility; small difference in day and night temp. is preferred	Heavy soils preferred for percolation losses, high tolerance to O_2 deficit; pH = 5.5-6.0
Safflower	spring: 120-160 autumn: 200-230	early growth: 15-20 later growth: 20-30 (10-35)		Tolerant to frost; cool temp. req. for good establishment and early growth	Fairly deep, well-drained soils, preferably medium-textured; pH = 6-8
Sorghum	100-140+	24-30 (15-35)	Short day/ day neutral	Sensitive to frost; for germination temp. > 10°C; cool temp. causes head sterility	Light to medium/heavy soils relatively tolerant to periodic waterlogging, pH = 6-8
Soybean	100-130	20-25 (18-30)	Short day/ day neutral	Sensitive to frost; for some var. temp. >24°C required for flowering	Wide range of soil except sandy, well-drained; pH = 6-6.5
Sugarbeet	160-200	18-22 (10-30)	Long day	Tolerant to light frost; toward harvest mean daily temp. <10°C for high sugar yield	Medium to slightly heavy-textured soils, friable and well-drained; pH = 6-7
Sugarcane	270-365	22-30 (15-35)	Short day/ day neutral	Sensitive to frost; during ripening cool (10-20°C), dry, sunny weather is required	Deep, well aerated with ground water deeper than 1.5-2 m but rel. tolerant to periodic high water tables and O_2 deficit; pH = 5-8.5; opt pH = 6.5
Sunflower	90-130	18-25 (15-30)	Short day/ day neutral	Sensitive to frost	Fairly deep soils; pH = 6-7.5
Tobacco	90-120 (+40-60 in nursery	20-30 (15-35)	Short day/ day neutral	Sensitive to frost	Quality of leaf depends on soil texture; pH = 5-6.5
Tomato	90-140 (+25-35 in nursery)	18-25 (15-28)	Day neutral	Sensitive to frost, high RH, strong wind; opt. night temp. 10-20°C	Light loam, well-drained without waterlogging; pH = 5-7
Watermelon	80-110	22-30 (18-35)	Day neutral	Sensitive to frost	Sandy loam is preferred; pH = 5.8-7.2
Wheat	spring: 100-130 winter: 180-250	15-20 (10-25)	Day neutral/ long day	Spring wheat : sensitive to frost; Winter wheat : resistant to frost during dormancy (> -18°C), sensitive during post-dormancy period; requires a cold period for flowering during early growth. For both, dry period required for ripening	Medium-texture is preferred; relatively tolerant to high water table; pH = 6-8

1/ mean daily temperatures

2/ ky of the total growing period:
- low : ky <0.85
- medium-low : ky 0.85 - 1.0
- medium-high: ky 1.0 - 1.15
- high : ky >1.15

Table 2 (continued)

Sensitivity to salinity	Fertilizer requirements N : P : K kg/ha/growing period	Water requirements mm/growing period	Sensitivity to water supply (ky)	Water utilization efficiency for harvested yield, Ey, kg/m³ (% moisture)	Crop
moderately sensitive	0-40 : 35-65 : 75-100	800-1600	low to medium-high (0.7-1.1)	1.5 - 2.0 hay (10-15%)	Alfalfa
sensitive	200-400: 45-60 : 240-480	1200-2200	high (1.2-1.35)	plant crop: 2.5-4 ratoon: 3.5-6 fruit (70%)	Banana
sensitive	20-40 : 40-60 : 50-120	300-500	medium-high (1.15)	lush: 1.5-2.0 (80-90%) dry: 0.3-0.6 (10%)	Bean
moderately sensitive	100-150: 50-65 : 100-130	380-500	medium-low (0.95)	12-20 head (90-95%)	Cabbage
sensitive	100-200: 35-45 : 50-160	900-1200	low to medium-high (0.8-1.1)	2-5 fruit (85%, lime: 70%)	Citrus
tolerant	100-180: 20-60 : 50-80	700-1300	medium-low (0.85)	0.4-0.6 seed cotton (10%)	Cotton
moderately sensitive	100-160: 40-60 : 160-230	500-1200	medium-low (0.85)	2-4 fresh fruit (80%)	Grape
moderately sensitive	10-20 : 15-40 : 25-40	500-700	low (0.7)	0.6-0.8 unshelled dry nut (15%)	Groundnut
moderately sensitive	100-200: 50-80 : 60-100	500-800	high (1.25)	0.8-1.6 grain (10-13%)	Maize
moderately tolerant	200-250: 55-70 : 160-210	600-800	low	1.5-2.0 fresh fruit (30%)	Olive
sensitive	60-100: 25-45 : 45-80	350-550	medium-high (1.1)	8-10 bulb (85-90%)	Onion
sensitive	20-40 : 40-60 : 80-160	350-500	medium-high (1.15)	fresh: 0.5-0.7 shelled (70-80%) dry: 0.15-0.2 (12%)	Pea
moderately sensitive	100-170: 25-50 : 50-100	600-900 (1250)	medium-high (1.1)	1.5-3.0 fresh fruit (90%)	Pepper
	230-300: 45-65 : 110-220	700-1000	low	plant crop: 5-10 ratoon: 8-12 fruit (85%)	Pineapple
moderately sensitive	80-120: 50-80 : 125-160	500-700	medium-high (1.1)	4-7 fresh tuber (70-75%)	Potato
moderately sensitive	100-150: 20-40 : 80-120	350-700	high	0.7-1.1 paddy (15-20%)	Rice
moderately tolerant	60-110: 15-30 : 25-40	600-1200	low (0.8)	0.2-0.5 seed (8-10%)	Safflower
moderately tolerant	100-180: 20-45 : 35-80	450-650	medium-low (0.9)	0.6-1.0 grain (12-15%)	Sorghum
moderately tolerant	10-20 : 15-30 : 25-60	450-700	medium-low (0.85)	0.4-0.7 grain (6-10%)	Soybean
tolerant	150 : 50-70 : 100-160	550-750	low to medium-low (0.7-1.1)	beet: 6-9 (80-85%) sugar: 0.9-1.4 (0%)	Sugarbeet
moderately sensitive	100-200: 20-90 : 125-160	1500-2500	high (1.2)	cane: 5-8 (80%) sugar: 0.6-1.0 (0%)	Sugarcane
moderately tolerant	50-100: 20-45 : 60-125	600-1000	medium-low (0.95)	0.3-0.5 seed (6-10%)	Sunflower
sensitive	40-80 : 30-90 : 50-110	400-600	medium-low (0.9)	0.4-0.6 cured leaves (5-10%)	Tobacco
moderately sensitive	100-150: 65-110 : 160-240	400-600	medium-high (1.05)	10-12 fresh fruit (80-90%)	Tomato
moderately sensitive	80-100: 25-60 : 35-80	400-600	medium-high (1.1)	5-8 fruit (90%)	Watermelon
moderately tolerant	100-150: 35-45 : 25-50	450-650	medium-high (spring: 1.15 winter: 1.0)	0.8-1.0 grain (12-15%)	Wheat

1 kg P = 2.4 kg P_2O_5

1 kg K = 1.2 kg K_2O

1. The " Wageningen " Method, by De Wit et al.(1965) and
2. The Agro-ecological Zone Method (Kassam, 1977).

The methods are summarized below:

2.1.1 The Wageningen Method

This method is based on simplified water availability - yield relationships which are tested extensively for a wide range of climatic conditions for four crop: alfalfa, maize, sorghum, and wheat. The method is based on work by Slabbers (1978) who established thata linear relationship could be successfully used to determine the crop yield four the four crops identified based on water availability. To do this, it was necessary to assume the maximum dry matter production occurs at ETm.

Production potential estimates are based on De Wit's (1965) work using radiation and ET data; for application to agricultural crops corrections are required using crop-dependent constraints and expressions of the effect of temperature, growth efficiency (respiration) and for the harvested part of the final yield. All yields are expressed as experimental yields (Yme). The estimate is, however, adjustable to actual field conditions. Reference information for yields of high producing crop varieties with adequate water supply, high level of agricultural inputs under irrigation reported in ton/ha is provided (Table 1). At the same time, the reference information provided (table 2) may be used to review the climatic, soil and water requirements for these crops.

The calculation procedure for establishing experimental yield (Yme) is:

A. Calculate gross dry matter production of a standard crop (Yo);
B. Apply correction for climate (ETm/(ea-ed));
C. Apply correction for crop species (K);
D. Apply correction for temperature (cT); and
E. Apply correction for harvested part (cH).

The calculation of Yo is based on De Wit's (1965) work on establishing levels of incoming active shortwave radiation for standard conditions, as defined in :

$$Yo = F * yo + (1-F) yc$$

where: Yo = gross dry matter production of a standard crop in kg/ha/day.

F = fraction of the daytime the sky is clouded, fraction; or F = (Rse - 0.5 Rs) /0.8 Rse where Rse is the maximum active incoming shortwave radiation on clear days in cal/cm*2/day (Table 3) and Rs is the actual measured incoming shortwave radiation in cal/cm*2/day. Rs expressed in mm/day equivalent evaporation, uses the conversion factor of 59 cal/cm*2 = 1 mm equivalent. When only sunshine duration data are available, Rs can be calculated as Rs = (0.25 + 0.5 n/N)Ra where Ra is the terrestrial radiation in mm/day (Table 10), N is the maximum possible sunshine duration in hours/day (Table 11) and n is the actual measured sunshine duration in hours /day.

yo = gross dry matter production rate of a standard crop for a given location on a completely overcast day by kg/ha/day (Table 3)

yc = gross dry matter production rate of a standard crop for a given location on a clear (cloudless) day, kg/ha/day (Table 3).

The correction for climate effect is (ETm / (ea-ed)). The resulting ratio represents the mean maximum ETm in mm/day and vapor pressure

Table 3 Maximum Active Incoming Shortwave Radiation (Rse in cal/cm²/day) and Gross Dry Matter Production on Overcast (yo) and Clear Days (yc) (in kg/ha/day) for a Standard Crop (De Wit, 1965)

North South		Jan July	Feb Aug	Mar Sept	Apr Oct	May Nov	June Dec	July Jan	Aug Feb	Sept Mar	Oct Apr	Nov May	Dec June
0°	Rse	343	360	369	364	349	337	343	357	368	365	349	337
	yc	413	424	429	426	417	410	413	422	429	427	418	410
	yo	219	226	230	228	221	216	218	225	230	228	222	216
10°	Rse	299	332	359	375	377	374	375	377	369	345	311	291
	yc	376	401	422	437	440	440	440	439	431	411	385	370
	yo	197	212	225	234	236	235	236	235	230	218	203	193
20°	Rse	249	293	337	375	394	400	399	386	357	313	264	238
	yc	334	371	407	439	460	468	465	451	425	387	348	325
	yo	170	193	215	235	246	250	249	242	226	203	178	164
30°	Rse	191	245	303	363	400*	417*	411*	384*	333	270	210	179
	yc	281	333	385	437	471*	489*	483*	456*	412	356	299	269
	yo	137	168	200	232	251*	261*	258*	243*	216	182	148	130
40°	Rse	131	190	260	339	396	422	413	369	298	220	151	118
	yc	219	283	353	427	480	506	497	455	390	314	241	204
	yo	99	137	178	223	253	268	263	239	200	155	112	91

deficit (ea-ed) in mbar - based on Bierhuizen and Slatyer, (1965). The mean saturation vapor pressure (ea) and mean actual vapor pressure (ed) both in mbar is referenced (Table 9).

Correction for crop species (K) against a standard crop is calculated as Yo * ETm / (ea-ed)). The equation is used to relate gross dry matter production of a standard crop (Yo) to the gross dry matter production of the four crops. The empirically-derived factors (K) for alfalfa = .9, maize = 1.9, sorghum = 1.6, spring wheat = 1.17, and winter wheat = .65 are provided (FAO, 1979)

Correction for temperature is possible by comparing actual mean daily temperature during the total growth period with that of the standard temperature conditions. The crop-specific temperature correction factor (cT) (see Table 4) is used to obtain net dry matter production

Table 4. Correction for Temperature (cT)
(from FAO, 1979)

	Mean temperature over the total growing period, °C						
	5	10	15	20	25	30	35
Alfalfa	0	0.2	0.4	0.55	0.6	0.6	0.5
Maize	0	0.1	0.35	0.5	0.6*	0.6*	0.6
Sorghum	0	0.1	0.3	0.45	0.55	0.6	0.6
Wheat	0.05	0.3	0.55	0.6	0.35	0.1	0

(Ydm) taking into account the 40% of total energy required by the plant for growth and respiration. For a crop with optimum plant density, Ydm = K * cT * G * Yo * ETm / (ea-ed) in kg/ha/period (where Yo is the average over the total growing period in days (G).

Correction for harvested part or harvest index (cH) is calculated as a ratio between net total dry matter and harvested yield (cH). The following correction factors (from FAO, 1979) are provided: alfalfa 0.4 - 0.5 for the first year and 0.8 - 0.9 for subsequent years, maize 0.4 - 0.5, sorghum 0.35 - 0.45, and wheat at 0.3 - 0.4.
For experimental conditions with high producing, climatically adapted varieties and grown under optimum conditions, the Maximum Experimental Yield (Yme) may be obtained via: Yme = K * cH * cT * G * Yo * ETm/(ea-ed). For instance the production under experimental conditions for Maize is calculated as : Yme = 1.9 * cH * cT * G * Yo * ETm / (ea-ed). The YIELD model uses the correction factors as described in this section for these crops.

2.1.2 The Agro-Ecological Zone Method For Yield Prediction

The calculation of potential yields for the other crops is accomplished using the Agro-Ecological Zone method. Here potential yields are calculated for a standard crop according to De Wit's (1965) concept of using radiation data for each climate considered. Corrections are made for genetically-controlled crop growth under identical climatic conditions. It is assumed that climatic crop requirements are met that other variables such as water, nutrients, salinity, pests and diseases will not affect potential yield.

Since local climatic variation and farm management practices may vary considerably, this method of yield prediction provides production potential indicators for relatively large and homogeneous production zones. Adjustment of yield estimates for specific local conditions may be required as a result of localized climatic variations and farming system parameters.

The procedures for calculating potential yield (Ymp) are:

A. Calculate the gross dry matter production of a standard crop (Yo) using the Wageningen method;
B. Make corrections for crop species and temperature variations;
C. Make corrections for crop development over time and for leaf area (cL);
D. Make corrections for net dry matter production (cN); and
E. Make corrections for harvested part (cH).

The calculatior of Yo is again based on De Wit's (1965) work on establishing levels of incoming active shortwave radiation for standard conditions (see also the Wageningen method), as defined in :

$$Yo = F * yo + (1-F) yc$$

where: Yo = gross dry matter production of a standard crop in kg/ha/day.

F = fraction of the daytime the sky is clouded, fraction; or F = (Rse - 0.5 Rs) /0.8 Rse where Rse is the maximum active incoming shortwave radiation on clear days in cal/cm*2/day/ (Table 3) and Rs is the actual measured incoming shortwave radiation in cal/cm*2/day.

yo = gross dry matter production rate of a standard crop for a given location on a completely overcast day by kg/ha/day (Table 3)

yc = gross dry matter production rate of a standard crop for a given location on a clear (cloudless) day, kg/ha/day (Table 3).

The first correction procedure is for crop species and temperature variations in the agro-ecological zone. Production rates (ym) for gross dry mater production, measured in kg/ha/hour according to the mean temperature, are listed (Table 5, from FAO, 1979). Four crop groupings are provided according to cool and warm temperature classifications in the northern and southern hemisphere.

Table 5. Production Rates (ym in kg/ha/hour) for Crop Groups and Mean Temperatures (from FAO, 1979)

Crop group	Mean temperature, °C 5	10	15	20	25	30	35	40	45
I cool	5	15	20	20	15	5	0	0	0
I warm	0	0	15	32.5	35	35	32.5	5	0
II cool	0	5	45	65	65	65	45	5	0
II warm	0	0	5	45	65	65	65*	45	5

I cool: alfalfa, bean, cabbage, pea, potato, tomato, sugarbeet, wheat
I warm: alfalfa, citrus, cotton, groundnut, pepper, rice, safflower, soybean, sunflower, tobacco, tomato
II cool: some maize and sorghum varieties
II warm: maize, sorghum, sugarcane

Corrections for yo and yc values are made by using De Wit's (1965) procedure. The equations are:

- when ym > 20 kg/ha/hour then,
Yo = F (0.8 +.01 ym) yo + (1-F) (.5 + .025 ym) yc kg/ha/day

- when ym < 20 kg/ha/day then,
Yo = F (0.5 + .025 ym) yo + (1-F) (.05ym) yc kg/ha/day

Corrections for time and leaf area (cL) have been calculated and are listed (Table 6). The standard crop leaf relationship is calculated using a leaf area index (LAI) for a mature crop which is assumed to represent five times the surface of the total ground area.

Table 6. Correction for Crop Development (cL) over Time and Leaf Area Index (LAI) (from FAO, 1979)

LAI	1	2	3	4	≥5
Correction cL	0.2	0.3	0.4	0.48	0.5*

The time factor incorporated into this relationship reflects the average growth rate during the five portions of the production cycle. Corrections for net dry matter production (cN) are made with the assumption that a part of the energy available is used for respiration and to maintain the original growth, while the rest is directed towards the production of new biomass. In general, when the mean temperature is less than 20 degrees Celsius 60 % is used for the production of new growth and 50% when the mean temperature is more than 20 degrees Celsius.

Correction factors for harvestable yield (cH) are calculated by determining the ratio between net total dry matter and harvested yield (Table 7). The harvested yield refers to the portion of the plant which is actually harvested such as grain, fruit, seed, tuber, leave, etc. The harvest index (cH) is based on varieties under irrigation (on dry weight bases).

Table 7. Harvest Index (cH) of High-producing Varieties under Irrigation (on Dry Weight Basis) (from FAO, 1979).

Crop	Product	cH	Crop	Product	cH
Alfalfa	hay	0.4-0.5[1]	Potato	tuber	0.55-0.65
		0.8-0.9[1]	Rice	grain	0.4-0.5
Bean	grain	0.25-0.35	Sorghum	grain	0.3-0.4
Cabbage	head	0.6-0.7	Soybean	grain	0.3-0.4
Cotton	lint	0.08-0.12	Sugarbeet	sugar	0.35-0.45
Groundnut	grain	0.25-0.35	Sugarcane	sugar	0.2-0.3
Maize	grain	0.35-0.45*	Sunflower	seed	0.2-0.3
Onion	bulb	0.7-0.8	Tobacco	leaf	0.5-0.6
Pea	grain	0.3-0.4	Tomato	fruit	0.25-0.35
Pepper	fruit	0.2-0.4	Wheat	grain	0.35-0.45
Pineapple	fruit	0.5-0.6			

[1] first and second year

Therefore, potential yield (Ymp) for a high-producing, climatically adapted variety grown under constraint-free conditions over a growth cycle of G days can be expressed as:

- when ym > 20kg/ha/hour,

$$Ymp = cL * cN * cH * G\,[F(.8 + .01ym)yo + (1F)(.5 + .025ym)yc]$$

in kg/ha/period

and when ym < 20 kg/ha/hour,

$$Ymp = cL * cN * cH * G\,[F(.5 + .025ym)yo + (1-F)(.5ym)yc]$$

in kg/ha/period

where: cL = correction crop development and leaf area;
cN = correction for dry matter production, (0.6 for cool and 0.5 for warm conditions);
cH = correction for harvest index;
G = total growing period (days);
F = fraction of the daytime the sky is clouded;
ym = maximum leaf gross dry matter production rate of a crop for a given climate, kg/ha/day;
yo = gross dry matter production of a standard crop for a given location on a completely overcast (clouded) day

yc = gross dry matter production rate of a standard crop for a given location on a clear (cloudless) day, kg/ha/day.

2.2 Phase II - Determination of Maximum Evapotranspiration (ETm).

Crop water requirements are usually expressed by the rate of evapotranspiration (ET) in mm/unit of time (day). ET is related to evaporative capacity of the air as controlled by temperature, which can be expressed as reference evapotranspiration (ETo) and calculated to predict the effect of climate on crop ET. ETo, as used here, represents the evapotranspiration rate of a large surface with 8 - 15 centimeter growing grass cover, without water deficit and completely shading the ground. Among the various methods available to calculate ETo, the YIELD model uses the Penman method. This method approximates values for ETo, which are provided for different agro-climatic regions (Table 8).

Maximum crop evapotranspiration (ETm) can be related to ETo using empirically determined crop coefficients (kc) if crop water requirements are fully met. Crop coefficients increase during the various development stages. Empirical kc values used in the YIELD model are listed (Table 18). For a given climate regime, crop type and development stage the following equation is used to determine ETm:

$$ETm = kc * ETo$$

ETm is achieved if all conditions for crop development are met under optimum agronomic management practices. The following calculation steps are used to determine ETm:

1. Calculate reference evapotranspiration (ETo) in mm/day using mean

1. Calculate reference evapotranspiration (ETo) in mm/day using mean meteorological data;

Table 8. Reference Evapotranspiration (ETo in mm/day) for Different Agro-climatic Regions (from FAO, 1979)

Regions	Mean daily temperature, °C: <10 (cool)	20 (moderate)	>30 (warm)
TROPICS			
humid	3 - 4	4 - 5	5 - 6
subhumid	3 - 5	5 - 6	7 - 8
semi-arid	4 - 5	6 - 7	8 - 9
arid	4 - 5	7 - 8	9 - 10
SUBTROPICS			
Summer rainfall:			
humid	3 - 4	4 - 5	5 - 6
subhumid	3 - 5	5 - 6	6 - 7
semi-arid	4 - 5	6 - 7	7 - 8
arid	4 - 5	7 - 8	10 - 11
Winter rainfall			
humid - subhumid	2 - 3	4 - 5	5 - 6
semi-arid	3 - 4	5 - 6	7 - 8
arid	3 - 4	6 - 7	10 - 11
TEMPERATE			
humid - subhumid	2 - 3	3 - 4	5 - 7
semi-arid - arid	3 - 4	5 - 6	8 - 9

2. Determine crop coefficient (kc) based on growing period and length of development stages; and
3. Calculate maximum evapotranspiration (ETm) in mm/day for period.

