VALIDATION OF SOIL WATER BALANCE MODELS FOR CROP ASSESSMENT AND YIELD PREDICTION UNDER TANZANIAN CONDITIONS

BY

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ABSTRACT

The information gathering for early warning and crop assessment in Tanzania is still based on physical inspection of standing crops in fields. The physical inspection is based on sown area, the state of crop development towards maturity, the prevailing and anticipated weather conditions (during and after) at the time of inspection and the extent of crop attack by pests and diseases. The process is subject to human error and it is also time consuming.

Developments in computer simulation models may provide an efficient method for analysis of data for early warning and crop assessment. This study was aimed at validating Irrigation Scheduling Information System (IRSIS) and Crop Growth and Irrigation Scheduling Model (CRPSMW) which are soil water balance simulation models for crop assessment and prediction of grain yields.

Five stations viz. Ilonga Agricultural Research and Training Center, Msimba Foundation Seed Farm, Selian Agricultural Research Institute, Arusha Foundation Seed Farm, and Tanzania Pesticides Research Institute were selected for this study. Input data for the models comprised of weather, crop and soil data. Weather data was of a 10 year duration where as for the crop data the record length varied from 3 to 10 years.

The IRSIS model appeared to overpredict grain yield of maize, sorghum, and wheat. This could be attributed to the inadequacy of the model to accurately account for the runoff, a fact that was depicted in the model output whereby a portion of the excess rainfall was utilized by the crop for evapotranspiration purposes.

On the other hand, the CRPSMW model results were not significantly different ($P \leq 0.05$) from the actual grain yields simulated yields of maize, sorghum, wheat, and beans. The simulated grain yields for the different planting dates falling on or after the probable date for start of the growing season during the long rains for both Morogoro and Arusha were not significantly different ($P \leq 0.05$) from the actual grain yield. Although there was a good agreement between the actual and the CRPSMW model simulated grain yields, it was observed that, mean values for predicted grain yields were consistently smaller than for actual grain yields. This could be attributed to lack of representative location specific input parameters required by the model.

These results indicate that the subroutine in the IRSIS model that considers runoff is inadequate and needs to be reformulated and/or allowance should be given for calibration of the model with respect to the runoff component.

From the results it can be concluded, that a subroutine which considers factors such as hill slope, rainfall, and catchment area in estimating surface runoff should be incorporated into the IRSIS model to take account of the effects of excessive water on crop yields. There is also a need to determine more representative location specific parameters required by the CRPSMW model and the influence of moisture stress on different growth stages and hence yields under tropical conditions in order to increase its accuracy in predicting grain yields.

DECLARATION

I, PYTHIAS MWAKAJILA NTELLA do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is my original work and that it has never been submitted for a degree in any other University.

Signature...

Date....27 November 1998....................................

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DEDICATION

To Mother, Father, Elder Brother, Sisters and Young Brothers.

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ABBREVIATIONS AND SYMBOLS

α	A constant weighting factor.
A	A constant, kg/ha/mm.
AFSF	Arusha Foundation Seed Farm.
C_m	Maximum crop growth rate, kg/ha/day.
CN	Curve Number.
CRPSMW	Crop Growth and Soil Water Management.
E_o	The evaporation rate, mm.
ET_a	Actual crop evapotranspiration, mm.
ET_m	Potential crop evapotranspiration, mm.
λ_i	an exponent to allow for weighting growth period i.
IARTC	Ilonga Agricultural Research and Training Centre.
IRSIS	Irrigation Scheduling Information System.
K_y	Yield response factor.
MFSF	Msimba Foundation Seed Farm.
n	Represent the n^{th} growth period.
S	Potential Infiltration, mm/hr.
SARI	Selian Agricultural Research Institute.
SLF	Seasonal yield factor.
T	Total transpiration, mm.
T_a	actual transpiration, mm.
t_g	Length of the growth period from germination to harvest, days.

T_i	Cumulative transpiration in growth period i, mm.
t_l	Time loss, days.
T_m	Maximum transpiration, mm.
T_p	The accumulated potential transpiration for a full season, mm.
T_{Pi}	Cumulative potential transpiration which occurs when soil water is not limiting during growth period i, mm.
T_{Pth}	The corresponding threshold transpiration for adequate total dry matter prediction, mm.
W_m	Dry weight of a crop at harvest, kg.
Y	Total dry matter yield, kg/ha.
Y_a	Actual yield, kg/ha.
Y_m	Maximum yield, kg/ha.
Y_p	Potential yield, kg/ha.