A number of methods exist to calculate reference evapotranspiration (ETo). The choice among the most prevalent methods, the Blaney-Criddle, Radiation, Penman and actual measurements using Pan Evaporation, depends on the data availability and accuracy requirements in determining water needs. Doorenbos and Pruitt (1979) indicate that the Penman method offers the best results (error plus or minus 10% in the summer, and up to 15% under low evaporative conditions) followed by the Pan Evaporation method (15% error depending on pan location). Error estimations for the Radiation and Blaney-Criddle method are 20% and 25%, respectively. A detailed description of the methods may be found in Doorenbos and Pruitt (1979).

The YIELD model uses the Penman method because of accuracy considerations. However, data requirements are also the most restrictive, and include: temperature, relative humidity, wind speed, (wind and humidity is the aerodynamic term) and sunshine. Radiation data (the energy term) are used if available, but are not essential. The following climatic data are needed: mean temperature (T in degrees Celsius), relative humidity (RH in %), total windrun (U in km/day at 2 m height), mean actual sunshine duration (n in hours/day) or mean radiation (Rs or Rn equivalent evaporation in mm/day). In addition, actual or estimated data on mean maximum relative humidity (RH max in %) and mean daytime windspeed (Uday in m/sec at 2 m height) must be available.

A modified equation is used to better predict ETo under windy conditions in arid regions. The form of the equation is as follows:

$$ETo = c [W * Rn + (1 - W) * f(U) * (ea - ed)]$$

where: ETo = reference crop evapotranspiration representing the mean value in mm/day, over the period considered;

(ea-ed) = difference in mbar between the saturation vapor pressure (ea) at T mean (Table 9) and actual vapor pressure (ed) where ed = ea * RH / 100;

f(U) = wind-related function of f(U) = 0.27 (1 + U/100) with U in km/day measured at 2 meter height;

Rn = total net radiation in equivalent evapotranspiration per day (mm/day). This factor is approximated (from Tables10, 11,12,13 and 14,if not available);

W = temperature and altitude dependent weighting factor (Table 15); and

c = adjustment factor to compensate for the effect of day and night conditions (Table 16).

To complete the calculation of Maximum Evapotranspiraticn (ETm = kc * ETo), the crop coefficient (kc) is needed. This requires the following information:

a) sowing date;
b) length of total growing season;
c) duration of initial-stage (germination to 10 % ground cover);
d) duration of crop development stage (10% to 80% ground cover);
e) duration of the mid-season stage (80% cover to start of ripening);
f) duration of the late-season stage (start of ripening to harvest).

Crop coefficients used in the model, according to development stage, are listed (Table 17).

2.3. Phase III - Determination of Actual Evapotranspiration (ETa).

Actual evapotranspiration (ETa) of a plant in relation to the maximum evapotranspiration (ETm) is determined by the the availability of water in the root zone and water extraction ability via the root system. Adequate soil water availability is present when ETa =ETm. A crop water deficit and possible induced plant stress occours when

Table 9 — Saturation Vapour Pressure (ea) in mbar as Function of Mean Air Temperature (T) in °C 1/

Temperature °C	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
ea mbar	6.1	6.6	7.1	7.6	8.1	8.7	9.3	10.0	10.7	11.5	12.3	13.1	14.0	15.0	16.1	17.0	18.2	19.4	20.6	22.0
Temperature °C	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**
ea mbar	23.4	24.9	26.4	28.1	29.8	31.7	33.6	35.7*	37.8*	40.1*	42.4	44.9	47.6	50.3	53.2	56.2	59.4	62.8	66.3	69.9

1/ Also actual vapour pressure (ed) can be obtained from this table using available Tdewpoint data. (Example: Tdewpoint is 18°C; ed is 20.6 mbar)

Table 10 — Extra-terrestrial Radiation (Ra) expressed in equivalent evaporation in mm/day

Northern Hemisphere													Southern Hemisphere											
Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Lat	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
6.4	8.6	11.4	14.3	16.4	17.3	16.7	15.2	12.5	9.6	7.0	5.7	40°	17.9	15.7	12.5	9.2	6.6	5.3	5.9	7.9	11.0	14.2	16.9	18.3
6.9	9.0	11.8	14.5	16.4	17.2	16.7	15.3	12.8	10.0	7.5	6.1	38	17.9	15.8	12.8	9.6	7.1	5.8	6.3	8.3	11.4	14.4	17.0	18.3
7.4	9.4	12.1	14.7	16.4	17.2	16.7	15.4	13.1	10.6	8.0	6.6	36	17.9	16.0	13.2	10.1	7.5	6.3	6.8	8.8	11.7	14.6	17.0	18.2
7.9	9.8	12.4	14.8	16.5	17.1	16.8	15.5	13.4	10.8	8.5	7.2	34	17.8	16.1	13.5	10.5	8.0	6.8	7.2	9.2	12.0	14.9	17.1	18.2
8.3	10.2	12.8	15.0	16.5	17.0	16.8	15.6	13.6	11.2	9.0	7.8	32	17.8	16.2	13.8	10.9	8.5	7.3	7.7	9.6	12.4	15.1	17.2	18.1
8.8	10.7	13.1	15.2	16.5	17.0	16.8*	15.7	13.9	11.6	9.5	8.3	30	17.8	16.4	14.0	11.3	8.9	7.8	8.1	10.1	12.7	15.3	17.3	18.1
9.3	11.1	13.4	15.3	16.5	16.8	16.7	15.7	14.1	12.0	9.9	8.8	28	17.7	16.4	14.3	11.6	9.3	8.2	8.6	10.4	13.0	15.4	17.2	17.9
9.8	11.5	13.7	15.3	16.4	16.7	16.6	15.7	14.3	12.3	10.3	9.3	26	17.6	16.4	14.4	12.0	9.7	8.7	9.1	10.9	13.2	15.5	17.2	17.8
10.2	11.9	13.9	15.4	16.4	16.6	16.5	15.8	14.5	12.6	10.7	9.7	24	17.5	16.5	14.6	12.3	10.2	9.1	9.5	11.2	13.4	15.6	17.1	17.7
10.7	12.3	14.2	15.5	16.3	16.4	16.4	15.8	14.6	13.0	11.1	10.2	22	17.4	16.5	14.8	12.6	10.6	9.6	10.0	11.6	13.7	15.7	17.0	17.5
11.2	12.7	14.4	15.6	16.3	16.4	16.3	15.9	14.8	13.3	11.6	10.7	20	17.3	16.5	15.0	13.0	11.0	10.0	10.4	12.0	13.9	15.8	17.0	17.4
11.6	13.0	14.6	15.6	16.1	16.1	16.1	15.8	14.9	13.6	12.0	11.1	18	17.1	16.5	15.1	13.2	11.4	10.4	10.8	12.3	14.1	15.8	16.8	17.1
12.0	13.3	14.7	15.6	16.0	15.9	15.9	15.7	15.0	13.9	12.4	11.6	16	16.9	16.4	15.2	13.5	11.7	10.8	11.2	12.6	14.3	15.8	16.7	16.8
12.4	13.6	14.9	15.7	15.8	15.7	15.7	15.7	15.1	14.1	12.8	12.0	14	16.7	16.4	15.3	13.7	12.1	11.2	11.6	12.9	14.5	15.8	16.5	16.6
12.8	13.9	15.1	15.7	15.7	15.5	15.5	15.6	15.2	14.4	13.3	12.5	12	16.6	16.3	15.4	14.0	12.5	11.6	12.0	13.2	14.7	15.8	16.4	16.5
13.2	14.2	15.3	15.7	15.5	15.3	15.3	15.5	15.3	14.7	13.6	12.9	10	16.4	16.3	15.5	14.2	12.8	12.0	12.4	13.5	14.8	15.9	16.2	16.2
13.6	14.5	15.3	15.6	15.3	15.0	15.1	15.4	15.3	14.8	13.9	13.3	8	16.1	16.1	15.5	14.4	13.1	12.4	12.7	13.7	14.9	15.8	16.0	16.0
13.9	14.8	15.4	15.4	15.1	14.7	14.9	15.2	15.3	15.0	14.2	13.7	6	15.8	16.0	15.6	14.7	13.4	12.8	13.1	14.0	15.0	15.7	15.8	15.7
14.3	15.0	15.5	15.5	14.9	14.4	14.6	15.1	15.3	15.1	14.5	14.1	4	15.5	15.8	15.6	14.9	13.8	13.2	13.4	14.3	15.1	15.6	15.5	15.4
14.7	15.3	15.6	15.3	14.6	14.2	14.3	14.9	15.3	15.3	14.8	14.4	2	15.3	15.7	15.7	15.1	14.1	13.5	13.7	14.5	15.2	15.5	15.3	15.1
15.0	15.5	15.7	15.3	14.4	13.9	14.1	14.8	15.3	15.4	15.1	14.8	0	15.0	15.5	15.7	15.3	14.4	13.9	14.1	14.8	15.3	15.4	15.1	14.8

Table 11 Mean Daily Duration of Maximum Possible Sunshine Hours (N) for Different Months and Latitudes

Northern Latitudes	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Southern Latitudes	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June
40	9.6	10.7	11.9	13.3	14.4	15.0	14.7	13.7	12.5	11.2	10.0	9.3
35	10.1	11.0	11.9	13.1	14.0	14.5	14.3	13.5	12.4	11.3	10.3	9.8
30	10.4	11.1	12.0	12.9	13.6	14.0	13.9*	13.2	12.4	11.5	10.6	10.2
25	10.7	11.3	12.0	12.7	13.3	13.7	13.5	13.0	12.3	11.6	10.9	10.6
20	11.0	11.5	12.0	12.6	13.1	13.3	13.2	12.8	12.3	11.7	11.2	10.9
15	11.3	11.6	12.0	12.5	12.8	13.0	12.9	12.6	12.2	11.8	11.4	11.2
10	11.6	11.8	12.0	12.3	12.6	12.7	12.6	12.4	12.1	11.8	11.6	11.5
5	11.8	11.9	12.0	12.2	12.3	12.4	12.3	12.3	12.1	12.0	11.9	11.8
0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0

Table 12 Effect of Temperature f(T) on Longwave Radiation (Rnl)

$T^{o}C$	0	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36
$f(T) = \sigma Tk^4$	11.0	11.4	11.7	12.0	12.4	12.7	13.1	13.5	13.8	14.2	14.6	15.0	15.4	15.9	16.3*	16.7	17.2	17.7	18.1

Table 13 Effect of Vapour Pressure f(ed) on Longwave Radiation (Rnl)

ed mbar	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
$f(ed) = 0.34 - 0.044\sqrt{ed}$	0.23	.22	.20	.19	.18	.16	.15	.14	.13*	.12	.12	.11	.10	.09	.08	.08	.07	.06

Table 14 Effect of the Ratio Actual and Maximum Bright Sunshine Hours f(n/N) on Longwave Radiation (Rnl)

n/N	0	.05	.1	.15	.2	.25	.3	.35	.4	.45	.5	.55	.6	.65	.7	.75	.8	.85	.9	.95	1.0
$f(n/N) = 0.1 + 0.9n/N$	0.10	.15	.19	.24	.28	.33	.37	.42	.46	.51	.55	.60	.64	.69	.73	.78	.82*	.87	.91	.96	1.0

Table 15 Values of Weighting Factor (W) for the Effect of Radiation on ETo at Different Temperatures and Altitudes

Temperature °C	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
W at altitude m																				
0	0.43	.46	.49	.52	.55	.58	.61	.64	.66	.69	.71	.73	.75	.77*	.78	.80	.82	.83	.84	.85
500	.45	.48	.51	.54	.57	.60	.62	.65	.67	.70	.72	.74	.76	.78	.79	.81	.82	.84	.85	.86
1 000	.46	.49	.52	.55	.58	.61	.64	.66	.69	.71	.73	.75	.77	.79	.80	.82	.83	.85	.86	.87
2 000	.49	.52	.55	.58	.61	.64	.66	.69	.71	.73	.75	.77	.79	.81	.82	.84	.85	.86	.87	.88
3 000	.52	.55	.58	.61	.64	.66	.69	.71	.73	.75	.77	.79	.81	.82	.84	.85	.86	.88	.88	.89

Table 16 Adjustment Factor (c) in Presented Penman Equation

	RHmax = 30%				RHmax = 60%				RHmax = 90%			
Rs mm/day	3	6	9	12	3	6	9	12	3	6	9	12
Uday m/sec	Uday/Unight = 4.0											
0	.86	.90	1.00	1.00	.96	.98	1.05	1.05	1.02	1.06	1.10	1.10
3	.79	.84	.92	.97	.92	1.00	1.11	1.19	.99	1.10	1.27	1.32
6	68	.77	.87	.93	.85	.96	1.11	1.19	.94	1.10	1.26	1.33
9	.55	.65	.78	.90	.76	.88	1.02	1.14	.88	1.01	1.16	1.27
	Uday/Unight = 3.0											
0	.86	.90	1.00	1.00	.96	.98	1.05	1.05	1.02	1.06	1.10	1.10
3	.76	.81	.88	.94	.87	.96	1.06	1.12	.94	1.04	1.18	1.28
6	.61	.68	.81	.88	.77	.88	1.02	1.10	.86	1.01	1.15	1.22
9	.46	.56	.72	.82	.67	.79	.88	1.05	.78	.92	1.06	1.18
	Uday/Unight = 2.0											
0	.86	.90	1.00	1.00	.96	.98	1.05	1.05	1.02	1.06	1.10	1.10
3	.69	.76	.85	.92	.83	.91	.99*	1.05*	.89	.98	1.10*	1.14*
6	.53	.61	.74	.84	.70	.80	.94	1.02	.79	.92	1.05	1.12
9	.37	.48	.65	.76	.59	.70	.84	.95	.71	.81	.96	1.06
	Uday/Unight = 1.0											
0	.86	.90	1.00	1.00	.96	.98	1.05	1.05	1.02	1.06	1.10	1.10
3	.64	.71	.82	.89	.78	.86	.94*	.99*	.85	.92	1.01*	1.05*
6	.43	.53	.68	.79	.62	.70	.84	.93	.72	.82	.95	1.00
9	.27	.41	.59	.70	.50	.60	.75	.87	.62	.72	.87	.96

Table 17. Crop Coefficients (kc) (from FAO, 1979)

CROP	Crop Development stages					Total growing period
	Initial	Crop develop-ment	Mid-season	Late season	At harvest	
Banana						
tropical	0.4 -0.5	0.7 -0.85	1.0 -1.1	0.9 -1.0	0.75-0.85	0.7 -0.8
subtropical	0.5 -0.65	0.8 -0.9	1.0 -1.2	1.0 -1.15	1.0 -1.15	0.85-0.95
Bean						
green	0.3 -0.4	0.65-0.75	0.95-1.05	0.9 -0.95	0.85-0.95	0.85-0.9
dry	0.3 -0.4	0.7 -0.8	1.05-1.2	0.65-0.75	0.25-0.3	0.7 -0.8
Cabbage	0.4 -0.5	0.7 -0.8	0.95-1.1	0.9 -1.0	0.8 -0.95	0.7 -0.8
Cotton	0.4 -0.5	0.7 -0.8	1.05-1.25	0.8 -0.9	0.65-0.7	0.8 -0.9
Grape	0.35-0.55	0.6 -0.8	0.7 -0.9	0.6 -0.8	0.55-0.7	0.55-0.75
Groundnut	0.4 -0.5	0.7 -0.8	0.95-1.1	0.75-0.85	0.55-0.6	0.75-0.8
Maize						
sweet	0.3 -0.5	0.7 -0.9	1.05-1.2	1.0 -1.15	0.95-1.1	0.8 -0.95
grain	0.3 -0.5*	0.7 -0.85*	1.05-1.2*	0.8 -0.95	0.55-0.6*	0.75-0.9*
Onion						
dry	0.4 -0.6	0.7 -0.8	0.95-1.1	0.85-0.9	0.75-0.85	0.8 -0.9
green	0.4 -0.6	0.6 -0.75	0.95-1.05	0.95-1.05	0.95-1.05	0.65-0.8
Pea, fresh	0.4 -0.5	0.7 -0.85	1.05-1.2	1.0 -1.15	0.95-1.1	0.8 -0.95
Pepper, fresh	0.3 -0.4	0.6 -0.75	0.95-1.1	0.85-1.0	0.8 -0.9	0.7 -0.8
Potato	0.4 -0.5	0.7 -0.8	1.05-1.2	0.85-0.95	0.7 -0.75	0.75-0.9
Rice	1.1 -1.15	1.1 -1.5	1.1 -1.3	0.95-1.05	0.95-1.05	1.05-1.2
Safflower	0.3 -0.4	0.7 -0.8	1.05-1.2	0.65-0.7	0.2 -0.25	0.65-0.7
Sorghum	0.3 -0.4	0.7 -0.75	1.0 -1.15	0.75-0.8	0.5 -0.55	0.75-0.85
Soybean	0.3 -0.4	0.7 -0.8	1.0 -1.15	0.7 -0.8	0.4 -0.5	0.75-0.9
Sugarbeet	0.4 -0.5	0.75-0.85	1.05-1.2	0.9 -1.0	0.6 -0.7	0.8 -0.9
Sugarcane	0.4 -0.5	0.7 -1.0	1.0 -1.3	0.75-0.8	0.5 -0.6	0.85-1.05
Sunflower	0.3 -0.4	0.7 -0.8	1.05-1.2	0.7 -0.8	0.35-0.45	0.75-0.85
Tobacco	0.3 -0.4	0.7 -0.8	1.0 -1.2	0.9 -1.0	0.75-0.85	0.85-0.95
Tomato	0.4 -0.5	0.7 -0.8	1.05-1.25	0.8 -0.95	0.6 -0.65	0.75-0.9
Watermelon	0.4 -0.5	0.7 -0.8	0.95-1.05	0.8 -0.9	0.65-0.75	0.75-0.85
Wheat	0.3 -0.4	0.7 -0.8	1.05-1.2	0.65-0.75	0.2 -0.25	0.8 -0.9
Alfalfa	0.3 -0.4				1.05-1.2	0.85-1.05
Citrus						
clean weeding						0.65-0.75
no weed control						0.85-0.9
Olive						0.4 -0.6

First figure : Under high humidity (RHmin >70%) and low wind (U <5 m/sec).
Second figure: Under low humidity (RHmin <20%) and strong wind (>5 m/sec).

ETa < ETm. Available soil water (Sa) may be defined as the fraction (p) to which the total available soil water may be depleted without causing ETa to become less than ETm. The value of the fraction (p) depends on the type of crop, the magnitude of ETm and the soil characteristics (e.g. texture of the profile in the root zone and compactness or inpermeability of layers).

Doorenbos and Kassam (FAO, 1979) define total available soil water (Sa) as the depth of water in mm/m soil depth between the water content at field capacity (Sfc or at soil water tension of 0.1 to 0.2 atmosphere) and the soil water content at wilting point (Sw or at soil water tension of 15 atmosphere). Other sources use different tension ranges, for different textural classes - 0.1 bar for coarse textured soils and 0.33 bar for moderately and fine textured soils (Jamison and Kroth, 1958; Colman, 1947).

Soil texture is a major factor in determining available soil water. However, soils with identical soil texture may vary considerably in available water (Sa) in the soil - root profile. A representative Sa value should be selected to compensate for layered soils in which dense layers restrict water holding capacity and distribution. The model provides, via a screen prompt, the general guidelines according to the FAO (1979). As general indication, the following Sa mm/m values for different soil textures are suggested (FAO, 1979):

heavy texture - 200 mm/m;
medium texture - 140 mm/m; and
coarse texture - 60 mm/m.

Obviously, this user-selectable model input has a significant impact on yield prediction. To further aid the user in selection, actual field observations and additional sources are recommended. The articles by Richie (1981) and Ratcliff et al. (1983) suggest that variation of potential extractable soil water, (the difference between highest field measured water content of a soil and the lowest field-measured water content of a soil after plants stop extracting water) might be less extreme than suggested by FAO (1979).

Empircal results also indicate that field measurements are preferred over laboratory test to increase accuracy in water balance calculations. (Ratcliff et al., 1983 and Richie, 1981). Given the importance of this factor in predicting yield, local measurements of soil water availability are suggested to improve the accuracy of location-specific yield estimates.

If significant local variation occur for a single production zone (e.g. sub-strata within an agro-ecological zone or resource production unit), it is recommended to conduct various simulation runs while varying the Sa factor for selected locations to better predict yield response for local conditions and spatial aggregates, thereof.

The effect of inadequate water on crop varies by crop group and by growing stage. The model considers four crop groups. The crops with a dry harvested part (cereals for dry grain, cotton, oil seed as listed in group 4, Table 18), have a higher tolerable range of fraction (p)

Table 18. Crop Groups according to Soil Water Depletion

Group	Crops
1	onion, pepper, potato
2	banana, cabbage, grape, pea, tomato
3	alfalfa, bean, citrus, groundnut, pineapple, sunflower, watermelon, wheat
4	cotton, maize*, olive, safflower, sorghum, soybean, sugarbeet, sugarcane, tobacco

to which the available soil moisture (Sa) may be depleted while ETa remains equal to ETm. For conditions where ETm is high, p is smaller (and the soil relatively wet) when ETa becomes less than ETm in comparison to when ETm is low (Table 19).

For agricultural zoning at the national level and under conditions of limited water supply, an estimate of ETa can be determined via the calculation of the available soil water index (ASI). The ASI indicates the part of the month when available soil moisture is

Groups and Maximum Evapotranspiration (ETm)
(from FAO, 1979)

Crop Group	ETm mm/day								
	2	3	4	5	6	7	8	9	10
1	0.50	0.425	0.35	0.30	0.25	0.225	0.20	0.20	0.175
2	0.675	0.575	0.475	0.40	0.35	0.325	0.275	0.25	0.225
3	0.80	0.70	0.60	0.50	0.45	0.425	0.375	0.35	0.30
4	0.875	0.80	0.70	0.60	0.55	0.50	0.45	0.425	0.40*

adequate to meet crop water requirements (ETa =ETm). By combining ASI, ETm and remaining available soil water [(1-p)Sa*D] an estimate of mean monthly ETa can be determined. This procedure requires the following steps:

a) Determine the Available Soil Moisture Index according to:

$$ASI(t) = \frac{In(t) + Pe(t) + Wb(t) - [\,(1-p) * Sa * D(t)\,]}{30 * ETm\,(t)}$$

where:
- In = net irrigation application, mm
- Pe = rainfall, mm
- Wb = soil water balance in the root zone [mm/day]
- p = depletion factor, fraction
- (1-p)Sa*D = depth of remaining available soil water when ETa < ETm, mm/root depth
- Sa = available soil water, mm/m
- D = root depth, m
- ETm = maximum evapotranspiration, mm/

This index is subject to the assumptions that irrigation and rainfall, when equal or smaller than 30 ETm will fully contribute to evapotranspiration without loss to runoff or deep percolation, and mean monthly ETa is only affected by total net irrigation, rainfall and actual depth of available soil water and not their distribution over the month.

Under most conditions, ASI will vary between 0 and 1. If the ASI is greater than or equal to 1, ETa = ETm. When ASI is smaller than 0 the ETa/ETm ratio is so small that crop growth will not occur unless ETm is low and remaining available soil water is high.

b) Adjustment of water balance (Wb) variable in this equation as a result location-specific farm management practices and infiltration rate as a function of slope gradient and major soil textural classes. This adjustment can de described as:

$$Wb(t) = Wb(t-1) + [Pe(t) + Ir(t)] * Roff - p * Wb(t-1) - ETa * (100.0 - Mu) / 100.0$$

where:

Wb(t)	=	Soil Moisture Balance at time t in mm;
Wb(t-1)	=	Soil Moisture Balance at time t-1 in mm;
Pe(t)	=	Precipitation at time t in mm;
Ir(t)	=	Irrigation at time t in mm;
Roff	=	Runoff coefficient (fraction);
p	=	Water depletion factor (fraction);
ETa	=	Actual Evapotranspiration at time t in mm; and
Mu	=	Evapotranspiration reduction factor as a result of mulching, tillage or intercropping or other farm management factors (%).

The Runoff coefficient, effectively reducing the infiltration of water in the soil profile and subsequent recharge as a function of slope gradient and soil texture is abstracted and modified from Beasley et al. (1984) (Table 20).

Table 20. Water Infiltration Rate (percentage) as a Function of Slope Percentage and Major Soil Textural Classes (modified after Beasley et al., 1984)

Slope Class	Soil Texture: Coarse Loamy	Soil Texture: Fine Loamy / Fine Silty and Fine	Soil Texture: Very Fine
0 - 4 %	90 %	80 %	70 %
4 - 8 %	70 %	60 %	50 %
8 - 12 %	62 %	52 %	42 %
12 - 15 %	55 %	45 %	35 %
15 - 20 %	50 %	40 %	30 %
20 - 30 %	40 %	30 %	20 %
30 - 50 %	38 %	25 %	18 %
> 50 %	37 %	27 %	17 %

c) Followed by the determination of ETa using the reference table (Doorenbos, 1979) provided (Table 21).

Table 21. Monthly mean Actual Evapotranspiration (ETa in mm/day) for ASI, Remaining Available Soil Water when ETa < ETm ([(1-p) Sa*D] in mm/root depth) and Maximum Evapotranspiration (ETm in mm/day) (after FAO, 1979)

	ASI = 0.83					ASI = 0.67					ASI = 0.5				
(1-p)Sa.D mm/root depth	ETm, mm/day 2	4	6	8	10	ETm, mm/day 2	4	6	8	10	ETm, mm/day 2	4	6	8	10
25	1.9	3.8	5.6	7.3	9.1	1.8	3.3	4.8	6.1	7.5	1.6	2.8	3.8	4.8	5.8
50	2.0	3.9	5.7	7.6	9.4	1.9	3.6	5.2	6.7	8.1	1.7	3.2	4.4	5.5	6.5
100	2.0	3.9	5.9	7.8	9.6	1.9	3.8	5.5	7.2	8.8	1.9	3.5	5.0	6.3	7.6
150	2.0	4.0	5.9	7.8	9.7	2.0	3.8	5.7	7.4	9.1	1.9	3.7	5.3	6.7	8.1
200	2.0	4.0	5.9	7.9	9.8	2.0	3.9	5.7	7.5	9.3	1.9	3.7	5.4	7.0	8.5

	ASI = 0.33					ASI = 0.17					ASI = 0				
(1-p)Sa.D mm/root depth	ETm, mm/day 2	4	6	8	10	ETm, mm/day 2	4	6	8	10	ETm, mm/day 2	4	6	8	10
25	1.3	2.1	2.8	3.5	4.2	1.1	1.5	1.8	2.2	2.5	0.8	0.8	0.8	0.8	0.8
50	1.6	2.7	3.5	4.3	5.0	1.4	2.1	2.8	3.0	3.3	1.2	1.5	1.6	1.7	1.7
100	1.8	3.2	4.3	5.3	6.2*	1.7	2.8	3.6	4.2	4.7	1.5	2.3	2.8	3.0	3.2
150	1.8	3.4	4.7	5.9	7.0	1.7	3.1	4.2	5.0	5.7	1.7	2.7	3.5	4.0	4.3
200	1.9	3.5	5.0	6.3	7.5	1.8	3.3	4.5	5.5	6.4	1.7	3.0	4.0	4.7	5.1

2.4 Phase IV - Calculation of Estimated Yield

As previously indicated, whenever crop water demand exceeds supply, actual evapotranspiration will be less than maximum evapotranspiration (ETa < ETm). The resulting crop stress will affect growth and, ultimately, harvestable yield. The significance of water stress as a yield reducing factor, will depend on the magnitude, the crop type and timing of the deficit during the crop development stages, and finally, its duration.

Even when water requirements are fully met, the amount of dry matter produced by various crops, expressed per unit water used (kg/m3), varies greatly. This fact is expressed as water utilization efficiency (in kg/m3) for dry matter (Em) and harvested yield (Ey). This is caused by different crop growth rates and water requirements during the development stages (Table 22), but also the result or the crop differences in dry matter harvested (e.g. peanuts versus maize, see also harvest index Table 7). In general, crops with a high harvest index and high producing varieties are less drought tolerant to stress, water-induced or not. Again, the user of the model should be cautioned, that yield response to water can not be considered in isolation of other farming systems factors, such as cropping schemes, farm management and conservation measures aimed at preserving organic material and soil moisture in the root zone.

To quantify the yield response to variable water supply conditions, the yield response factor (ky) is introduced (FAO, 1979). It relates relative yield decrease (1 - Ya/Ym) to relative evapotranspiration deficit (1 - ETa/ETm). Water deficit may occur throughout the growing

Table 22. Sensitive Growth Periods for Water Deficit.

Alfalfa	just after cutting (and for seed production at flowering)
Banana	throughout but particularly during first part of vegetative period, flowering and yield formation
Bean	flowering and pod filling; vegetative period not sensitive when followed by ample water supply
Cabbage	during head enlargement and ripening
Citrus	
grapefruit	flowering and fruit set >fruit enlargement
lemon	flowering and fruit set >fruit enlargement; heavy flowering may be induced by withholding irrigation just before flowering
orange	flowering and fruit set > fruit enlargement
Cotton	flowering and boll formation
Grape	vegetative period, particularly during shoot elongation and flowering >fruit filling
Groundnut	flowering and yield formation, particularly during pod setting
Maize	flowering >grain filling; flowering very sensitive if no prior water deficit
Olive	just prior flowering and yield formation, particularly during the period of stone hardening
Onion	bulb enlargement, particularly during rapid bulb growth >vegetative period (and for seed production at flowering)
Pea	flowering and yield formation >vegetative, ripening for dry peas
Pepper	throughout but particularly just prior and at start of flowering
Pineapple	during period of vegetative growth
Potato	period of stolonization and tuber initiation, yield formation > early vegetative period and ripening
Rice	during period of head development and flowering >vegetative period and ripening
Safflower	seed filling and flowering >vegetative
Sorghum	flowering yield formation >vegetative; vegetative period less sensitive when followed by ample water supply
Soybean	yield formation and flowering; particularly during pod development
Sugarbeet	particularly first month after emergence
Sugarcane	vegetative period, particularly during period of tillering and stem elongation > yield formation
Sunflower	flowering > yield formation > late vegetative, particularly period of bud development
Tobacco	period of rapid growth > yield formation and ripening
Tomato	flowering > yield formation > vegetative period, particularly during and just after transplanting
Water melon	flowering, fruit filling > vegetative period, particularly during vine development
Wheat	flowering > yield formation > vegetative period; winter wheat less sensitive than spring wheat

period or during the individual crop development stages (i.e. establishment, vegetative, flowering, yield formation, or ripening). The yield response factor used in the model (Table 23) is based on the various development stages, if significant differences are present and known from experimental data, or for the total growing period. In general, crops with higher ky values show greater yield reductions under limited water supply distributed equally over the growing season. Crop groups associated with the generalized relationship between relative yield decrease (1 - Ya/Ym) and relative evaporation deficit (1-ETa/ETm) are listed (Figure 2).

As previous indicated, the model assumes that optimum fertilizer conditions are met and that no other growth limiting factors, such as salinity or toxidity causing factors are present. To permit adjustment for variable local conditions, the user is offered the option to adjust the final yield estimate based on the following two factors:

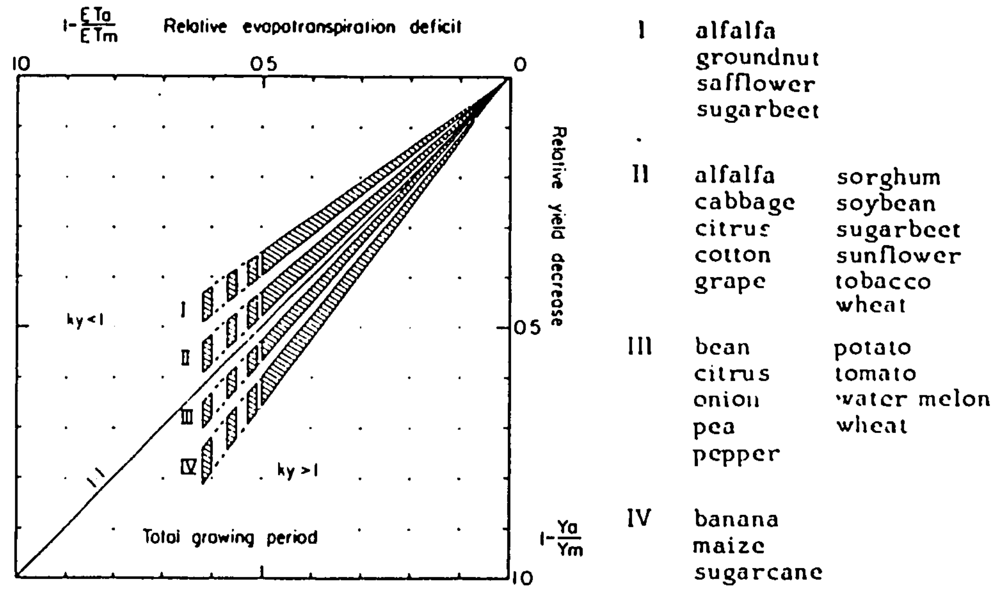
a. Presence of general fertilizer deficit for the optimum combination of nitrogen, phosporus and potassium (NPK) percentage based on a generalized relationship between applied percentage of NPK and yield decrease for all crops; and

b. Prevailing salinity level and crop-specific yield reduction response.

The first yield reduction relationship based on the generalized fertilizer response as presented by Evans (1980). The generalized response curve used in the model is provided (Figure 3). During execution of the simulation process, the user will be prompted to

Table 23. Yield Response Factor (ky)

Crop	Vegetative period (1) early (1a)	late (1b)	total	Flowering period (2)	Yield formation (3)	Ripening (4)	Total growing period
Alfalfa			0.7-1.1				0.7-1.1
Banana							1.2-1.35
Bean			0.2	1.1	0.75	0.2	1.15
Cabbage	0.2				0.45	0.6	0.95
Citrus							0.8-1.1
Cotton			0.2	0.5		0.25	0.85
Grape							0.85
Groundnut			0.2	0.8	0.6	0.2	0.7
Maize			0.4	1.5*	0.5	0.2	1.25*
Onion			0.45		0.8	0.3	1.1
Pea	0.2			0.9	0.7	0.2	1.15
Pepper							1.1
Potato	0.45	0.8			0.7	0.2	1.1
Safflower		0.3		0.55	0.6		0.8
Sorghum			0.2	0.55	0.45	0.2	0.9
Soybean			0.2	0.8	1.0		0.85
Sugarbeet							
beet							0.6-1.0
sugar							0.7-1.1
Sugarcane			0.75		0.5	0.1	1.2
Sunflower	0.25	0.5		1.0	0.8		0.95
Tobacco	0.2	1.0			0.5		0.9
Tomato			0.4	1.1	0.8	0.4	1.05
Water melon	0.45	0.7		0.8	0.8	0.3	1.1
Wheat							
winter			0.2	0.6	0.5		1.0
spring			0.2	0.65	0.55		1.15



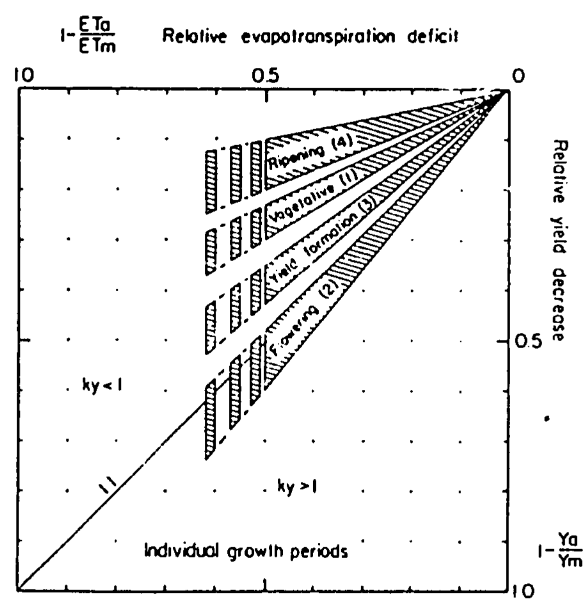


Figure 4. - Generalized relationship between relative yield decrease (1 - Ya/Ym) and relative evaporation deficit (1-ETa/ETm).

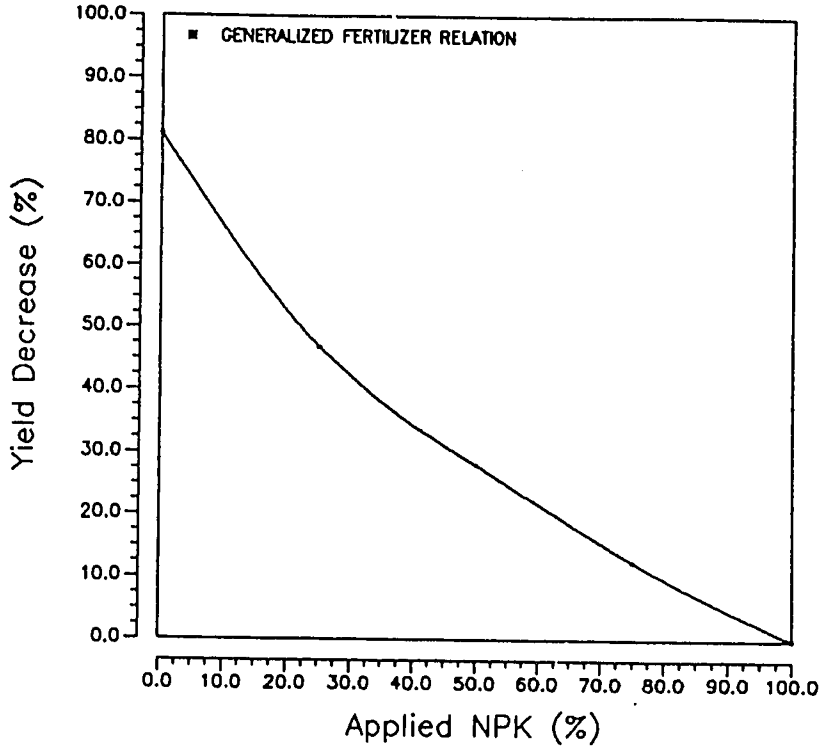


Figure 5. - Generalized Yield Adjustment for all Crops as a Function of Fertilizer Availability (NPK) in Percentage adapted from Evans (1980).

indicate optional fertilizer deficits and the yield will be adjusted accordingly. The same user option is provided to adjust crop yield response due to prevailing or anticipated salinity levels. This reflects the frequent reality under irrigated productions in regions were high evapotranspiration ratios or water quality conditions may cause a rapid increase in soil salinity and a reduction in crop yield. The reduction in yield is based on the general information provided by Doorenbos and Kassam (FAO, 1979).

To facilitate the yield calculation in relevant units, the user is provided with the option to calculate final estimated yield in dry matter or in total biomass produced with the use of a standard correction factor.

2.5 Theoretical and Applied Model Limitations.

The equations used in the YIELD model are derived from experimental research and empirical data. As such, they are subject to boundaries conditions dictated by the experimental design procedures and environmental conditions. The applied use of these equations in a simulation model, requires the use of a numerical procedure such as interpolation and extrapolation. Interpolation procedures are restricted to the numerical interval in which the variables are assumed to vary. Extrapolation procedures are not necessarily restricted to a given numerical interval. In fact, the derived variables may vary in a much larger numerical interval, which may fall outside the limits defined by the empirical results or experimentation. In this case, use of extrapolation may results in variables and derived results that are not meaningful in the context of the simulation. The YIELD model, represents a simulation model that does not permit extrapolation of certain values and environmental conditions. For instance, beyond certain temperature or moisture boundary conditions empirical equations become meaningless. If, during model simulations, input values or values resulting from any computations fall outside an empirical range of boundary conditions as defined by Doorenbos and Kassam (1979), then the maximum or the minimum value for the abscissa is assumed. This means that model simulation for crop yield for a certain location is based on the assumption that conditions exist which make agricultural production feasible. For instance, yield model results may be meaningless under extreme temperature and drought conditions, such as represented by rain-fed production in an arid environment.

The model is not designed to find out if crops can be grown under unfavorable environmental conditions but to is be used as a yield estimator to determine the comparative advantage of crop production for regions or locations where basic crop requirements can be met with a reasonable probability.

In addition to the limitations listed earlier in the text, the user should realize that the model is based on some general model assumptions. To provide users with a more complete overview of limitations in planning and policy analysis, the following section is provided.

Crop yield estimation is based on a complex relationship between production and a large number of variables. They include soil characteristics, climate, other factors affecting moisture availability, crop variety, fertilizer availability, toxidity, salinity, pests and disease, and agronomic practices.

The relationships presented in this model refer to high producing varieties, well-adapted to the environment, growing in large fields where optimum agronomic and irrigation practices, including adequate input supplies, except for water under rainfed conditions, are present. As is the case in commodity-specific models, additional model refinements may be accomplished by adjustment of selected model parameters for site-specific conditions to improve the accuracy offered by the methodology based on validation through adaptive research. This may involve the inclusion of additional crop and location considerations other than climate, such as crop and variety-specific fertilizer and toxidity response, additional soil characteristics, aspect in combination with slope, management practices, etc. The general crop requirements and crop coefficients used in the YIELD model were derived from general empirical data and experimental research. The current model makes no adjustments for affects of pests and diseases, or adverse local conditions such as water logging which may significantly reduce yields. Also, no adjustments are made for (post) harvest losses which may significantly reduce cash or nutritional value of the crops produced. In addition, a large number of political and socio-economic factors effect a farmer's decision to select crops, the cropping practices used or the availability of inputs. In concert, these factors exercise a significant influence in determining current agro-ecological zone productivity.

3. EXECUTION OF YIELD SIMULATION RUNS

This chapter describes procedures and protocols to successfully install and execute the yield simulation model.

3.1 Model Installation and Initiation of Execution.

The model requires a standard IBM-XT, AT or compatible computer equipped with a math processor, a hard disk configured as C drive, Version 2.1 or later of MS-DOS and a printer with 130 column capability.

Installation of the software is accomplished by inserting the first disk in the A drive and by typing "INSTALL" upon receipt of the >A prompt. The installation program will be executed, preparing the appropriate batch files, YIELD subdirectory and loading the executable code after consecutive prompting for the insertion of the appropriate diskettes in the A drive.