1. INTRODUCTION

1.1 General

Agriculture forms the backbone of the economies of most Sub-Saharan African countries. However, compared to Asia where the per capita agricultural production has increased, Africa has been showing a declining trend. Nevertheless, it still remains the major employer upon which the livelihood of the majority of the population depends. Most of the agricultural activities in these countries depend on natural rainfall such that, any significant variation in the temporal and spatial distribution of rainfall usually results in serious food shortages and a worsening poverty trap for those whose livelihood directly depend on farming. In the past, the traditional farmers' remedy for climatic variability in rainfed agriculture has been to establish, on the basis of trial and error, conservative farming systems which provide a minimum livelihood in even the least favourable seasons. Because of increased climatic variability, some of these conservative farming systems are now obsolete. Many are now realising that food security can only be attained and sustained through application of scientific information (Unganai and Kabanda, 1994).

For many decades, much more emphasis has been placed on ways to increase agricultural production through crop selection, the use of fertilisers and improved agricultural technology, employing a wide range of cheap energy. It is relatively recently that renewed attention has been focused on weather influences on crop growth and development, in particular, with regard to the relationship between weather and yields (Frere and Popov, 1979).

A search for an understanding of basic relationships between plants and environment has kept man occupied for centuries. Man has learned to use his knowledge of these basic relationships to his advantage for increasing crop production. The role of modelling in this search is an attempt to bring all factors involved in the soil-plant-atmosphere system together in order that various cause and effect relationships can be simulated (Shawcroft *et al.*, 1974).

Basic research into crop-water relationships has provided fundamental knowledge for modelling the response of crops to their environment under a wide range of soils, climate and agronomic patterns. The most common subject areas for which agroclimatic models have been developed are atmospheric conditions, soil conditions, crop development or phenological stages, crop performance, and farm management. With the availability of modem computer facilities and the new requirement for interpretation of weather and climate in terms of crop performance, agroclimatic modelling has developed rapidly from a research tool to an essential component of operational systems (Baier, 1981).

A food shortage occurring on large scale necessitates taking emergency measures. Early warning schemes and related crop yield forecasting methods aim at predicting a possible crop failure as early as possible in the course of the growing season. This allows the producer to estimate in advance the size of the harvest and the portion of it which can be sold or exported (Snijders, 1986). Early warning schemes are also important for the food-deficit regions or importing countries in order to predict in advance the size of the national harvest, their export capacity, and the portion of the country's food consumption to be procured from elsewhere. For such prediction, the inspection of the standing crop (sown area, state of development, attacks by pests and diseases etc.) in the region under consideration is a natural means. This physical inspection of the standing crop can be supplemented by the use of mathematical models predicting crop yield as a function of relevant observable variables such as rainfall and parameters of soil, crop and climate. It must be emphasised that the use of these models is only sensible in combination with physical inspection of the crop and in collaboration with farmers and agricultural experts (Snijders, 1986).

In Tanzania, field crop inspection method is used for Early Warning and Crop Yield Prediction. The Agricultural Extension Workers collect data related to crop production in fields of farmers selected as representatives of other farmers within a representative village. For each village, a sample of 15 households is assumed to give reasonable estimates of crop yield at regional level. The Agricultural Extension Workers, under the prevailing and anticipated weather conditions, provide estimates of crop yields at the state of crop development toward maturity. These estimates are then passed through various stages of the administration of the Ministry of Agriculture, for counterchecking, until they are finally put together into the country's totals at the Ministry.

Recent developments in computer models for predicting crop yields as influenced by weather, crop characteristics, and soil physical properties have a potential to provide more reliable results. Soil water balance simulation models such as Irrigation Scheduling Information System (IRSIS) by Raes *et al.* (1988) and Crop and Soil Water Management and Water Requirements Simulation Model (CRPSMW) by Hill (1997), are two such models. The models take into consideration soil physical characteristics and also incorporate crop-weather analysis.

1.2 Objectives of the study

The main objective of this study was to validate two soil water balance simulation models viz. IRSIS and CRPSMW models for crop assessment and crop yield prediction.

The specific objectives were:

- to collect and process relevant soil, climatic and crop data for calibration of IRSIS and CRPSMW simulation models;
- to compare IRSIS and CRPSMW results with actual field crop performance; and
- to select the most suitable simulation model for adoption.