Upon completion of the installation process, the user may initiate execution of the model (*) by changing to the YIELD directory and by typing YIELD.

If the user has additional CRIES GIS and AIS software resident on the computer, the software may be accessed by typing: RIS (for resource information system) followed by <return>, after which all models may be selected from the screen menu's.

3.2 Data Requirements and Data Management.

To successfully run the deterministic YIELD simulator, a data base has to be assembled by the user. The data base must contain several

* Note: The user has to make sure that the yield programs and the data set are in the same directory.

data sets which will provide the information necessary to run the model. (The user will be prompted during the data management phase to insert the appropriate data.) These data include (optional data are prefaced by *):

A. - a LOCAL data set is required to identify the location, the region or agro-ecological zone parameters for which the simulation will be carried out. The local data set contains the following information:

1. Average Altitude in meters
2. Average Latitude in degrees
3. Hemisphere (north or south)
4. Predominant Slope class specification in percentage
5. Soil type
6. Major soil textural class
7. Soil moisture content at sowing date in millimeters/m
8. * Soil salinity level in mmhos/cm
9. AEZ parameters identification.
   - code
   - name

B. - a FARM MANAGEMENT PRACTICES data set is required to identify relevant farming system practices:

1. Crop sowing date and harvesting date
   - day
   - month
   - year
2. Crop first stage duration in number of days (from germination to 10 % ground cover)
3. Crop second stage duration in number of days (from 10 - 80 % ground cover
4. Crop third stage duration in number of days (from 80 % cover to start of ripening)
5. Crop fourth stage duration in number of days (from start of ripening to harvest)
6. Crop fifth stage duration in number of days (at harvest period)
7. * Fertilizer usage in percentage
8. * Evaporation reduction factor in percentage (due to moisture preservation techniques)
9. Irrigation parameters (in mm/day)
   - by crop development stages

C.- the CROP INFORMATION data set must contains the following information:

1. Crop type
2. Root depth for the first stage in centimeters

3. Root depth for the second stage in centimeters
4. Root depth for the third stage in centimeters
5. Root depth for the fourth stage in centimeters
6. Root depth for the fifth stage in centimeters
7. Crop production rate group
8. Crop water depletion group

D.- the ENVIRONMENTAL - CLIMATE data set includes:

1. Temperature in daily or monthly means in degree Celsius (contains the temperatures values in monthly means or daily readings of temperature values for the location identified)
2. Precipitation in daily or monthly means in millimeters (contains precipitation values in monthly means or daily readings of the precipitation for the location identified)
3. Relative humidity in daily or monthly means in percentage (contains the relative humidity in monthly means or daily readings of the relative humidity for the location identified)
4. * Solar radiation in daily or monthly means of sunshine hours/day (contains the monthly average or daily readings of the solar radiation for the location identified)
5. Wind velocity and wind velocity day/night ratio in meters/second (contains the monthly average or daily readings of the wind velocity and wind ratio, which define the night/day wind velocity ratio, for the location identified)

The data set discussed above is necessary to run the model. The user should have these data available before any attempt to run the yield simulator. The model will abort if any required data set is missing and no results will be provided. The user will be prompted for these data during the execution of a simulation run.

The simulation model is menu-driven permitting execution of simulation runs of the four different phases of the yield simulator or the data management phase which contains the data entry/append and the data editing procedures.

A detailed description of the execution of the yield simulator is provided. The user must respond all the system's prompts properly in order to successfully run the entire model.

Upon typing "YIELD" or initiating the model via the AIS menu, the following execution options, selected by function keys, are provided below (Figure 6).

```
                         yield
                           |
            -----------------------------
            |                           |
  run simulation model        data management phase
            |                           |
         phase 1             --------------------
            |                |                  |
    screen/printer   data entry/append      data edit
        output
            |        -local                 -local
            |        -temperature           -temperature
         phase 2     -precipitation         -precipitation
            |        -solar radiation       -solar radiation
            |        -wind velocity         -wind velocity
            |        -relativehumidity     -relative humidity
    screen/printer
        output
            |
         phase 3
            |
    screen/printer
        output
            |
         phase 4
            |
    screen/printer
        output
            |
         end run
```

Figure 6. - Schematic Overview of the Yield Model Execution Options

The main menu of the yield simulator, provides the user with the option to select program execution via the function keys as indicated in the screen menu below:

```
Yield response to water
    Yield simulator

*** Yield MAIN menu ***
 [F1]  Run the yield model
 [F2]  Data management
 [F9]  Exit
```

Selection of the F1 key will initiate YIELD model execution, F2 data management and F9 will exit the simulation model and return the user to the DOS system.

3.2 Data Management Operations

Prior to the fist model execution, data have to be entered. Upon selection of the F2 key, the data management menu will appear on the screen and the computer will wait for the user selection (see below).

```
        Yield response to water
            Yield simulator

*** Yield DATA MANAGEMENT menu ***

        [F1]  Data entry/append
        [F2]  Data edit
        [F8]  Return to MAIN menu
        [F9]  Exit
```

Four options are available to the user at this point. Selection F1 will allow the user enter data and/or append data to a existing file, selection F2 will allow the user to edit a particular file, selection F8 will return the user to the main menu, and selection F9 will exit the simulation model and return the user to the Disk Operating System (DOS).

Upon selection of F1, the user will be able to enter data into the model or to append data to a existing file. This selection will invoke a screen with a yield data entry/append menu which permits the user to select a particular data file for data entry/append operation, below:

DATA MANAGEMENT: DATA ENTRY/APPEND.

```
                    Yield response to water
                        Yield simulator

              *** Yield DATA ENTRY/APPEND menu ***
                   [F1]  Local
                   [F2]  Temperature
                   [F3]  Precipitation
                   [F4]  Wind Velocity
                   [F5]  Relative Humidity
                   [F6]  Solar Radiation
                   [F7]  Return to DATA MANAGEMENT menu
                   [F8]  Return to MAIN menu
                   [F9]  Exit
```

At this point, nine options are available to the user. -Selection F1 will allow the user to create a local data file. This file will contain data on a specific location for which the simulation will be carried out.

-Selection F2 will allow the user to create a temperature data file or to append data to a existing temperature file.

-Selection F3 will allow the user to create a precipitation data file or to append data to a existing precipitation data file.

-Selection F4 will allow the user to create a wind velocity data file or to append data to a existing wind velocity data file.

-Selection F5 will allow the user to create a relative humidity data file or to append data to a existing relative humidity data file.

-Selection F6 will allow the user to create a solar radiation data file or to append data to a existing solar radiation data file.

-Selection F7 will allow the user to return to data management menu.

-Selection F8 will allow the user to return to main menu.

-Selection F9 will allow the user to exit the model and return to DOS.

The various options and input operations are discussed below:

DATA MANAGEMENT:

DATA ENTRY/APPEND:

LOCAL DATA FILE.

Upon selection of the F1 key, the model will allow the user to enter the name of the local data file.

Enter the name of the LOCAL data file.

File name: WORTHY

The model will look into the yield directory for a data file named WORTHY.loc. If this file exists, proper prompts will allow user to change file name or to overwrite a specific local data file. If the user given local file name does not exist, the model will prompt for entries for the local data file.

DATA MANAGEMENT phase
<data entry>

File name: WORTHY.loc

Data field: COUNTRY NAME <char>

Please enter data: JAMAICA______________

Upon receiving this prompt, the user must type a string of 20 characters or less (in this case JAMAICA, observe underline guide) which should represent the country's name for which the yield simulation will be run, followed by the <enter> key. This information will be used to generate the location-specific yield summary reports. After this the following prompt will appear on the screen.

DATA MANAGEMENT phase
<data entry>

File name: **WORTHY.loc**

Data field: **POL./ADM. DISTRICT** **<char>**

Please enter data: ST. CATHERINE_______

The same procedure should be followed to enter the political district and weather station names (see prompt below)

DATA MANAGEMENT phase
<data entry>

File name: **WORTHY.loc**

Data field: **WEATHER STATION NAME** **<char>**

Please enter data: **WORTHY PARK**_________

Upon entering these data the user is prompted for data input for the agro-ecological zone number and production potential unit (representing unique topographical or farming system characteristics affecting water availability characteristics as identified by the user). These prompts and data entry requirements are outlined below.

DATA MANAGEMENT phase
<data entry>

File name: **WORTHY.loc**

Data field: **AGRO-ECOLOGICAL ZONE** **<int>**

Please enter data: 12

Upon receiving this prompt, the user must enter an integer number which indicates the agro-ecological zone code for which the yield simulation will be run. This data field is not used in any computation but it will be shown on screen reports and/or on printed reports. After typing the agro-ecological zone, the user must continue with identification of production potential areas (PPA's), as indicated below. Upon the prompt:

DATA MANAGEMENT phase
<data entry>

File name: **WORTHY.loc**

Data field: **PROD POTENTIAL UNIT** **<int>**

Please enter data: 2

Upon receiving this prompt, the user must enter an integer number which indicates the production potential area unit code for which the yield simulation will be run. This data field is not used in any computation but it will be shown on screen reports and/or on printed reports. After entering the production potential area unit code, a new prompt will appear on the screen:

DATA MANAGEMENT phase
<data entry>

File name: **WORTHY.loc**

Data field: **HEMISPHERE <N,S>**

Please enter data: **N**

Upon receiving this prompt, the user must enter the selection for the position of location in the northern or southern hemisphere (S or N). The information in this data field is used in the computations for solar radiation. After entry, a new prompt will appear on the screen:

DATA MANAGEMENT phase
<data entry>

File name: WORTHY.loc

Data field: LATITUDE <degrees>
Please enter data: 18.01

Upon receiving this prompt, the user must type a number which indicates the latitude of the location selected for the simulation. The latitude is entered in a decimal format indicating the respective number of degrees. The information in this data field is used in the computations. Data entry results in the following prompt:

DATA MANAGEMENT phase
<data entry>

File name: WORTHY.loc

Data field: ALTITUDE <meters>

Please enter data: 59.24

Upon receiving this prompt, the user must type a number which indicates the altitude of the location for the simulation. The altitude is entered in decimal form using meter as unit of measurement. The information in this data field is used in the computations. Once this entry is completed the local file called WORTHY.loc (Worthy is an example) will be created on disk for later use in future simulation run for selected crops.

At this point, the local file is complete. For modification or editing the user must refer to data edit section on the edit selection.

At this point, the screen displays the yield data entry/append menu (see top next page). Once the local data file is created, the user must proceed to create the temperature data file using the <F2> <return> keys. This permits temperature data entry. The following prompt will appear on the screen:

Enter the name of the TEMPERATURE data file.

File name: WORTHY

Yield response to water
Yield simulator

***** Yield DATA ENTRY/APPEND menu *****

```
[F1]  Local
[F2]  Temperature
[F3]  Precipitation
[F4]  Wind Velocity
[F5]  Relative Humidity
[F6]  Solar Radiation
[F7]  Return to DATA MANAGEMENT menu
[F8]  Return to MAIN menu
[F9]  Exit
```

After entering the name of the temperature data file, the model will check for existence of the file named WORTHY.tpt. If present, the model will work in the append mode and any data entered will be appended to the existing file. If no matching file name is found, a new temperature data file will be created. The user will be prompted for temperature data entry, as follows:

CRIES - AIS - YIELD

DATA MANAGEMENT phase
<data enter>

File name: WORTHY.TPT
Data field: REFERENCE YEAR <int>
Please enter data: 1980

User entry should be an integer number with four digits, that will indicate the reference year for the temperature data. After typing in the year, the following warning will appear:

WARNING: You will not be allowed to change this data using the edit phase. Is REFERENCE YEAR ok? (y or n)

This message indicates that this data entry is part of a file header and creation of the temperature file (or appending information to an existing temperature file) will be based on that value. Therefore, the user must make sure that the reference data is entered correctly. If the reference year is correct type y (yes), if it not correct type n (no) and you will be permitted to correct the previous entry. After the reference year is entered, the following prompt will appear on the screen:

CRIES - AIS - YIELD

DATA MANAGEMENT phase
<data enter>

File name: WORTHY.TPT

Data field: FREQUENCY OF THE DATA <D,M>
Please enter data: M

This screen indicates that the user must type a letter D, which indicates that daily temperature data will be entered, or a letter M, which indicates that monthly means temperature will be entered. After typing D or M, as indicated, the model will provide a warning to the user, on the bottom of the screen, which indicates :

WARNING: You will not be allowed to change this data using the edit phase. Is FREQUENCY OF THE DATA ok? (y or n)

This message indicates that this data entry is part of a file header and that creation of the temperature file (or appending information to an existing temperature file) will be based on that value, so the user must make sure that the frequency is entered correctly. Upon this selection the following screen will appear:

CRIES - AIS - YIELD
DATA MANAGEMENT phase
<data enter>

File name: WORTHY.TPT
Data field: TEMPERATURE SCALE <C,F>
Please enter data: F

Upon receiving this prompt, the user must type a letter C, which indicates that the temperature scale used is Centigrade or a letter F, which indicates that the temperature scale used is Fahrenheit. After typing C or F, as indicated, the model will provide the following warning on the bottom of the screen:

WARNING: You will not be allowed to change this data using edit phase. Is TEMPERATURE SCALE ok? (y or n)

This message indicates that this data entry is part of a file header and that creation of the temperature file (or appending information to an existing temperature file) will be based on that value, so the user must make sure that the frequency is entered correctly. Upon this selection the following screen will appear:

CRIES - AIS - YIELD

DATA MANAGEMENT phase
<data enter>

File name: WORTHY.TPT

Data field: MONTHLY TEMPERATURE VALUE <real>
Year: 1980
Month: January
Please enter temperature value: 77

Upon receiving this prompt, the user must type a number which indicates the temperature value (monthly mean) for the month of january. After typing the numerical value, the model will continue to ask for monthly temperature values up to the month of december. If the user enters a wrong temperature value, it will be possible to correct it by using the edit phase. The temperature file name always has the extension of .TPT.

After the temperature values for the year are entered, the model will ask the user if some more temperature data will be entered, via the following prompt:

Do you want to ENTER/APPEND more data? (y,n)

If the user answers <y>, the process of entering the temperature values is started again. In the user answer <n>, the user will be returned to the data management menu and a selection must be made.

The next data input selection is for precipitation <F3>, upon the receiving screen prompt:

Yield response to water
Yield simulator

***** Yield DATA ENTRY/APPEND menu *****

[F1] Local
[F2] Temperature
[F3] Precipitation
[F4] Wind Velocity
[F5] Relative Humidity
[F6] Solar Radiation
[F7] Return to DATA MANAGEMENT menu
[F8] Return to MAIN menu
[F9] Exit

Selection F3 will prompt:

Enter the name of the PRECIPITATION data file.

File name: WORTHY

The user must enter the name. If existing (e.g., WORTHY.pcp) the entries will be appended, otherwise a new file will be created by prompting for precipitation data entry:

CRIES - AIS - YIELD

DATA MANAGEMENT phase
<data enter>

File name: WORTHY.PCP

Data field: REFERENCE YEAR <int>
Please enter data: 1980

The user must type an integer number with four digits, that will indicate the reference year for the precipitation data. After typing the year, as indicated, the model will provide the standard warning:

WARNING: You will not be allowed to change this data using edit phase. Is REFERENCE YEAR ok? (y or n)

The next prompt screen will appear:

CRIES - AIS - YIELD

DATA MANAGEMENT phase
<data enter>

File name: WORTHY.PCP

Data field: FREQUENCY OF THE DATA <D,M>
Please enter data: M

The daily <D> or monthly <M> option should be selected for the precipitation means (the scale option will follow), and the standard warning will appear:

WARNING: You will not be allowed to change this data using edit phase. Is FREQUENCY OF THE DATA ok? (y or n)

This is followed by the scale selection in inches or millimeters:

CRIES - AIS - YIELD

DATA MANAGEMENT phase
<data enter>

File name: WORTHY.PCP

Data field: PRECIPITATION SCALE <I,M>
Please enter data: M

After typing I or M, as indicated, the model will provide the standard warning:

WARNING: You will not be allowed to change this scale using the edit phase. Is PRECIPITATION SCALE ok? (y or n)

The next screen prompts for values:

CRIES - AIS - YIELD

DATA MANAGEMENT phase
<data enter>

File name: WORTHY.PCP

Data field: MONTHLY PRECIPITATION VALUE <real>
Year: 1980
Month: January
Please enter precipitation value: 5.32

After typing the numerical value, the model will continue to ask for precipitation values up to the month of december. If the user enters a wrong precipitation value, it will be possible to correct it by using the edit phase. The precipitation file name always has a extension name .PCP.

After the precipitation values for the year are entered, the model will ask the user if some more precipitation data will be entered. The following prompt will appear on the screen:

Do you want to ENTER/APPEND more data? (y,n)

In the user answer y, the process of entering the precipitation values is started again. In the user answer n, the user will be returned to the data management menu and the next (or other) selection must be made:

Yield response to water
Yield simulator

***** Yield DATA ENTRY/APPEND menu *****

[F1] Local
[F2] Temperature
[F3] Precipitation
[F4] Wind Velocity
[F5] Relative Humidity
[F6] Solar Radiation
[F7] Return to DATA MANAGEMENT menu
[F8] Return to MAIN menu
[F9] Exit

Assuming that the user wants to create or append data to a wind velocity data file, (use <F4>), the following prompt will appear on the screen:

Enter the name of the WIND VELOCITY data file.

File name: WORTHY

After entering the name of the wind velocity data file, the system will append to the existing file or prompt the user to create a wind velocity data file and prompt for wind velocity data entry.

CRIES - AIS - YIELD

DATA MANAGEMENT phase
<data enter>

File name: WORTHY.WDV

Data field: REFERENCE YEAR <int>
Please enter data: 1980

The user must type an integer number with four digits, that will indicate the reference year for the wind velocity data. After typing the year, as indicated, the model will provide the standard warning:

WARNING: You will not be allowed to change this data using edit phase. Is REFERENCE YEAR ok? (y or n)

This indicates that this data is part of a file header and creation of the wind velocity file (or in appending information to a existing file) will be based on that value. After the reference year is entered, the following prompt will appear on the screen:

CRIES - AIS - YIELD

DATA MANAGEMENT phase
<data enter>

File name: WORTHY.WDV

Data field: FREQUENCY OF THE DATA <D,M>
Please enter data: M

D, indicates that daily wind velocity data will be entered. M, indicates that monthly means wind velocity will be entered. After entry the user will provided the standard warning:

WARNING: You will not be allowed to change this data using edit phase. Is FREQUENCY OF THE DATA ok? (y or n)

This indicates that this data is part of a file header and creation of the file (or in appending information to a existing file) will be based on that value.

Next the system prompts for selection of wind velocity scale:

CRIES - AIS - YIELD

DATA MANAGEMENT phase
<data enter>

File name: WORTHY.WDV

Data field: WIND VELOCITY SCALE <F,M>
Please enter data: M

F, indicates that the wind velocity scale used is feet per second and M, indicates that the wind velocity scale used is meters per second. After selection the standard warning will appear:

WARNING: You will not be allowed to change this data using edit phase. Is WIND VELOCITY SCALE ok? (y or n)

This indicates that this data is part of a file header and creation of the file (or in appending information to a existing file) will be based on that value.

The next prompts are for the wind velocity value (monthly mean) for the month of january and for the night/day wind velocity ratio. Subsequent prompts appear for all months.

CRIES - AIS - YIELD

DATA MANAGEMENT phase
<data enter>

File name: WORTHY.WDV

Data field: MONTHLY WIND VEL VALUE AND RATIO
Year: 1980
Month: January
Please enter wind velocity value: 5.32
Please enter wind ratio value: 1.2

If the user enter a wrong wind velocity value and/or wind velocity ratio, correction is possible using the edit phase. The wind velocity file name always has the extension .WDV.

After the wind velocity values for the year are entered, the model will ask the user if more wind velocity data will be entered. The following prompt will appear on the screen:

Do you want to ENTER/APPEND more data? (y,n)

In the user answers y, the process of entering the wind velocity values is started again. In the user answers n, the user will be returned to the data management menu and a selection must be made.

Yield response to water
Yield simulator

***** Yield DATA ENTRY/APPEND menu *****

[F1] Local
[F2] Temperature
[F3] Precipitation
[F4] Wind Velocity
[F5] Relative Humidity
[F6] Solar Radiation
[F7] Return to DATA MANAGEMENT menu
[F8] Return to MAIN menu
[F9] Exit

Selection of <F5> permits creation or appending of data to a humidity data file initiated by the prompt:

Enter the name of the HUMIDITY data file.

File name: WORTHY

If this file exist, the model will work in the append mode and any data entered will be append to the existing file. If not, the model will prompt for creation of a relative humidity data file:

CRIES - AIS - YIELD

DATA MANAGEMENT phase
<data enter>

File name: WORTHY.HUM

```
            Data field: REFERENCE YEAR  <int>
      Please enter data: 1980
```

Upon receiving this prompt, the user must type an integer number with four digits, which indicates the reference year for the relative humidity data. After typing the year, the model will indicate:

```
WARNING: You will not be allowed to change this data
         using edit phase. Is REFERENCE YEAR ok? (y or n)
```

This indicates that this data is part of a file header and creation of the file (or in appending information to an existing file) will be based on that value. The next prompt will appear:

```
                  CRIES - AIS - YIELD

               DATA MANAGEMENT phase
                    <data enter>

          File name: WORTHY.HUM

            Data field: FREQUENCY OF THE DATA  <D,M>
      Please enter data: M
```

Selection of D, indicates that daily relative humidity data will be entered. M, indicates that mean monthly relative humidity data will be entered. After selection, the standard warning appears:

```
WARNING: You will not be allowed to change this data
         using edit phase. Is FREQUENCY OF THE DATA ok? (y or n)
```

This indicates that this data is part of a file header and creation of the file (or in appending information to an existing file) will be based on that value. The is followed by the next prompt:

```
                  CRIES - AIS - YIELD

               DATA MANAGEMENT phase
                    <data enter>

          File name: WORTHY.HUM
```

Data field: HUMIDITY SCALE <F,P>
Please enter data: P

Selection F, indicates that the relative humidity scale used is a fraction, P, indicates that the relative humidity scale used is a percentage. After selection, the standard warning will appear:

WARNING: You will not be allowed to change this data using edit phase. Is HUMIDITY SCALE ok? (y or n)

This indicates that this data is part of a file header and creation of the file (or in appending information an existing file) will be based on that value. The next prompt will appear:

CRIES - AIS - YIELD

DATA MANAGEMENT phase
<data enter>

File name: WORTHY.HUM

Data field: MONTHLY MEAN HUMIDITY VALUE
Year: 1980
Month: January
Please enter humidity value: 80

Upon receiving this prompt, the user must type a number which indicates the relative humidity value (monthly mean) for the month of january. After typing the numerical value, the model will continue to ask for relative humidity values up to the month of december. Wrong entries may be corrected using the edit phase. The file created has the extension .HUM. File creation is followed by:

Do you want to ENTER/APPEND more data? (y,n)

In the user answer y, the process of entering the relative humidity values is started again. In the user answer n, the user will be returned to the data management menu and a selection must be made.

Yield response to water
Yield simulator

***** Yield DATA ENTRY/APPEND menu *****

[F1] Local
[F2] Temperature
[F3] Precipitation
[F4] Wind Velocity
[F5] Relative Humidity
[F6] Solar Radiation
[F7] Return to DATA MANAGEMENT menu
[F8] Return to MAIN menu
[F9] Exit

Selection <F6> permits creation or appending data to a solar radiation data file, (extension .sol) after the prompt:

Enter the name of the SOLAR RADIATION data file.

File name: WORTHY

If this file exist, the model will work in the append mode and any data entered will be append to the existing file. If not, the next screen will appear:

CRIES - AIS - YIELD

DATA MANAGEMENT phase
<data enter>

File name: WORTHY.SOL

Data field: REFERENCE YEAR <int>
Please enter data: 1980

Upon receiving this prompt, and entering an integer number with four digits which indicates the reference year for the solar radiation data, the standard warning appears:

WARNING: You will not be allowed to change this data using edit phase. Is REFERENCE YEAR ok? (y or n)

This indicates that this data is part of a file header and creation of the file (or in appending information to a existing file) will be based on that value. This is followed by the option:

CRIES -- AIS - YIELD

DATA MANAGEMENT phase
<data enter>

File name: WORTHY.SOL

Data field: FREQUENCY OF THE DATA <D,M>
Please enter data: M

Selection D, indicates that daily solar radiation data will be entered, M, that monthly means solar radiation will be entered. This is followed by the standard warning:

WARNING: You will not be allowed to change this data using edit phase. Is FREQUENCY OF THE DATA ok? (y or n)

This indicates that this data is part of a file header and creation of the file (or in appending information to a existing file) will be based on that value. This is followed by the option:

CRIES - AIS - YIELD

DATA MANAGEMENT phase
<data enter>

File name: WORTHY.sol

Data field: SOLAR RADIATION SCALE <H,F>
Please enter data: H

Selection of H indicates that the solar radiation scale used is number of hours of sunshine a day, F, indicates that the solar radiation scale used is a fraction. This is followed by the warning:

WARNING: You will not be allowed to change this data using edit phase. Is SOLAR RADIATION SCALE ok? (y or n)

This indicates that this data is part of a file header and creation of the file (or in appending information to an existing file) will be based on that value. The next prompt will appear:

CRIES - AIS - YIELD

DATA MANAGEMENT phase
<data enter>

File name: WORTHY.SOL

Data field: MONTHLY SOLAR RADIATION VALUE
Year: 1980
Month: January
Please enter solar radiation value: 4.5

Upon receiving this prompt, the user must type a number which indicates the solar radiation value (monthly mean) for the month of january. After typing the numerical value, the model will continue to ask for solar radiation values up to the month of december.

If the user enter a wrong solar radiation value, it will be possible to correct it by using the edit phase. The solar radiation file name always has a extension name .SOL.

After the solar radiation values for the year are entered, the following prompt will appear:

Do you want to ENTER/APPEND more data? (y,n)

In the user answers y, the process of entering the solar radiation values is started again. In the user answers n, the user will be returned to the data management menu and a selection must be made:

Yield response to water
Yield simulator

***** Yield DATA MANAGEMENT menu *****

[F1] Data entry/append
[F2] Data edit
[F8] Return MAIN menu
[F9] exit

This phase permits editing of data files. It may be used to show on the content of a file and to modify the content of a data field in a particular file.

While using the edit phase, a new file is created and all data from the old file will be copied into the new file as well as the changes made by the user. Selection of <F2> from the menu below, provides a set of screens and prompts for editing of the data files:

Yield response to water
Yield simulator

***** Yield DATA EDIT menu *****

[F1] Local
[F2] Temperature
[F3] Precipitation
[F4] Wind Velocity
[F5] Relative Humidity
[F6] Solar Radiation
[F7] Return to DATA MANAGEMENT menu
[F8] Return to MAIN menu
[F9] exit

At this point a selection must be made in order to proceed with the editing phase. (e.g. F1)

To see what kind of information is contained in a (local) file, the user must select the relating function key. For F1 for instance, the the system will prompt the user for some information, such as:

Enter the name of the LOCAL data file.

File name: WORTHY

The system will ask the name of the new local file name to be assigned to the data file which will contain the corrected information.

Enter name NEW local data file.

File name: NWORTHY

At this point the following prompt will appear:

CRIES - AIS
YIELD SIMULATOR
DATA MANAGEMENT phase
<data edit>

Old file name: WORTHY.loc
New file name: NWORTHY.loc

Data field: COUNTRY NAME <char>

Old data: JAMAICA
Is it O.K ? (y or n)

If the user answer is n the model will prompt for correction:

CRIES - AIS
YIELD SIMULATOR
DATA MANAGEMENT phase
<data edit>

Old file name: WORTHY.loc
New file name: NWORTHY.loc

Data field: COUNTRY NAME <char>

Old data: JAMAICA
New data: ______________________

At this point the user should enter the new country name. Note, the country name must have 20 or less characters (observe underline). After typing the country name. the model will prompt for the next data field:

```
                    CRIES - AIS
                  YIELD SIMULATOR
              DATA MANAGEMENT phase
                    <data edit>

      Old file name: WORTHY.loc
      New file name: NWORTHY.loc

         Data field:  POL./ADM. DISTRICT <char>

           Old data: St. CATHERINE
           Is it ok? (y or n)
```

If the user answer is n, the model will prompt for correction:

```
                    CRIES - AIS
                  YIELD SIMULATOR
              DATA MANAGEMENT phase
                    <data edit>

      Old file name: WORTHY.loc
      New file name: NWORTHY.loc

         Data field:  POL./ADM. DISTRICT <char>

           Old data: St. CATHERINE
           New data: ____________________
```

At this point the user should enter the new pol./adm. district name. Note, the pol./adm. district name must have 20 or less characters (observe underline). After typing the pol./adm. district name, the model will prompt the next data field:

CRIES - AIS
YIELD SIMULATOR
DATA MANAGEMENT phase
<data edit>

Old file name: WORTHY.loc
New file name: NWORTHY.loc

Data field: WEATHER STATION NAME <char>

Old data: WORTHY PARK
Is it ok? (y or n)

If the user answer is n the model will prompt for correction:

CRIES - AIS
YIELD SIMULATOR
DATA MANAGEMENT phase
<data edit>

Old file name: WORTHY.loc
New file name: NWORTHY.loc

Data field: WEATHER STATION NAME <char>

Old data: WORTHY PARK
New data: ____________________

At this point the user should enter the new weather station name. Note, the weather station name must have 20 or less characters (observe underline). After typing the weather station name, the model will prompt for the next data field:

CRIES - AIS
YIELD SIMULATOR
DATA MANAGEMENT phase
<data edit>

Old file name: WORTHY.loc
New file name: NWORTHY.loc

Data field: AGRO-ECOLOGICAL ZONE <int>

Old data: 121
Is it ok? (y or n)

If the user answer is n the model will then prompt for correction:

```
                    CRIES - AIS
                  YIELD SIMULATOR
               DATA MANAGEMENT phase
                    <data edit>

     Old file name: WORTHY.loc
     New file name: NWORTHY.loc

        Data field: AGRO-ECOLOGICAL ZONE  <int>

          Old data: 121
          New data:
```

At this point the user should enter the new agro-ecological zone code. Note, the agro-ecological zone code is a numerical field and integer. After typing the agro-ecological zone code, the model will prompt for the next data field:

```
                    CRIES - AIS
                  YIELD SIMULATOR
               DATA MANAGEMENT phase
                    <data edit>

     Old file name: WORTHY.loc
     New file name: NWORTHY.loc

        Data field: PROD POTENTIAL UNIT <int>

          Old data: 11
          Is it ok? (y or n)
```

If the user answer is n, the model will prompt for correction:

```
                    CRIES - AIS
                  YIELD SIMULATOR
               DATA MANAGEMENT phase
                    <data edit>

     Old file name: WORTHY.loc
     New file name: NWORTHY.loc

        Data field: PROD POTENTIAL UNIT  <int>

          Old data: 11
          New data:
```

At this point the user should enter the new production potential unit code. Note, the production potential unit code is a numerical and integer data field. After typing the production potential unit code, the model will prompt for the next data field.

```
                         CRIES - AIS
                       YIELD SIMULATOR
                    DATA MANAGEMENT phase
                         <data edit>

          Old file name: WORTHY.loc
          New file name: NWORTHY.loc

             Data field: HEMISPHERE   <N,S>

               Old data: N
               Is it ok? (y or n)
```

If the user answer is n, the model will prompt for correction:

```
                         CRIES - AIS
                       YIELD SIMULATOR
                    DATA MANAGEMENT phase
                         <data edit>

          Old file name: WORTHY.loc
          New file name: NWORTHY.loc

             Data field: HEMISPHERE   <N,S>

               Old data: N
               New data:
```

At this point the user should enter a new letter which indicates the hemisphere location for which the simulation will be carried out. The user should enter N or S if the hemisphere is northern or southern respectively. Note, that the hemisphere data field is a character field and only N or S must be used. After typing in the required data, the model will prompt for the next data field:

```
                         CRIES - AIS
                       YIELD SIMULATOR
                    DATA MANAGEMENT phase
                         <data edit>
```

```
Old file name: WORTHY.loc
New file name: NWORTHY.loc

   Data field: LATITUDE  <degrees>

     Old data: 18.01
     Is it ok? (y or n)
```

If the user answer is n the model will then prompt for correction:

```
                 CRIES - AIS
               YIELD SIMULATOR
           DATA MANAGEMENT phase
                 <data edit>

Old file name: WORTHY.loc
New file name: NWORTHY.loc

   Data field: LATITUDE  <degrees>

     Old data: 18.01
     New data:
```

At this point the user should enter a new latitude value, which is a numeric field and indicates the latitude of the simulation location. The user should enter a real numerical value. After typing in the latitude data, the model will prompt for the next data field:

```
                 CRIES - AIS
               YIELD SIMULATOR
           DATA MANAGEMENT phase
                 <data edit>

Old file name: WORTHY.loc
New file name: NWORTHY.loc

   Data field: ALTITUDE <meters>

     Old data: 59.24
     Is it ok? (y or n)
```

If the user answer is n, the model will prompt for correction:

```
                 CRIES - AIS
               YIELD SIMULATOR
           DATA MANAGEMENT phase
                 <data edit>

Old file name: WORTHY.loc
New file name: NWORTHY.loc
```

Data field: ALTITUDE <meters>
Old data: 59.24
New data:

At this point the user should enter a new altitude value, which is a numeric field and indicates the altitude of the location. The user should enter a real numerical value. After typing in the altitude data, the model will give the following prompt:

Your old file is: WORTHY.tpt

Do you want to save it? (y or n)

If the user wants to save the old file, answer y, if not answer n. If the answer is n the file will be deleted from the disk.

In the same manner, selection of F2 from the edit menu permit editing of the other data sets , e.g.:

Yield response to water
Yield simulator

***** Yield DATA EDIT menu *****

[F1] Local
[F2] Temperature
[F3] Precipitation
[F4] Wind Velocity
[F5] Relative Humidity
[F6] Solar Radiation

[F7] Return to DATA MANAGEMENT menu
[F8] Return to MAIN menu

[F9] exit

After selection, the following prompts will appear on the screen:

Enter name OLD temperature data file.

File name: WORTHY

Enter name NEW temperature data file.

File name: NWORTHY

Enter REFERENCE YEAR to edit data: 1980

The reference year means the year in the temperature data file for which you wish to edit data. This will invoke the following prompt:

```
                    CRIES - AIS
                  YIELD SIMULATOR
               DATA MANAGEMENT phase
                    <data edit>

        Old file name: WORTHY.tpt
        New file name: NWORTHY.tpt

           Data field: MONTHLY TEMPERATURE VALUE <real>
                 Year: 1980
                Month: January
Old temperature value: 77.00

Is it ok? (y or n)
```

If the answer is n, the model will proceed and show the temperature value for the other month. If the answer is y, the system will give the following prompt:

```
                    CRIES - AIS
                  YIELD SIMULATOR
               DATA MANAGEMENT phase
                    <data edit>

        Old file name: WORTHY.tpt
        New file name: NWORTHY.tpt

           Data field: MONTHLY TEMPERATURE VALUE <real>
                 Year: 1980
                Month: January
Old temperature value: 77.00
New temperature value: 67
```

The model will proceed up to the end of reference year. After that, the following prompt will appear:

Do you want to EDIT more data? (y or n)

If the answer is y, the temperature editing process will start all over again. If the answer is n, the system will prompt as follow:

Your OLD file is: WORTHY.tpt

Do you want to save it? (y or n)

If the answer is y, the system will prompt for a new name. If the answer is n, the model will delete the old temperature file.

The next section deals with editing of precipitation data.

Yield response to water
Yield simulator

***** Yield DATA EDIT menu *****

[F1] Local
[F2] Temperature
[F3] Precipitation
[F4] Wind Velocity
[F5] Relative Humidity
[F6] Solar Radiation
[F7] Return to DATA MANAGEMENT menu
[F8] Return to MAIN menu
[F9] exit

Upon selection of F3 the system will prompt:

Enter name OLD precipitation data file.

File name: WORTHY

Enter name NEW precipitation data file.

File name: NWORTHY

Enter REFERENCE YEAR to edit data: 1980

The reference year is the year for which data will be edited after the prompt:

```
                    CRIES - AIS
                  YIELD SIMULATOR
              DATA MANAGEMENT phase
                    <data edit>

          Old file name: WORTHY.tpt
          New file name: NWORTHY.tpt

             Data field: MONTHLY PRECIPITATION VALUE <real>
                   Year: 1980
                  Month: January
Old precipitation value: 12.50

Is it ok? (y or n)
```

If the answer is n, the screen display will show the precipitation value for the next month. If the answer is y, the model will prompt:

```
                    CRIES - AIS
                  YIELD SIMULATOR
              DATA MANAGEMENT phase
                    <data edit>

          Old file name: WORTHY.tpt
          New file name: NWORTHY.tpt

             Data field: MONTHLY PRECIPITATION VALUE <real>
                   Year: 1980
                  Month: January
Old precipitation value: 12.50
  New temperature value: 10.50
```

This will continue to the end of reference year. After that, the following prompt will appear:

```
Do you want to EDIT more data? (y or n)
```

If the answer is y, the precipitation editing process will start all over again. If the answer is n, the system will prompt as follows:

```
Your OLD file is:  WORTHY.pop
```

Do you want to save it? (y or n)

If the answer is y, the user should enter the new file name. If the answer is n, the old precipitation file will be deleted.

The next section represents the editing of the wind velocity data. This can be invoked by the selecting the function key in the menu below.

Yield response to water
Yield simulator

***** Yield DATA EDIT menu *****

[F1] Local
[F2] Temperature
[F3] Precipitation
[F4] Wind Velocity
[F5] Relative Humidity
[F6] Solar Radiation

[F7] Return to DATA MANAGEMENT menu

[F8] Return to MAIN menu
[F9] exit

The following prompts will appear on the screen:

Enter name OLD wind velocity data file.

File name: WORTHY

Enter name NEW wind velocity data file.

File name: NWORTHY

Enter REFERENCE YEAR to edit data: 1980

The reference year is the year for which data are to be edited. The system will prompt:

```
                    CRIES - AIS
                  YIELD SIMULATOR
              DATA MANAGEMENT phase
                    <data edit>

       Old file name: WORTHY.wdv
       New file name: NWORTHY.wdv

          Data field: MONTHLY WIND VEL AND RATIO VALUE <real>
                Year: 1980
               Month: January
Old wind velocity value: 5.30

Is it ok? (y or n)
```

If the answer is n, the system will show the wind velocity value for the next month. If the answer is y, the systems will prompt:

```
                    CRIES - AIS
                  YIELD SIMULATOR
              DATA MANAGEMENT phase
                    <data edit>

       Old file name: WORTHY.wdv
       New file name: NWORTHY.wdv

          Data field: MONTHLY PRECIPITATION VALUE <real>
                Year: 1980
               Month: January
Old wind velocity value: 5.30
New wind velocity value: 7.50
```

The system will proceed up to the end of reference year. After that, it provides the following prompt:

```
Do you want to EDIT more data? (y or n)
```

If the answer is y, the wind velocity editing process will start all over again. If the answer is n, the model will prompt as follows:

Your OLD file is: WORTHY.wdv

Do you want to save it? (y or n)

If the answer is y, the model will give a prompt, and the user should enter the new file name. If the answer is n, the model will delete the old wind velocity file.

The next option is editing of humidity data from the menu, below.

Yield response to water
Yield simulator

***** Yield DATA EDIT menu *****

[F1] Local
[F2] Temperature
[F3] Precipitation
[F4] Wind Velocity
[F5] Relative Humidity
[F6] Solar Radiation
[F7] Return to DATA MANAGEMENT menu
[F8] Return to MAIN menu
[F9] exit

Upon selection, the following prompt will appear on the screen:

Enter name OLD humidity data file.

File name: WORTHY

Enter name NEW humidity data file.

File name: NWORTHY

Enter REFERENCE YEAR to edit data: 1980

Upon entering the reference year, the system will prompt:

CRIES - AIS
YIELD SIMULATOR
DATA MANAGEMENT phase
<data edit>

Old file name: WORTHY.wdv
New file name: NWORTHY.wdv

Data field: MONTHLY HUMIDITY VALUE <real>
Year: 1980

Month: January
Old humidity value: 78.00

Is it ok? (y or n)

If the answer is n, the system will proceed and show the humidity value for the next month. If the answer is y, the system will prompt:

CRIES - AIS
YIELD SIMULATOR
DATA MANAGEMENT phase
<data edit>

Old file name: VORTHY.hum
New file name: NWORTHY.hum

Data field: MONTHLY HUMIDITY VALUE <real>
Year: 1980
Month: January
Old humidity value: 78.00
New humidity value: 85.00

The system will proceed up to the end of reference year. After that, the following prompt will appear:

Do you want to EDIT more data? (y or n)

If the answer is y, the humidity file editing process will start all over again. If the answer is n, the system will prompt:

Your OLD file is: WORTHY.hum

Do you want to save it? (y or n)

If affirmative, the system will prompt for a filename, if no, the model will delete the humidity file.

The next option for editing, selectable by function key from the menu is the solar radiation data set (see next page):

Yield response to water
Yield simulator

***** Yield DATA EDIT menu *****

[F1] Local
[F2] Temperature
[F3] Precipitation
[F4] Wind Velocity
[F5] Relative Humidity
[F6] Solar Radiation
[F7] Return to DATA MANAGEMENT menu
[F8] Return to MAIN menu
[F9] exit

The following prompt will appear on the screen:

Enter name OLD solar radiation data file.

File name: WORTHY

Enter name NEW solar radiation data file.

File name: NWORTHY

Enter REFERENCE YEAR to edit data: 1980

Upon entry of reference year, the system will prompt

CRIES - AIS
YIELD SIMULATOR
DATA MANAGEMENT phase
<data edit>

Old file name: WORTHY.sol
New file name: NWORTHY.sol

Data field: MONTHLY SOLAR RADIATION VALUE <real>
Year: 1980
Month: January
Old solar radiation value: 6.00

Is it ok? (y or n)

If the answer is n, the system will proceed and show the solar radiation value for the next month. If the answer is yes, the system will prompt:

```
                    CRIES - AIS
                  YIELD SIMULATOR
              DATA MANAGEMENT phase
                   <data edit>

       Old file name: WORTHY.sol
       New file name: NWORTHY.sol

          Data field: MONTHLY SOLAR RADIATION VALUE <real>
                Year: 1980
               Month: January
Old solar radiation value: 6.00
New solar radiation value: 3.30
```

The model will proceed up to the end of reference year. After that, the following prompt will appear:

Do you want to EDIT more data? (y or n)

If the answer is y, the solar radiation file editing process will start all over again. If the answer is n, the system will prompt:

Your OLD file is: WORTHY.sol

Do you want to save it? (y or n)

If the answer is y, the system will prompt for a new file name. If the answer is n, the model will delete the solar radiation file.