2. LITERATURE REVIEW

2.1 Crop forecasting methods based on agrometeorological data

Agroclimatic models are defined as techniques for interpreting climatological data and other physical/biological information in support of agricultural research, development and services (Baier, 1979). These techniques range from rather simple (e.g. degree days) to complex soil/crop/climate models. Although this rather broad definition encompasses many types of models, Baier (1979) proposed a classification system based on approach, time scale, data source, purpose and application of crop/weather models. The following three types of models were identified on the basis of their predominant approach and emphasis on biological, physical, and statistical aspects:

- Multiple regression yield models;
- Mechanistic-type crop growth simulation models; and
- Statistically based crop-weather analysis models.

2.1.1 Multiple Regression Yield Models

These models are developed from a sample of yield, weather, and soil data obtained from the same area and are then used to produce estimates of multiple regression coefficients by regression technique (Baier, 1981). The validity and potential application of such models depend on the representativeness of the input data, the selection of variables, and the design of the model. The approach does not easily lead to an explanation of the cause-and-effect relationship, but it is a feasible procedure that makes use of available yield and climatic data for weather-based evaluations of historical, current, and expected crop yield statistics (Baier, 1981).

The usefulness of regression yield models has been demonstrated in four areas of application namely: (a) the assessment of potential crop production based on climate, (b) the monitoring of crop prospects from current weather data, (c) the evaluation of the impact of natural or man induced climatic variability on crop yields, and (d) the interpretation of the effect of weather (Baier, 1981). Regression yield models are sufficiently robust in the sense that site characteristics like weather and soil, which vary from place to place are required inputs into the model such that the models could be used anywhere (Xevi, 1992).

Certain problems related to design, data base, and use of multiple regression have been observed. Biswas (1980), pointed out five major problems:

- multiple regression analyses often lead to the development of black box models that do not provide an understanding of the interrelations of different physical/ecological processes involved, yet they may give statistically significant results because of spurious correlation or other misuses of statistical techniques;
- coefficients of these models are statistical estimates and are subject to statistical errors;

- the square of the multiple regression coefficient (r^2) is only an indicator of the statistical significance of the model and is not an indication of the model's structural accuracy;
- the data base is inadequate and does not cover the full range of possible data because the variations in the dependent variable (Y) and in the independent variable (X) are small, a situation that occurs if the period of observation is short (a real problem in developing countries) and that the statistics imply a linear relationship between crop yields and weather variables;
- linear regression analysis assumes that independent variables are not closely related to each other although meteorological variables (mean monthly values of temperature and precipitation) are frequently closely correlated and sometimes also for adjacent months and that this severe multicollinearity can result in major errors in the correlation coefficient between crop yields and independent variables to the extent that even the sign of the coefficient may be erroneous.

Another difficulty with regression yield models, especially when analysing long-term yield/weather data, is separating the effects due to technological change. Long-term series of yield statistics, particularly in developed countries, are often affected by a time trend due to technology (increased fertilizer use, improved varieties, more efficient farm machinery for planting, cultivation, and harvesting; etc.). It is difficult to separate properly such technological advances reflected in the time trend from weather or climate trends. A good knowledge of data base and understanding of the statistical procedures employed in the analysis is necessary to develop an effective time trend function (Baier, 1981).

Haigh (1977) investigated the problem of weather-time separation in great detail. He analyzed 35-year series of corn, soybeans, winter wheat, and spring wheat yields in selected States of U.S.A. and concluded that:

- There is no evidence that technology has reduced the sensitivity of grain yields to weather;
- The percent of yield variation explained by management is roughly two to three times the percent explained by weather;
- The interaction between management and weather ranges between 10 to 20 percent of the total yield variation.

2.1.2 Mechanistic-type Crop Growth Simulation models

A crop growth simulation model may be defined as a simplified representation of physical, chemical and physiological mechanisms underlying plant growth processes (Frere and Popov, 1979). It is assumed that the impact of meteorological variables on specific processes such as photosynthesis, transpiration or respiration can be adequately simulated by means of a set of mathematical equations based on experiments or available knowledge of the particular process. In humid climates with low temperatures and radiation levels, the model will generally show the greatest response of yields to increase in total radiation received. In an arid and hot climate it will show the greatest response to the distribution and total amount of precipitation (Baier, 1979).

The Crop-Environment Resource Synthesis (CERES) models by Xevi (1992), have been designed to simulate crop phenological development and growth. Weather inputs are daily maximum and minimum air temperatures, solar radiation, and precipitation. The development of the crop is divided into development stages during which dry matter partitioning between various plant organs remains fairly constant and being dependent on temperature, water and nutrient stresses. Dry matter, in the CERES models, is calculated as a linear function of intercepted photosynthetically active radiation (PAR). The potential dry matter depends on the amount of biomass already produced and the leaf area index. The model utilizes the lower and upper limit of plant extractable water to apportion total infiltrated water among the various soil layers by a simple cascading principle.