At this point, the data edit menu will appear on the screen, and the user may, upon finishing editing, return to the main menu, using the F8 key (see next page).

Yield response to water
Yield simulator

***** Yield DATA EDIT menu *****

[F1] Local
[F2] Temperature
[F3] Precipitation
[F4] Wind Velocity
[F5] Relative Humidity
[F6] Solar Radiation

[F7] Return to DATA MANAGEMENT menu
[F8] Return to MAIN menu

[F9] exit

This will return the main menu:

Yield response to water
Yield simulator

***** Yield MAIN menu *****

[F1] Run the yield model

[F2] Data management

[F9] Exit

At this point, a simulation run may be initialized using the <F1> key.

3.3 Execution of the CRIES-AIS-YIELD Simulation Model.

Upon pressing the F1 key, the user will receive a prompt to input the location name (e.g. worthy) of the files from which the model will read the data. This is indicated by the following prompt:

Enter WEATHER STATION name: worthy

The weather station, representing a single location or a weather profile for an agro-ecological zone, must be represented by name in the data base. That name will be the default for a series of system prompts asking for data files names, as indicated below:

Enter existing LOCAL file name [worthy]:

That prompt ask for the local file name, where the local information is located. The default file name is the weather station name, in this example "worthy", entered after the last prompt. This name will be de default name for the other climate variables.
If the user wants to enter a different local data file name, the data file name should be entered at this point the next prompt, then the next prompt will appear on the screen:

Enter existing TEMPERATURE file name [worthy]:

That prompt refers to the temperature data file. The default name for the temperature file (the name of the data file entered before), is given inside the brackets, If the user wants to enter a different file name for the temperature data, he/she should do it so at this time. If the data from "worthy" is to be used, press the enter key on the computer's keyboard.

Enter existing HUMIDITY file name [worthy]:

The humidity data file name should be entered at this point. The default data file name is the name of the weather station used before, (worthy in this example) If the user wants the default value, the enter key must be pressed, otherwise enter the humidity file name.

The next prompt will ask the user to enter precipitation data.

Enter existing PRECIPITATION file name [worthy]:

At that prompt, the user must enter the data file name which contains precipitation data. The default file name is the file name used in the last prompt. If the user wishes to enter a different file name he/she may do so by entering the precipitation file name at this prompt, otherwise, the defaultvalue will be used.
The next prompt will ask the user for the wind velocity data file.

Enter existing WIND VELOCITY file name [worthy]:

Upon receiving this prompt, the user must enter a file name that contains wind velocity data. The default file name is the file name used before. If the default file name is the file name to be entered, press the enter key, otherwise, type the new wind velocity file name.
The next prompt refers to the solar radiation data:

Enter existing SOLAR RADIATION file name [worthy]:

The user must enter the file name that contains solar radiation data. The default file name is the name of the weather station used before. If the user wants to enter a different file name, he/she must enter the new file name at this prompt otherwise the default can be used by pressing the enter key. In this case the default solar radiation data file is called worthy, which contains data from the worthy weather station.

At this point, execution of the the first phase of the YIELD model may be initiated. This involves an interactive process whereby several prompts will appear on the screen which permit the user to enter the parameters necessary to run this phase. This phase starts with the display of:

```
           CRIES -- Agro-Economic Information System
      Module: YIELD SIMULATOR, Phase: STANDARD CROP
                       Version 1.00
                    Serial # MSU CRIES
         (C) Copyright 1986. All Rights Reserved
 Comprehensive Resource Inventory and Evaluation System (CRIES)
    Michigan State University, East Lansing, MI 48824, USA
```

The first phase computes the maximum potential yield for a standard crop. The first prompt for this phase is:

PLEASE ENTER SOWING DATE (MONTH) :

The month must be entered in which the sowing will occur. The value for the month must be a valid integer number (1 to 12). The model will reject any entry which is not within that range. Upon the next prompt, the user will be able to enter the sowing day:

PLEASE ENTER SOWING DATE (DAY) :[15]

A sowing date must be entered or the default value, indicated in brackets, may be used. If the user wants to use the default value, the enter key must be pressed, otherwise, a number from 1 to 31 must be entered. The model will reject any number outside this range. Upon the next prompt:

PLEASE ENTER HARVEST DATE (MONTH) :

The month in which the harvest will occur should be entered. The value for the month must be a valid integer number (1 to 12). The model will reject any entry which is not within that range. This is followed by:

PLEASE ENTER HARVEST DATE (DAY) :[15]

Now enter the actual or anticipated harvest date. The default value is indicated within the brackets. If the user wants to use the default value, the enter key must be pressed, otherwise, a number from 1 to 31 must be entered. The model will reject any number outside this range. The next prompt permit selection of the simulation step size:

PLEASE ENTER SIMULATION STEP SIZE :[5]

This parameter will indicate to the model the number of days that should grouped in the simulation process. The default value is 5. Any integer number in the 1 to 30 range may be used. Numbers outside that range will be rejected. This is followed by:

IS THE GROWING PERIOD WITHIN A YEAR? (y or n)

Indicate the appropriate response. This is followed by:

SIMULATE AVERAGE YEAR? (y or n)

This permits the user to run the yield model for a standard or "average year". This choice results in the arithmetic averaging of the input data files. If averaging is desired answer y(yes), if averaging is desired answer n(no).

PLEASE ENTER SOWING YEAR :

Select the sowing year. The sowing year indicates the initial year for the simulation run. The model expects four integer number, e.g. 1980.

After that last input prompt, the system will ask if there is any change to be made in the parameters entered so far.

ANY CORRECTION? (y or n)

If the user wants to see the parameters entered before or if some changes need to be made, the answer to this question is y(yes) if not, answer n(no).

Upon answering y, the model will show on the screen the parameters selected so far (see the following example):

```
[1] SOWING DATE (MONTH)      : 2
[2] SOWING DATE (DAY)        : 17
[3] HARVEST DATE (MONTH)     : 5
[4] HARVEST DATE (DAY)       : 18
[5] SIMULATION STEP SIZE     : 5
[6] SOWING YEAR              : 1980

PLEASE ENTER A NUMBER (8 FOR OK) :[8]
```

After this the model will starting the first phase of the simulation model. The following prompts will ask the user specific question about the crop for which the simulation run will be carried out:

```
SELECT THE CROP GROUP ACCORDING TO THE TEMPERATURE DEPENDENT
PRODUCTION RATE (IN KG/HA/HOUR) FOR THE CROP GROUPS INDICATED
BELOW (FOR CROPS NOT LISTED USER MAY SPECIFY SIMILAR GROUP)
```

CROP GROUP		CROP NAME
[1]	Cool	alfafa,bean,cabbage,pea,potato, tomato,sugarbeet,wheat
[2]	Warm	alfalfa,citrus,cotton,groundnut, pepper,rice,safflower,soybean, sunflower,tobacco,tomato
[3]	Cool	some maize and sorghum varieties
[4]	Warm	maize,sorghum,sugarcane

```
ENTER CROP GROUP NUMBER: 4


SELECT CROP ACCORDING TO THE FOLLOWING TABLE.
```

CP N	CROP NAME	CP N	CROP NAME
[1]	BANANA TP	[16]	RICE
[2]	BANANA ST	[17]	SAFFLOWER
[3]	BEAN GR	[18]	SORGHUM
[4]	BEAN DRY	[19]	SOYBEAN
[5]	CABBAGE	[20]	SUGAR BEET
[6]	COTTON	[21]	SUGAR CANE
[7]	GRAPE	[22]	SUNFLOWER
[8]	GROUNDNUT	[23]	TOBACCO
[9]	MAIZE SWT	[24]	TOMATO
[10]	MAIZE GR	[25]	W MELON
[11]	ONION DRY	[26]	WHEAT
[12]	ONION GR	[27]	ALFALFA
[13]	PEA FRESH	[28]	CITRUS W
[14]	PEPPER FRS	[29]	CITRUS
[15]	POTATO	[30]	OLIVE

ENTER CROP NUMBER: 21

This is followed by:

THE LEAVE AREA INDEX (LAI) IS A MEASURE ASSOCIATED WITH THE EFFECTIVE RATE OF CROP DEVELOPMENT DEFINED AS A FUNCTION OF THE TOTAL LEAF AREA. FOR A STANDARD CROP AN ACTIVE LAI OF 5 IS ASSUMED. FOR LESS EFFECTIVE CROPS A REDUCTION FACTOR MUST BE APPLIED

EXAMPLES:

THE FOLLOWING GUIDELINES, ADJUSTED FOR VARIETIES MAY BE USED:

BANANA	**LAI = 5**
SUGARCANE	**LAI = 4**
MAIZE	**LAI = 4**
BEANS	**LAI = 3**
TOMATO	**LAI = 3**

ENTER LEAF AREA INDEX (LAI) [1-5]: 3

The next prompt request entry of the harvest index.

THE HARVEST INDEX (cH) IS DEFINED AS THE RATIO BETWEEN NET TOTAL DRY MATTER AND HARVESTED YIELD FOR HIGH PRODUCING VARIETIES WITHOUT WATER DEFICIT

THE HARVEST INDEX (FAO, 1979) IS: .258

NOTE: IF LISTED AS 0.0 NO DEFAULT VALUE IS AVAILABLE. THE USER SHOULD PROVIDE A NON ZERO VALUE.

DO YOU WISH TO ENTER A DIFFERENT INDEX VALUE? (Y/N) [Y]:

After the entries to the prompts have been completed, the model execute the first phase. The following message will appear:

Executing phase 1 ....

DO YOU WANT TO PRINT THE RESULT OF THE PHASE 1? (Y/N) [N]:y

DO YOU WANT TO SEE RESULTS ON THE SCREEN? (y or n)

DO YOU WANT TO SEE RESULTS OF LAST SIMULATION RUN? (y or n)

If the answer is n(no), the user will be prompted to indicate the file name,

ENTER FILE NAME:

If the answer is y(yes), the model will get the file generated by the first phase of the last run (see example next page):
Now the second phase two of the simulation model starts and the following logo will appear on the screen:

CRIES - AGRO-ECONOMIC INFORMATION SYSTEM
YIELD GENERATOR (CRIES - AIS - YIELD)
MICHIGAN STATE UNIVERSITY, EAST LANSING, MI 48823

COUNTRY NAME: Dominican-Republic
POL./ADM. DISTRICT: San-Juan
WEATHER STATION NAME: Ocoa
RESOURCE PROD UNIT OR
AGRO-ECOLOGICAL ZONE: II

CROP TYPE: MAIZE GRAIN
YEAR OF ORIGIN: 1977
GROWTH PERIOD: 2/15/1977 TO 6/15/1977
FARMING SYSTEM: 1.12

LATITUDE: 18.40(deg)
HEMISPHERE: NORTHERN
AVERAGE ALTITUDE: 1000.00(m)
TIME INCREMENTS (DT): 5 (days)

PHASE I: CALCULATION OF MAXIMUM POTENTIAL YIELD (Ym).

T (DAYS)	MTH/DAY	GROSS DRY MATTER PRODUCTION STANDARD CROP - (kg/ha) **** total **** (absol change)	(cumm change)	** overcast day * (absol change)	(cumm change)	*** clear day *** (absol change)	(cumm change)	GROSS DRY MATTER PRODUCTION ********* corrections ************ (prod rate)	(cloud perc)	(leaf area f)	(net prod f)	(harvs index)	POTENTIAL YIELD ****** (kg/ha) ****** (absolute change)	(cumm change)
5	2/20	2861.	2861.	988.	988.	1892.	1892.	49.60	.21	.48	.50	.40	275.	275.
10	2/25	2922.	5783.	1005.	1993.	1920.	3812.	50.20	.21	.48	.50	.40	281.	555.
15	3/ 2	2984.	8767.	1023.	3016.	1949.	5761.	50.80	.22	.48	.50	.40	286.	842.
20	3/ 7	3046.	11813.	1040.	4056.	1977.	7738.	51.40	.22	.48	.50	.40	292.	1134.
25	3/12	3109.	14923.	1057.	5114.	2005.	9743.	52.00	.22	.48	.50	.40	299.	1433.
30	3/17	3173.	18096.	1075.	6188.	2034.	11777.	52.60	.23	.48	.50	.40	305.	1737.
35	3/22	3202.	21298.	1091.	7279.	2060.	13837.	53.20	.25	.48	.50	.40	307.	2045.
40	3/27	3208.	24507.	1106.	8386.	2085.	15922.	53.80	.28	.48	.50	.40	308.	2353.
45	4/ 1	3214.	27721.	1122.	9508.	2109.	18031.	54.40	.30	.48	.50	.40	309.	2661.
50	4/ 6	3219.	30940.	1137.	10645.	2134.	20165.	55.00	.32	.48	.50	.40	309.	2970.
55	4/11	3224.	34164.	1153.	11798.	2159.	22324.	55.60	.35	.48	.50	.40	310.	3280.
60	4/16	3229.	37394.	1168.	12966.	2184.	24508.	56.20	.37	.48	.50	.40	310.	3590.
65	4/21	3240.	40633.	1179.	14145.	2203.	26711.	56.73	.38	.48	.50	.40	311.	3901.
70	4/26	3254.	43887.	1187.	15332.	2218.	28929.	57.27	.39	.48	.50	.40	312.	4213.
75	5/ 1	3268.	47156.	1196.	16528.	2234.	31163.	57.80	.40	.48	.50	.40	314.	4527.
80	5/ 6	3283.	50438.	1204.	17732.	2249.	33413.	58.33	.41	.48	.50	.40	315.	4842.
85	5/11	3296.	53735.	1212.	18944.	2265.	35678.	58.87	.42	.48	.50	.40	316.	5159.
90	5/16	3310.	57045.	1220.	20164.	2280.	37958.	59.40	.43	.48	.50	.40	318.	5476.
95	5/21	3341.	60386.	1225.	21389.	2290.	40248.	59.93	.43	.48	.50	.40	321.	5797.
100	5/26	3383.	63769.	1228.	22616.	2296.	42544.	60.47	.42	.48	.50	.40	325.	6122.
105	5/31	3426.	67195.	1231.	23847.	2302.	44846.	61.00	.42	.48	.50	.40	329.	6451.
110	6/ 5	3469.	70664.	1233.	25080.	2307.	47153.	61.53	.41	.48	.50	.40	333.	6784.
115	6/10	3512.	74176.	1236.	26316.	2313.	49467.	62.07	.41	.48	.50	.40	337.	7121.
120	6/15	3556.	77732.	1239.	27555.	2319.	51786.	62.60	.40	.48	.50	.40	341.	7462.
TOTAL			77732.		27555.		51786.							7462.

```
CRIES - Agro-Economic Information System
Module: YIELD SIMULATOR, Phase: REFERENCE EVAPOTRANSPIRATION
Version 1.00
Serial # MSU CRIES
(C) Copyright 1986. All Rights Reserved
Comprehensive Resource Inventory and Eva[illegible]
Michigan State University, East Lansing, MI 48824, USA
```

Upon pressing any key, the user will be prompted to enter the duration of the each phase of the growing period. A careful reading of the informations on the screen will help you to enter the requested parameters.

```
the "initial" stage
the "crop development" stage
the "mid-season" stage
the "late season" stage ,and
the "at harvest" stage.


The growth period must be equal to the sum of the
    duration of the each stage. The last stage is
    computed by the system.


ENTER DURATION "INITIAL"           STAGE [days]: 20
ENTER DURATION "CROP DEVELOPMENT"  STAGE [days]: 30
ENTER DURATION "MID-SEASON"        STAGE [days]: 30
ENTER DURATION "LATE SEASON"       STAGE [days]: 10
                     initial stage duration     =    20.days
                     crop development duration  =    30.days
                     mid-season duration        =    30.days
                     late season duration       =    10.days
                     at harvest stage duration  =    31.days


OK? (Y/N) [Y]:
```

The OK prompt, below, will appear. If wrong data were entered, answer n, otherwise, press the enter key.

OK? (Y/N) [Y]:

Now the following message will indicate the execution of the second phase:

Executing phase 2 ....

Followed by the prompts:

DO YOU WANT TO PRINT THE RESULT OF THE PHASE 2? (Y/N) [N]:y

and

DO YOU WANT TO SEE RESULTS ON THE SCREEN? (y or n)

and

DO YOU WANT TO SEE RESULTS OF LAST SIMULATION RUN? (y or n)

If the answer is y(yes), the user will be prompted to indicate the file name;

ENTER FILE NAME:

If the answer is y(yes), the model will access the file generated by the second phase of the last run.

CRIES - AGRO-ECONOMIC INFORMATION SYSTEM
YIELD GENERATOR (CRIES - AIS - YIELD)
MICHIGAN STATE UNIVERSITY, EAST LANSING, MI 48823

COUNTRY NAME: Dominican-Republic
POL./ADM. DISTRICT: San-Juan
WEATHER STATION NAME: Ocoa
RESOURCE PROD UNIT OR
AGRO-ECOLOGICAL ZONE: II

CROP TYPE: MAIZE GRAIN
YEAR OF ORIGIN: 1977
GROWTH PERIOD: 2/15/1977 TO 6/15/1977
FARMING SYSTEM: 1.12

LATITUDE: 18.40(deg)
HEMISPHERE: NORTHERN
AVERAGE ALTITUDE: 1000.00(m)
TIME INCREMENTS (DT): 5 (days)

PHASE 2: CALCULATION OF MAXIMUM EVAPOTRANSPIRATION USING THE PENMAN METHOD (ETm)

T (DAYS)	MTH/DAY	CROP STAGE	REF EVAPT(ETo) (mm/dT)	******* CROP COEFFICIENT (Kc) ******* Kc1	Kc2	Kc3	Kc4	Kc5	Tot	MAX EVAPT(ETm) (mm/dT)
5	2/20	I	23.05	.40	.00	.00	.00	.00	.82	9.22
10	2/25	I	23.64	.40	.00	.00	.00	.00	.82	9.46
15	3/ 2	I	24.25	.40	.00	.00	.00	.00	.82	9.70
20	3/ 7	I	24.85	.40	.00	.00	.00	.00	.82	9.94
25	3/12	II	25.44	.00	.77	.00	.00	.00	.82	19.72
30	3/17	II	26.00	.00	.77	.00	.00	.00	.82	20.15
35	3/22	II	26.32	.00	.77	.00	.00	.00	.82	20.39
40	3/27	II	26.48	.00	.77	.00	.00	.00	.82	20.52
45	4/ 1	II	26.63	.00	.77	.00	.00	.00	.82	20.64
50	4/ 6	II	26.79	.00	.77	.00	.00	.00	.82	20.76
55	4/11	III	26.92	.00	.00	1.13	.00	.00	.82	30.28
60	4/16	III	27.04	.00	.00	1.13	.00	.00	.82	30.42
65	4/21	III	27.03	.00	.00	1.13	.00	.00	.82	30.41
70	4/26	III	26.95	.00	.00	1.13	.00	.00	.82	30.31
75	5/ 1	III	26.86	.00	.00	1.13	.00	.00	.82	30.21
80	5/ 6	III	26.77	.00	.00	1.13	.00	.00	.82	30.11
85	5/11	III	26.68	.00	.00	1.13	.00	.00	.82	30.01
90	5/16	III	26.59	.00	.00	1.13	.00	.00	.82	29.91
95	5/21	IV	26.78	.00	.00	.00	.88	.00	.82	23.43
100	5/26	IV	27.16	.00	.00	.00	.88	.00	.82	23.77
105	5/31	IV	27.55	.00	.00	.00	.88	.00	.82	24.10
110	6/ 5	IV	27.94	.00	.00	.00	.88	.00	.82	24.45
115	6/10	V	28.34	.00	.00	.00	.00	.58	.82	16.30
120	6/15	V	28.75	.00	.00	.00	.00	.58	.82	16.53

Now, phase three of the simulation model starts and the following logo will appear on the screen:

```
CRIES - Agro-Economic Information System
Module: YIELD SIMULATOR, Phase: ACTUAL EVAPOTRANSPIRATION
Version 1.00
Serial # MSU CRIES
(C) Copyright 1985. All Rights Reserved
Comprehensive Resource Inventory and Evaluation System (CRIES)
Michigan State University, East Lansing, MI 48824, USA
```

Upon pressing any key, the user will be prompted to enter the parameters required to run phase 3 of the yield model. This includes the selection of the crop group based on the water depletion factor, the Sa factor, the selection of dominant slope gradient and soil texture, soil moisture content at sowing date, average rooting depth during the five development stages, irrigation option and schemes, farm management practices affecting soil moisture preservation and the general fertilizer availability using the screens below:

SELECT THE CROP GROUP TO DETERMINE THE WATER DEPLETION
FACTOR (INCREASING FROM LOW - GROUP 1 TO HIGH - GROUP 4).
FOR GROUPS NOT LISTED, USER MAY SPECIFY SIMILAR GROUP.

CROP GROUP ACCORDING TO WATER DEPLETION	
GROUP	CROPS
[1]	onion,pepper,potato
[2]	banana,cabbage,grape,pea,tomato
[3]	alfalfa,bean,citrus,groundnut,wheat, pineapple,sunflower,watermelon
[4]	cotton,maize,olive,safflower,sorghum, soybean,sugarbeet,sugarcane,tobacco

Total available soil water (Sa) is defined here as the depth of water in mm/m soil depth between the soil water content at field capacity (Sfc or at soil water tension of 0.1 to 0.2 atmosphere) and the soil water content at wilting point (Sw or at soil water tension of 15 atmosphere). Total available soil water (Sa) can vary widely for soils having a similar texture. Also, most soils are layered and integrated values of Sa over soil depth should be selected; dense layers restrict water distribution.

As a general guideline, (FAO, 1979), the following Sa (mm/m) values for different soil textural classes are provided.

heavy textured soil	200mm/m
medium textured soil	140mm/m
coarse textured soil	60mm/m

ENTER TOTAL AVAILABLE SOIL WATER: 115

ADJUSTMENT OF WATERHOLDING CAPACITY BASED ON INFILTRATION RATE DIFFERENTIAL IN SOIL TEXTURAL CLASSES AND AS A FUNCTION OF SLOPE GRADIENT

SELECT DOMINANT SLOPE GRADIENT (PERCENTAGE):

0 - 4%	LEVEL TO GENTLY UNDULATING	[1]
> 4 - 8%	MODERATELY UNDULATING	[2]
> 8 - 12%	HIGHLY UNDULATING	[3]
>12 - 15%	STEEP UNDULATING	[4]
>15 - 20%	MODERATELY STEEP	[5]
>20 - 30%	STEEP	[6]
>30 - 50%	VERY STEEP	[7]
>50%	PRECIPITOUS TO VERTICAL	[8]

ENTER SELECTION:

SELECT DOMINANT AND AGGREGATE SOIL TEXTURAL CLASS:

COARSE LOAMY [1]
FINE SILTY, FINE LOAMY & FINE [2]
VERY FINE [3]

ENTER SELECTION:

ENTER SOIL MOISTURE CONTENT AT SOWING DATE (IN MM/M):

The growth period is devided into five stages.
the "initial" stage
the "crop development" stage
the "mid-season" stage
the "late season" stage ,and
the "at harvest" stage.

Please enter AVERAGE root growth, (cm), for each stage of the growing season.

ROOT "INITIAL" STAGE [cm]: 10
ROOT "CROP DEVELOPMENT" STAGE [cm]: 20
ROOT "MID-SEASON" STAGE [cm]: 40
ROOT "LATE SEASON" STAGE [cm]: 50
ROOT "AT HARVEST" STAGE [cm]: 60

DO YOU WANT TO USE IRRIGATION? (Y/N) [Y]:

Note: If the user selects irrigation, prompts will appear requesting input of an irrigation scheme in mm/day.

DO YOU WISH TO CONSIDER SOIL MOISTURE PRESERVING FARM MANAGEMENT TECHNIQUES, SUCH AS MINIMUM TILLAGE, MULCHING OR OTHERS (Y,N) [N]:

IF FERTILIZER REQUIREMENT IS FULLY MET ENTER 100.0.
OTHERWISE ENTER THE FERTILIZER PERCENTAGE USED:

The ok prompts will appear, if wrong data were entered, answer n, otherwise, press the enter key.

OK? (Y/N) [Y]:

This will start execution of the third phase of the yield model, indicated by:

Executing phase 3 ....

followed by:

DO YOU WANT TO PRINT THE RESULT OF THE PHASE 3? (Y/N) [N]:y

and

DO YOU WANT TO SEE RESULTS ON THE SCREEN? (y or n)

DO YOU WANT TO SEE RESULTS OF LAST SIMULATION RUN? (y or n)

If the answer is y(yes), the user will be prompted to indicate the file name and the screen output of phase three will be generated (see next page,

If the answer is n(no) the model access the file generated by the last run and execute the final phase, indicated by:

CRIES - Agro-Economic Information System
Module: YIELD SIMULATOR, Phase: ESTIMATED YIELD
Version 1.00
Serial # MSU CRIES

Comprehensive Resource Inventory and Evaluation System (CRIES)
Michigan State University, East Lansing, MI 48824, USA

CRIES - AGRO-ECONOMIC INFORMATION SYSTEM
YIELD GENERATOR (CRIES - AIS - YIELD)
MICHIGAN STATE UNIVERSITY, EAST LANSING, MI 48823

COUNTRY NAME:	Dominican-Republic	CROP TYPE:	MAIZE GRAIN	LATITUDE:	18.40(deg)
POL./ADM. DISTRICT:	San-Juan	YEAR OF ORIGIN:	1977	HEMISPHERE:	NORTHERN
WEATHER STATION NAME:	Ocoa	GROWTH PERIOD:	2/15/1977 TO 6/15/1977	AVERAGE ALTITUDE:	1000.00(m)
RESOURCE PROD UNIT OR AGRO-ECOLOGICAL ZONE:	11	FARMING SYSTEM:	1.12	TIME INCREMENTS (DT):	5 (days)

PHASE 3: CALCULATION OF ACTUAL EVAPOTRANSPIRATION (ETa).

T (DAYS)	MTH/DAY	MAX EVAPT(ETm) (mm/dt)	*********** WATER AVAILABILITY PARAMETERS******* Preci (mm/dt)	Irrig (mm/dt)	Sa, mm (mm)	R Depth (m)	Soil Water index(avg)	ACT EVAPT(ETa) (mm/dt)
5	2/20	9.20	1.61	.00	1.76	.10	.48	4.80
10	2/25	9.45	1.41	.00	.00	.10	.10	3.24
15	3/ 2	9.70	1.21	.00	.00	.10	.08	3.01
20	3/ 7	9.95	1.01	.00	.00	.10	.06	2.79
25	3/12	19.72	.81	.00	.00	.40	.00	.66
30	3/17	20.15	.61	.00	.01	.40	.00	.45
35	3/22	20.39	.82	.00	.01	.40	.00	.63
40	3/27	20.51	1.29	.00	.00	.40	.00	1.04
45	4/ 1	20.64	1.77	.00	.00	.40	.00	1.44
50	4/ 6	20.76	2.24	.00	.00	.40	.00	1.85
55	4/11	30.28	2.72	.00	.09	.60	.00	1.89
60	4/16	30.41	3.19	.00	.10	.60	.00	2.29
65	4/21	30.41	3.69	.00	.09	.60	.00	2.70
70	4/26	30.31	4.21	.00	.09	.60	.00	3.13
75	5/ 1	30.21	4.73	.00	.08	.60	.00	3.56
80	5/ 6	30.11	5.25	.00	.08	.60	.00	3.98
85	5/11	30.01	5.77	.00	.08	.60	.00	4.41
90	5/16	29.91	6.29	.00	.07	.60	.00	4.84
95	5/21	23.43	5.97	.00	.10	.80	.00	4.44
100	5/26	23.77	5.09	.00	.11	.80	.00	3.72
105	5/31	24.10	4.20	.00	.12	.80	.00	2.99
110	6/ 5	24.45	3.32	.00	.13	.80	.00	2.25
115	6/10	16.30	2.44	.00	.05	1.00	.00	1.77
120	6/15	16.54	1.55	.00	.05	1.00	.00	1.05

Followed by:

Executing phase 4 ....

DO YOU WANT TO PRINT THE RESULT OF THE PHASE 4? (Y/N) [N]:y

DO YOU WANT TO SEE RESULTS ON THE SCREEN? (y or n)

DO YOU WANT TO SEE RESULTS OF LAST SIMULATION RUN? (y or n)

If the answer is y(yes), the user will be prompted to indicate the file name,

ENTER FILE NAME:

If the answer is y(yes), the model will display the file generated by the fourth phase of the last run (next page).

CRIES - AGRO-ECONOMIC INFORMATION SYSTEM
YIELD GENERATOR (CRIES - AIS - YIELD)
MICHIGAN STATE UNIVERSITY, EAST LANSING, MI 48823

COUNTRY NAME:	Dominican-R ublic	CROP TYPE:	MAIZE GRAIN	LATITUDE:	18.40(deg)
POL./ADM. DISTRICT:	San-Juan	YEAR OF ORIGIN:	1977	HEMISPHERE:	NORTHERN
WEATHER STATION NAME:	Ocoa	GROWTH PERIOD:	2/15/1977 TO 6/15/1977	AVERAGE ALTITUDE:	1000.00(m)
RESOURCE PROD UNIT OR AGRO-ECOLOGICAL ZONE:	11	FARMING SYSTEM:	1.12	TIME INCREMENTS (DT):	5 (days)

PHASE 4: CALCULATION OF ESTIMATED YIELD (Ye) Ye = DRY MATTER PRODUCTION

T (DAYS)	MTH/DAY	MAX EVAPT(ETm) (mm/dT)	ACT EVAPT(ETa) (mm/dT)	YLD RESP FACTOR (kv)	CHANGE P YIELD (kg/ha)	CHANGE E YIELD (kg/ha)	CUMM YIELD (Ye) (kg/ha)
5	2/20	9.22	4.80	.40	274.65	222.11	222.
10	2/25	9.46	3.24	.40	280.52	206.78	429.
15	3/ 2	9.70	3.01	.40	286.46	207.43	636.
20	3/ 7	9.94	2.79	.40	292.45	208.27	845.
25	3/12	19.72	.66	1.50	298.50	.00	845.
30	3/17	20.15	.45	1.50	304.61	.00	845.
35	3/22	20.39	.63	1.50	307.43	.00	845.
40	3/27	20.52	1.04	1.50	308.00	.00	845.
45	4/ 1	20.64	1.44	1.50	308.55	.00	845.
50	4/ 6	20.76	1.85	1.50	309.06	.00	845.
55	4/11	30.28	1.89	.50	309.54	164.43	1009.
60	4/16	30.42	2.29	.50	310.00	166.67	1176.
65	4/21	30.41	2.70	.50	311.01	169.31	1345.
70	4/26	30.31	3.13	.50	312.40	172.33	1517.
75	5/ 1	30.21	3.56	.50	313.77	175.37	1693.
80	5/ 6	30.11	3.98	.50	315.12	178.39	1871.
85	5/11	30.01	4.41	.50	316.45	181.48	2053.
90	5/16	29.91	4.84	.50	317.76	184.59	2237.
95	5/21	23.43	4.44	.20	320.71	268.72	2506.
100	5/26	23.77	3.72	.20	324.79	270.00	2776.
105	5/31	24.10	2.99	.20	328.90	271.28	3047.
110	6/ 5	24.45	2.25	.20	333.03	272.55	3320.
115	6/10	16.30	1.77	.20	337.19	277.08	3597.
120	6/15	16.53	1.05	.20	341.37	277.43	3874.
TOTAL							3874.

4. MODEL VALIDATION FOR SELECTED CROPS IN JAMAICA

Initial validation of the YIELD model was accomplished for a limited number of crops in Jamaica and the Dominican Republic, as part of a technical assistance activities funded by the U.S. Agency for International Development and the World Bank. However, the availability of reliable time series data for various crop yields representing a variety of agro-ecological conditions and farm management practices in these countries, is limited. The only location-specific yield data available represent large scale mono-cultivations of irrigated sugarcane in Jamaica. Other yield data represent average yields for the country, reported on an annual basis, or reported yield ranges for the regions as reported by the Ministry of Agriculture.

In the case of Jamaica, yearly predictions were made for three sugarcane producing regions, namely Worthy Park, Caymanas, and Monymusk. These locations represent traditionally well producing regions. Observed yields were available for a twenty year period from 1963 to 1982.

In addition, yield predictions for tobacco and sorghum were carried out for these regions using the "average" mode, representing mean annual conditions during the growing period of the environmental variables precipitation, temperature, relative humidity, solar radiation, and wind velocity. These simulation results are compared with the actual average yield for tobacco and sorghum for the regions of Worthy Park, Caymanas, and Monymusk in Jamaica.

4.1 Data Inputs for Model Simulation in Jamaica.

The following inputs, representing the National Data Base for Jamaica (CRIES, 1982 and other non-published documentation compiled by CRIES and the MOA, Jamaica) complemented with empirical data (FAO, 1979) were used predict crop yields:

A) Environmental Data Set;
1. monthly mean temperature,
2. monthly mean precipitation,
3. monthly mean relative humidity,
4. monthly mean solar radiation, and
5. monthly mean wind velocity and day/night wind ratio.

B) Crop Production Parameters;
1. average root size for each phase of the growing period,
2. leaf area index (LAI),
3. water depletion factor (p),
4. production rate (ym),
5. crop coefficient (kc), and
6. yield response factor (ky).

C) Farm Management Practice Parameters;
1. sowing or planting date,
2. harvesting date,
3. duration of each stage of the growth period,
4. irrigation parameter and/or values,
5. evaporation reduction factor, and
6. fertilizer usage.

D) Local Parameters;
1. altitude,
2. latitude,
3. location (northern or southern hemisphere),
4. slope class (Table 20)
5. soil type (Table 20)
6. soil textural class,
7. soil moisture availability, and
8. soil salinity level.

The specific the crop parameters used in the simulation runs for Worthy Park, Caymanas, and Monymusk in Jamaica are represented below (Table 24).

Table 24. Deterministic YIELD Simulator: Jamaica - Crop Parameters - Sugarcane, Tobacco, and Sorghum for Worthy Park, Caymanas, Monymusk. (1979) (*)

Crop Parameter Type	Sugarcane	Tobacco	Sorghum
Root Size Variation in Centimeters (1)	20 - 120	10 - 150	10 - 175
Leaf Area Index (LAI)	3	3	2
Water Depletion Factor Variation (p) (2)	.400 - .875	.400 - .875	.400 - .875
Production rate (ym) (3)	.0 - 65.0	.0 - 35.0	.0 - 65.0
Crop coefficient (kc) (4)	.40 - 1.30	.30 - 1.20	.30 - 1.15
Yield response factor (ky) (5)	.10 - 0.75	.20 - 1.00	.20 - 0.55

(*) Doorenbos and Kassam (1979)
(1) Adjusted for local conditions according to RPPD data
(2) ETm - Maximum Evapotranspiration dependent factor
(3) Temperature dependent factor
(4) Depends on crop stage, wind velocity and relative humidity
(5) Depends on crop stage.

The specific values given to those parameters are defined in the table below (Table 25).

Table 25. Deterministic YIELD Simulator: Jamaica - Farm Management Practice Parameters for Sugarcane, Tobacco and Sorghum, for Worthy Park, Caymanas, and Monymusk. (*)

Farm Management Practice Parameters	Sugarcane	Tobacco	Sorghum
Sowing or Planting Date MM/DD/YY	02/15/YY	02/15/YY	02/15/YY
Harvesting Date MM-MM/YY+ (1)	01-04/YY+1	05-06/YY	06-07/YY
Duration of Growth Stages in Days (2)			
stage 1	30 - 80	10 - 15	15 - 20
stage 2	80 - 120	20 - 30	20 - 30
stage 3	100 - 220	30 - 35	15 - 20
stage 4	30 - 80	30 - 40	35 - 40
stage 5	30 - 60	10 - 20	10 - 15
Irrigation Parameter or Value (3)	F	F	F
Evaporation Reduction Factor(4)	N	N	N
Fertilizer Usage(5)	80 - 100	80 - 100	80 - 100

(*) Source: Jamaica - Ministry of Agriculture
Rural and Physical Planning Division.

(1) +1 means following year.

(2) Compiled from Doorenbos and Kassam, (1979) and adjust with RPPD data.

(3) Full irrigation was used. No data available on irrigation scheme, or amount of water used in irrigated crop production.

(4) No evaporation reduction factor was used. Information not available.

(5) Fertilizer usage in percent relative to Doorenbos and Kassam (1979) Crop requirement guidelines.

Specific local parameter values are identified in the table below (Table 26).

Table 26. Deterministic YIELD Simulator: Jamaica - Local Parameters for Worthy Park, Caymanas, and Monymusk. (*)

Crop Parameter	Worthy Park	Caymanas	Monymusk
Average Altitude in Meters	381.00	27.75	9.15
Average Latitude in Degrees	18.09	17.58	17.48
Location	1	1	1
Average Slope Class (1)	1	1	1
Average Soil Type (1)	2	2	2
Average Soil Textural Class in mm/m	115	125	125
Soil Moisture in mm/m (2)	90	90	90
Soil Salinity Level (3)	N/A	N/A	N/A

(*) Source: Jamaica - Ministry of Agriculture, Rural and Physical Planning Division.
(1) Table 1 - Chapter III
(2) Moisture at sowing date
(3) N/A - Data not available

4.2 Sugarcane Production in Jamaica.

For the period indicated, yield simulation for sugarcane was carried out and compared with observed yield data. The tabulated results for irrigated and rainfed yield in Worthy Park are provided on a yearly basis for the period 1963 to 1982 (see Table 27).

Table 27. Deterministic YIELD Simulator: Jamaica - St. Catherine - Worthy Park. Sugarcane - Observed Yield and Simulated Irrigated and Rainfed Yield 1963 - 1982. (tons/ha) (*)

Year	Observed Yield(**)	Simulated Irrigated Yield	Simulated Rainfed Yield
1963	80.82	86.94	81.90
1964	76.00	85.39	82.67
1965	79.95	94.67	89.71
1966	81.06	97.59	80.89
1967	71.58	79.16	72.12
1968	86.55	102.95	95.17
1969	76.99	82.60	74.05
1970	89.31	94.48	86.30
1971	78.87	86.97	79.63
1972	90.97	93.98	83.93
1973	85.64	89.66	85.49
1974	82.50	82.15	71.78
1975	79.34	90.10	85.19
1976	85.31	91.11	76.30
1977	63.77	95.04	91.93
1978	95.49	93.86	90.75
1979	90.72	89.04	86.25
1980	79.31	100.43	99.00
1981	85.58	92.21	81.98
1982	77.73	91.66	85.46

(*) Compiled from Simulation Results
(**) Source: Jamaica, Ministry of Agriculture
RPPD - Rural and Physical Planning Division.

Figure 7 represents a time plot of the observed (irrigated) sugarcane yield and simulated irrigated yield for Worthy Park, facilitating a visual comparison for the period 1963 to 1982.

As may be observed, the model responses represents the trend in observed yields from 1963 to 1974 very well. The period from 1975 to 1982 is characterized as an unstable production environment. Significant political and socio-economic changes affected productivity and final harvest results. It may be also observed that

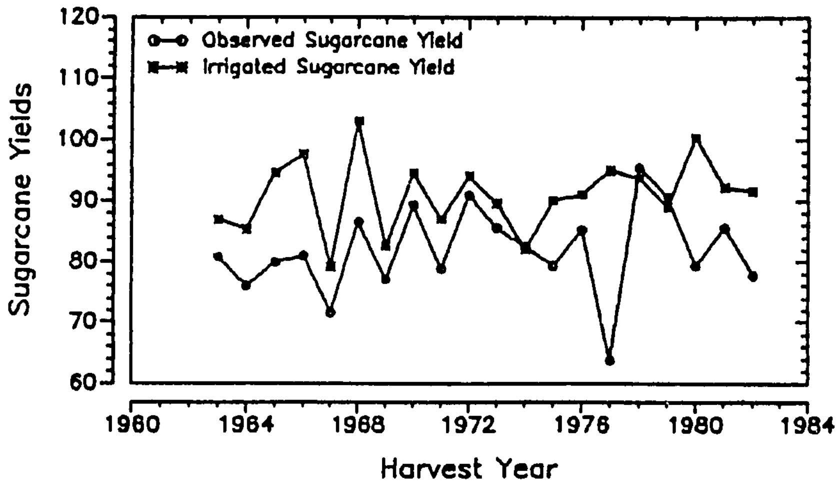


Figure 7. Deterministic YIELD Simulator: Jamaica - Worthy Park, Sugarcane Observed Yield and Simulated Irrigated Yield from 1963 to 1982.

simulated irrigated yields exceed frequently observed "irrigated" yields, indicating that existing water management procedures may constitute a production constraint for the period indicated. Lack of irrigation data makes it impossible to confirm this expectation.

The relationship between the observed yield and simulated rain-fed yield is depicted on the next page (Figure 8). Here it can be concluded that experienced water deficits cause a close relationship between observed and rain-fed yields, possibly confirming the expectation referred to above.

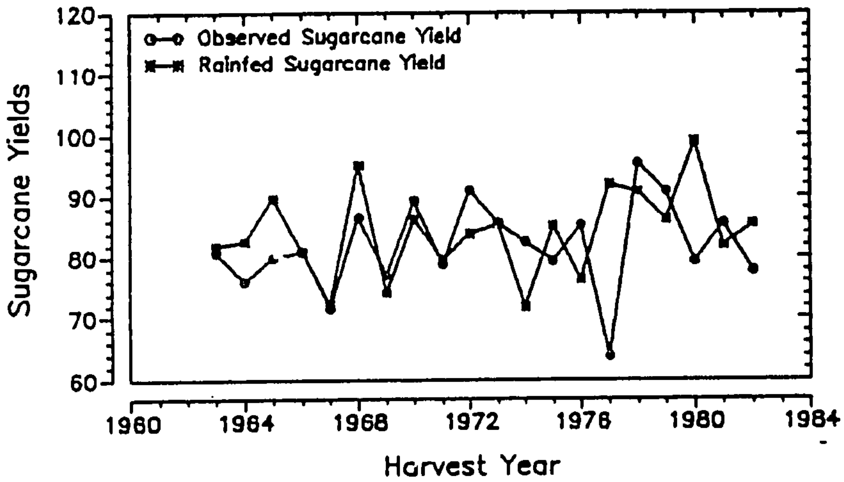


Figure 8. Deterministic YIELD Simulator: Jamaica - Worthy Park, Sugarcane Observed Yield and Simulated Rainfed Yield from 1963 to 1982.

Scattergrams of the different yield data are represented in the figures below (Figure 9 and Figure 10) The scattergrams include the "non-representative" time series for the period 1975 - 1982.