Reviewed dynamic growth and development model by Stewart *et al.* (1975) was based on the assumption that crop production is directly related to evapotranspiration (ET) or evapotranspiration deficit (ETd). It has shown a strong linear relation between grain sorghum yield and seasonal ET.

2.1.3 Statistically Based Crop-Weather Analysis Models

Frere and Popov (1979), defined Crop-weather analysis models as the product of two or more factors, each representing the functional relationship between a particular plant response (e.g. yield) and the variations in selected variables at different plant development phases. Crop-weather analysis models can also be considered as a compromise between the mathematical crop growth simulators and statistical regression models (Baier, 1981).

These models often use soil moisture or evapotranspiration and other derived or observed data on a day-by-day basis and relate these data, together with other information, to morphological development, vegetative growth, or crop yields. A biological clock or sub model to monitor the state of crop development toward maturity is often incorporated in crop-weather analysis models. Standard climatic data are used as primary input. Data input usually consists of climatological data, derived variables (e.g. soil moisture), soil characteristics, and some observed or derived indicator of the crop development stage. Conventional statistical procedures and non-linear regression techniques are used to evaluate the coefficients relating crop response to the input variables.

The primary objective of a crop-weather analysis model, as proposed by Baier (1973), is to analyse the daily contributions of up to three selected agrometeorological variables to the final or seasonal yield. The crop response to each of the three input variables is either linear (positive or negative) or quadratic (concave or convex). The response changes gradually during the life cycle of annual crops as a function of biometeorological time (Robertson, 1968). The decision regarding the functional relationship to be used in the model is based on the assumption that crop yield depends basically on three agrometeorological variables: solar energy, temperature and soil moisture. These three variables modify each other on any particular day during the life cycle of a crop and produce a positive or negative effect on the final yield.

Of particular interest in this category is the "crop forecasting method based on agrometeorological information" defined by the Crop Ecology and Genetic Resource Unit of the Plant Production and Protection Division of FAO (Frere and Popov, 1979). The method is based on cumulative water balance established over the entire growing season for a given crop for successive periods of 10 days (or 7 days if preferred). The extent to which the water requirements of an annual crop have been satisfied in a cumulative way at any stage of its growing period is expressed as an index.

Initially, the index is assumed to be 100 and will remain at 100 for the successive decades until either water surplus of more than 100 mm or deficit appears. If a surplus of more than 100 mm occurs during a decade, the index is reduced by 3 units to 97 and remains at this level until a further surplus or stress period occurs. If a deficit appears, then the quotient between the water deficit and the total water requirements is calculated to obtain a fraction of water requirement which is not satisfied. This amount is subtracted from the previous index figure (i.e. 97) (Frere and Popov, 1979).

The calculation is pursued to the end of the growing season whereby the index will reflect the cumulative stress endured by the crop through excess and deficits of water and will usually be closely linked with the final yield of the crop, unless some other harmful factors have predominant effects (Baier, 1981). The index is directly related to yield and can at least give a very satisfactory and early qualitative appreciation of the yield (Frere and Popov, 1979).

It is also possible to derive quantitative estimates of yields, but these estimates have to be based on the potential yield of crops, which will depend on the local environmental conditions and will vary from place to place. In this way the establishment of precise correlation linking index and actual yields will only be possible when precise agricultural yield statistics are available for given regions. While the method allows good qualitative assessments, the quantitative forecast will always depend on good historical statistics of yield and production (Frere and Popov, 1979).

Shalhevet *et al.* (1976) pointed out that for many crops there is a strong relationship between yield and evapotranspiration (ET). Stewart *et al.* (1977) reported a similar relationship for corn as did Hillel and Guron (1973). Bielorai *et al.* (1964), Hanks *et al.* (1969) and Stewart *et al.* (1975) have also reported a strong linear relationship between grain sorghum yield and seasonal ET.

Models which are based on the assumption that crop yield is directly related to evapotranspiration (ET) are somewhat site and year specific and require measurements or estimates of ET and maximum yield. A major problem involves the amount of soil evaporation, E, which varies from year to year and from site to site (Hanks and Hillel, 1980).

An extension of the ET model are the transpiration (T) models which are based on the strong linear relation with yield as reported by Jensen (1968) and Hanks (1974). These models eliminate the problems mentioned above and are more readily transferable to different locations and years because the E part of ET is corrected for.