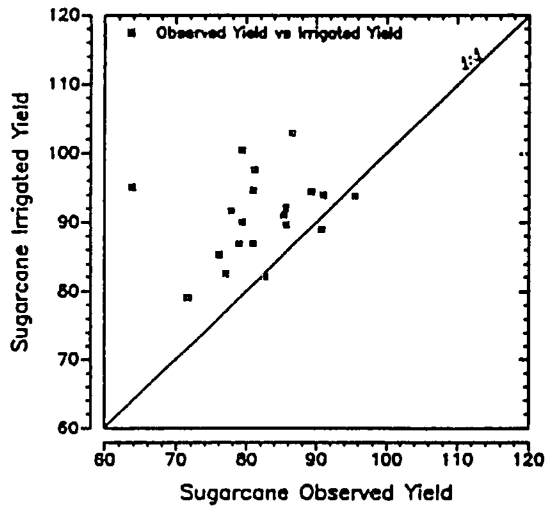


Figure 9. Deterministic YIELD Simulator: Jamaica - Worthy Park, Sugarcane Observed Yield versus Simulated Irrigated Yield.

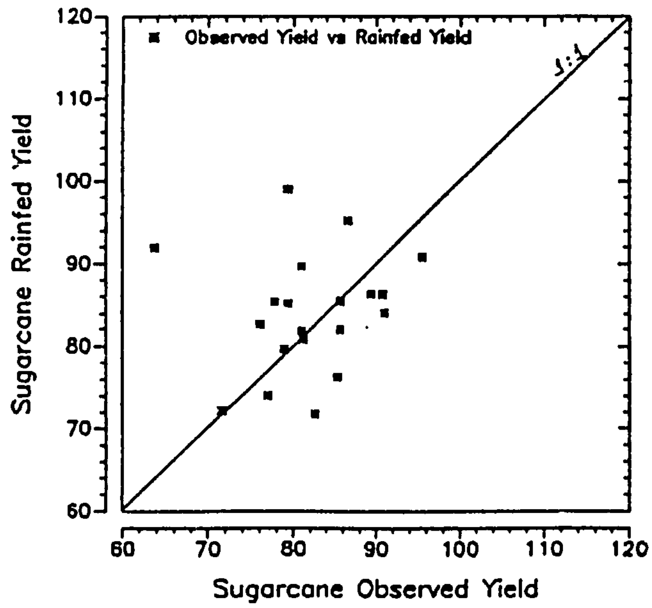


Figure 10. Deterministic YIELD Simulator: Jamaica - Worthy Park, Sugarcane Observed Yield versus Simulated Rainfed Yield.

Additional results for sugarcane are presented in tabular and graphic form for the other locations in Jamaica. Simulation results for Caymanas are depicted for the period 1963 -1982 (Table 28 and Figure 11).

Again, the model's performance as a measure of predicting irrigated sugarcane yields may be considered considered very good for the period from 1963 to 1976. In those years (see figure 11) the observed (irrigated) yield trend is followed closely by the predicted irrigated yield trend. For the the same reasons mentioned above, the period from 1977 to 1982 does not seems to represent a "normal relationship" between past production levels and agro-physiological and management conditions as represented in the YIELD model. These conclusions are confirmed by government sources in the country. The process of nationalization, political and socio-economic uncertainty

Table 28. Deterministic YIELD Simulator: Jamaica - St. Catherine - Caymanas. Sugarcane - Observed Yield and Simulated Irrigated and Rainfed Yield 1963 - 1982. (tons/ha) (*)

Year	Observed Yield(**)	Simulated Irrigated Yield	Simulated Rainfed Yield
1963	95.39	101.91	72.17
1964	91.46	102.03	82.67
1965	93.46	111.35	80.74
1966	91.29	110.56	75.98
1967	94.18	111.55	82.15
1968	76.62	110.06	64.34
1969	77.48	97.59	57.55
1970	84.62	102.60	80.79
1971	79.63	97.81	75.66
1972	97.39	115.87	74.97
1973	84.18	96.55	75.26
1974	82.20	98.77	63.82
1975	92.28	106.51	73.38
1976	78.72	95.29	60.27
1977	63.75	101.99	56.96
1978	68.98	105.07	67.97
1979	67.67	96.72	68.67
1980	63.72	102.90	82.62
1981	61.91	104.51	81.02
1982	65.75	101.02	77.95

(*) Compiled from Simulation Results
(**)Source: Jamaica, Ministry of Agriculture
RPPD - Rural and Physical Planning Division.

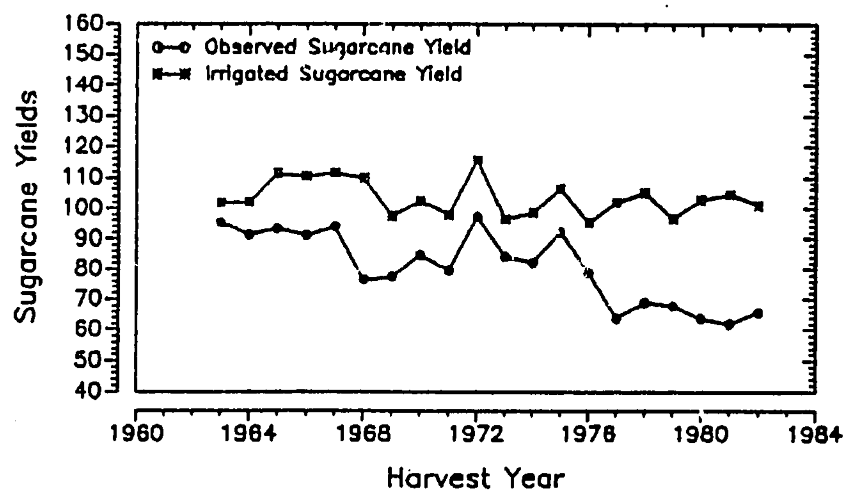


Figure 11. Deterministic YIELD Simulator: Jamaica - Caymanas, Sugarcane Observed Yield and Simulated Irrigated Yield from 1963 to 1982.

seemed to have contributed significantly to this unusual production relationship experienced during that period. This period was characterized by strikes, political unrest, crop destruction by the labor force, refusal to timely harvest crops, etc. For the period prior to 1976, the same conclusions may be drawn as discussed earlier. The relationship between the sugarcane observed yield and simulated rainfed yield is depicted below (Figure 12).

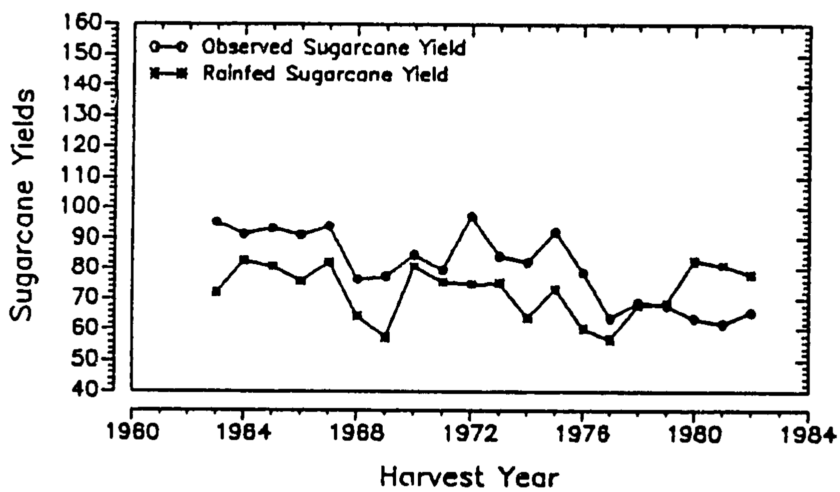


Figure 12. Deterministic YIELD Simulator: Jamaica - Caymanas, Sugarcane Observed Yield and Simulated Rainfed Yield from 1963 to 1982.

In this figure one may observe that the simulated rainfed yield is closest to the observed (irrigated) yield for the years considered. Observed sugarcane yield values are in most case above the simulated rainfed yields. These facts may suggest that better water management procedures could have provided increases in sugarcane yield. Again the effects of political problems related to sugarcane industry in Jamaica is shown by a strong random variation on the observed yield trend from 1975 to 1982.

To provide additional orientation, scattergrams of all values are presented in the figures below (Figures 13 and 14).

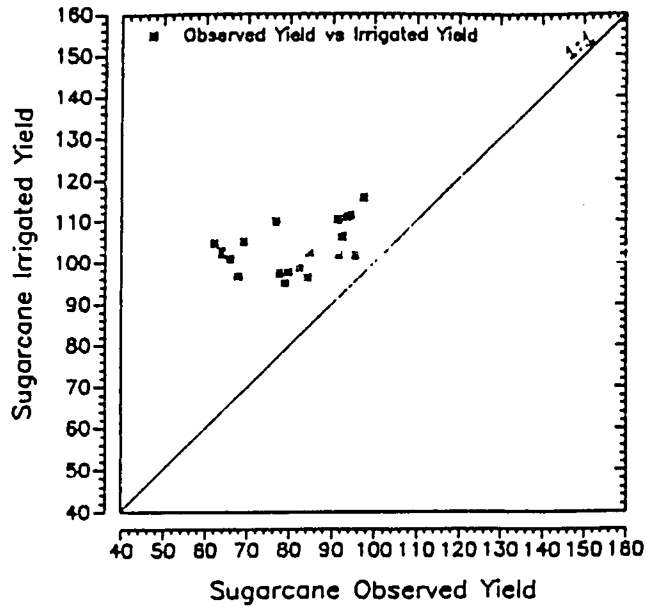


Figure 13. Deterministic YIELD Model: Jamaica - Caymanas, Sugarcane Observed Yield versus Simulated Irrigated Yield.

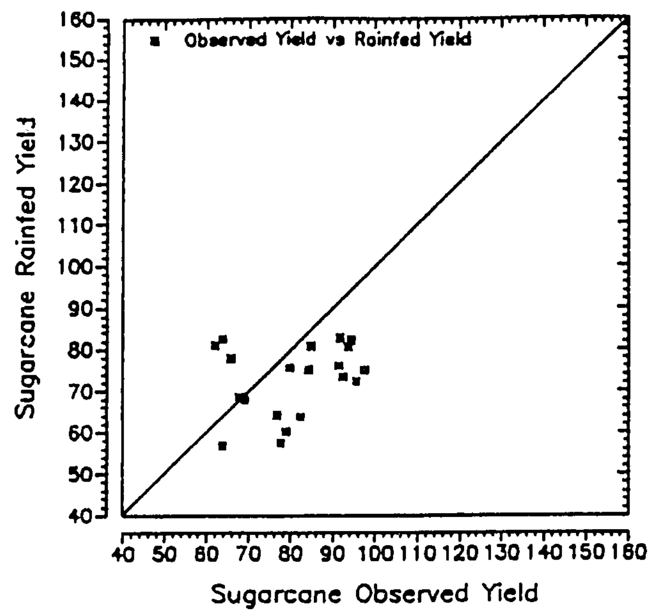


Figure 14. Deterministic YIELD Model: Jamaica - Caymanas, Sugarcane Observed Yield versus Simulated Rainfed Yield.

In the following table (Table 29) and graphic representation (Figure 15), observed and predicted sugarcane yield for the Monymusk region, Clarendon Parish, Jamaica are presented for the period 1963 - 1982.

Table 29. Deterministic YIELD Simulator: Jamaica - Clarendon - Monymusk. Sugarcane - Observed Yield and Simulated Irrigated and Rainfed Yield 1963 - 1982. (tons/ha) (*)

Year	Observed Yield(**)	Simulated Irrigated Yield	Simulated Rainfed Yield
1963	92.35	118.66	87.29
1964	86.94	111.05	87.75
1965	83.76	108.25	80.39
1966	90.97	126.55	92.77
1967	76.68	108.28	81.63
1968	70.62	106.53	58.78
1969	78.03	115.05	77.65
1970	82.97	121.92	102.62
1971	71.21	106.28	83.29
1972	78.57	122.41	105.05
1973	62.15	104.16	81.39
1974	70.47	109.70	81.13
1975	71.18	107.99	77.61
1976	72.37	117.84	68.69
1977	54.43	110.33	68.84
1978	74.00	129.05	99.12
1979	67.23	116.88	85.06
1980	61.50	127.45	103.86
1981	55.55	120.31	93.31
1982	53.92	131.90	116.33

(*) Compiled from Simulation Results.
(**)Source: Jamaica, Ministry of Agriculture
RPPD - Rural and Physical Planning Division.

Figure 15 represents a plot of the observed sugarcane yield and simulated irrigated yield for Monymusk for the same period. Similar conclusion may be drawn from these results. The following figures (Figure 16, 17 and 18) represent the results of the rainfed and irrigated yield predictions plotted against the observed (irrigated) values.

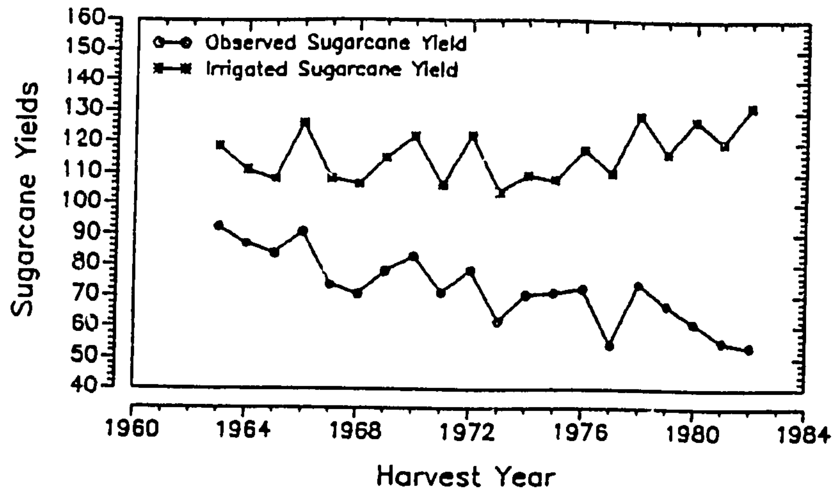


Figure 15. Deterministic YIELD Simulator: Jamaica - Monymusk, Sugarcane Observed Yield and Simulated Irrigated Yield from 1963 to 1982.

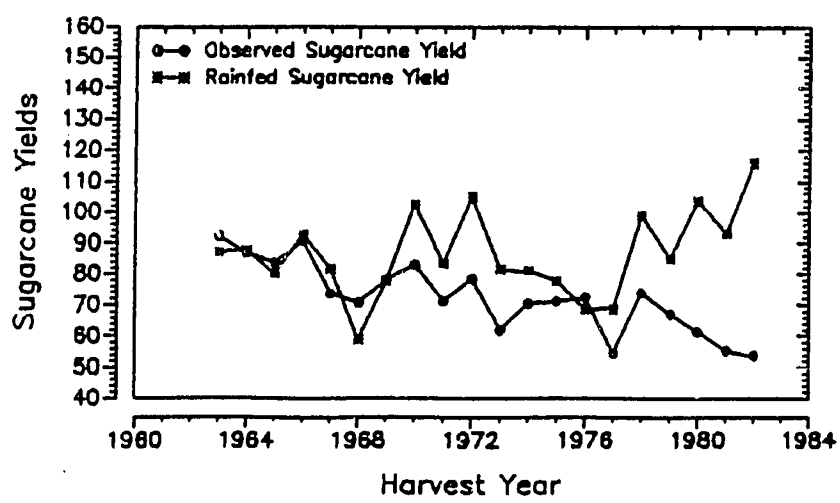


Figure 16. Deterministic YIELD Simulator: Jamaica - Monymusk, Sugarcane Observed Yield and Simulated Rainfed Yield from 1963 to 1982.

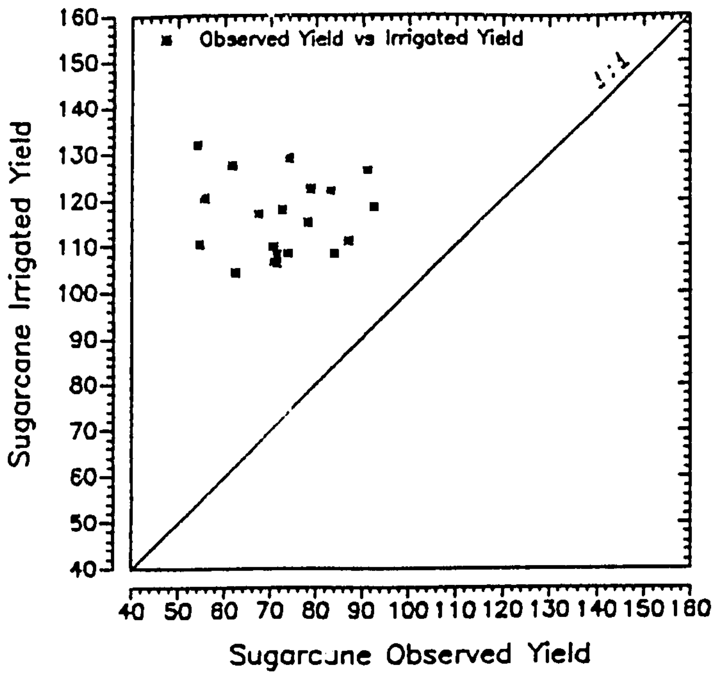


Figure 17. Deterministic YIELD Simulator: Jamaica-Monymusk, Sugarcane Observed Yield versus Simulated Irrigated Yield.

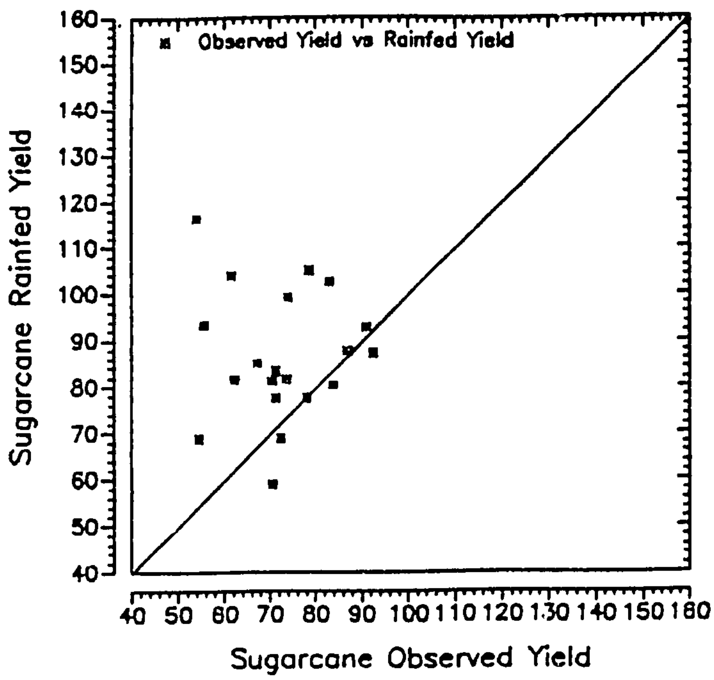


Figure 18. Deterministic YIELD Simulator: Jamaica - Monymusk, Sugarcane Observed Yield versus Simulated Rainfed Yield.

4.3 A Comparison between Predicted and Mean Observed Yield Values for Tobacco and Sorghum in Jamaica

Since location-specific yield observation are not available for Tobacco and Sorghum, this section represents a summary overview of predicted average annual yields and reported average annual yields in tabular and graphic form. First, a summary of average predicted yields is provided for the three locations (Table 30).

Table 30 Deterministic YIELD Simulator: Tobacco and Sorghum Jamaica - Worthy Park, Caymanas, and Monymusk. Simulated "Average" Yield Results Over the Period from 1963 to 1982. (tons/ha) (*)

Region	......Tobacco......		.......Sorghum.....	
	Irrigated	Rainfed	Irrigated	Rainfed
Worthy Park	3.148	2.462	3.869	3.803
Caymanas	3.033	2.212	3.308	2.866
Monymusk	4.862	3.589	3.627	3.250

(*) Source: Compiled from Simulation Results.

This may be compared with the averages for Jamaica as provided by the Rural Physical Planning Division of the Ministry of Agriculture (Personal Communication, 1984) These are:

1. tobacco: 1.0 to 2.0 tons per hectare,
2. sorghum 0.297 to 1.028 tons per hectare, and under good management for a selected cultivar 1.136 tons per hectare.

FAO (Doorenbos and Kassam,1979) indicates the following yields of high-producing varieties adapted to the climatic conditions of the available growing season under adequate water supply and high level of agricultural inputs under irrigated farming conditions for sugarcane, tobacco, and sorghum:

1. sugarcane	(cane)	100.00 to 150.00	tons/ha,
2. tobacco	(leaf)	1.50 to 2.50	tons/ha,
3. Sorghum	(grain)	2.00 to 5.00	tons/ha.

The deterministic YIELD simulator's results for sugarcane are largely within the yield value ranges given by Doorenbos and Kassam (1979). For sorghum, the simulation results are quite good when compared to Doorenbos and Kassam (1979), but very high when compared to the Jamaica average suggesting that adequate crop improvement potential exist for Jamaica's sorghum production system.

The simulation results in terms of average are very high compared to the average Jamaica tobacco yield and also high when compared to the values provided by Doorenbos and Kassam (1979). However, the user should keep in mind that the model's main purpose is to predict yields witout adjustments for pest and diseases or other factors and to evaluate production potential on a comparative basis for the agro-ecological conditions concerned. In addition, the tobacco production system is subject to many different cultivation and harvesting practices affecting "final reported yield". For instance, the crop is transplanted to the field at a certain stage of the growing season and harvesting techniques tend to very under different climatic conditions. Leaves are harvested during a period of time.

Additional simulations for crops grown under varied agro-ecological conditions are cuurently underway in a number of countries.

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