A simple transpiration model devised by Hanks (1974) used field capacity type water balance method to predict T and E separately from inputs of potential transpiration (T_m), potential evaporation (E_m), and soil water storage properties. The relative yield was related to relative transpiration as follows:

$$Y_a/Y_m = T_a/T_m \qquad [1]$$

where:

Y_a = actual yield

Y_m = maximum yield

T_a = actual transpiration

T_m = maximum transpiration

The input data E_m and T_m reflect crop properties (crop cover). The yield predictions are limited to the crop tested and would need to be revised considerably for another type of crop. The disadvantage with the transpiration model is that, estimates of potential yield are required from some other source. However the limited tests made using this model indicate good predictions (Hanks and Hill, 1980).

Jensen (1968) proposed a corn grain yield equation, which accounts for the effect of growth stages. The season is divided into stages and relative yield is computed as:

$$Y_a/Y_p = \left(T_1/T_{p_1}\right)^{\lambda_1} \times \left(T_2/T_{p_2}\right)^{\lambda_2} \times \left(T_3/T_{p_3}\right)^{\lambda_3} \times \ldots \times \left(T_n/T_{p_n}\right)^{\lambda_n} \qquad [2]$$

Where:

Y_a = estimated grain, lint or other production for any situation;

Y_p	=	potential yield when transpiration is equal to potential transpiration;
T_i	=	cumulative transpiration in growth period i;
T_{pi}	=	cumulative potential transpiration which occurs when soil water is not limiting during growth period i;
λ_i	=	an exponent to allow for weighting growth period i; and
$1,..n$	=	represent the n growth periods.

Equation [4] alone was found not satisfactory for predicting yields of corn, wheat, and beans with late planting dates for which transpiration ratios were high but yield was low. Hill *et al.* (1979) hypothesized that this was due to insufficient accumulation of dry matter. There may be a threshold value of accumulated transpiration below which a corresponding decrease in total dry matter production limits grain yields. Equation [4] was thus adapted by Hill (1997) to the CRPSMW model for predicting yields for beans, corn, and wheat by using a season length factor given by:

$$SLF = 1.0, \quad \text{if } T_p \geq T_{th} \qquad [3]$$

$$SLF = \left({T_p}/{T_{P\,th}} \right)^{\alpha}, \quad \text{if } T_p < T_{pth} \qquad [4]$$

Where:

SLF	=	the seasonal yield factor;
T_p	=	the accumulated potential transpiration for a full season;
T_{pth}	=	the corresponding threshold transpiration for adequate total dry matter prediction; and

α = a constant weighting factor.

Models relating yield to transpiration are more sound than those relating to evapotranspiration because they account for the water that goes through the plant although it is difficult to separate the two processes (Hanks and Hill, 1980).

Leaf photosynthesis and solar radiation are integrated on a daily basis and used to model daily dry matter production of a crop canopy in the model SUCROS (Xevi, 1992). Essentially, the model accumulates dry matter as a function of climate, soil and management operations from emergence to maturity.

Irrigation Scheduling Information System (IRSIS) by Raes *et al.* (1987) affords an easy and quick way to evaluate alternative irrigation schedules for a given climate-soil-crop combination. The underlying principles for calculating the irrigation schedule and the effect of the schedule on irrigation efficiency and yield response have been kept simple and proportional to the available input data. The core of the program is a simplified water balance model (BUDGET) (Raes *et al.*, 1987) for cropped soils.

In running IRSIS, the user has the option of using the model parameters or in case better defined parameter values are locally available, the default parameter values can be replaced. The yield response expressed as the ratio of the actual to maximum yield (Y_a/Y_m) is calculated according to:

$$\left(Y_a/Y_m\right) = 1 - K_y\left(1 - ET_a/ET_m\right) \qquad [5]$$

If the ratio of the actual to the potential crop evapotranspiration (ET_a/ET_m) is smaller than 0.5 (due to the high water stress), the equation may not be valid and the results become very unreliable and if the ratio is equal to 1.0, there is no yield reduction.

Crop and Soil Water Management and Water Requirements Simulation Model (CRPSMW) by Hill (1997) is a crop yield, crop water use, irrigation scheduling, and soil water management simulation model which combines the influence of weather conditions on crop water use and plant growth to predict yield as influenced by daily soil water content during each stage. This latest version incorporates the CROPWAT (USU) water requirements option which calculates only evapotranspiration ET for given crops and for a project's specified crop mix. Daily reference evapotranspiration may be estimated using various methods: (a) Penman-Monteith, (b) Jensen-Haise, (c) Hargreaves, (d) FAO Blaney-Criddle, and (e) pan evaporation. CRPSMW allows for non-calendar year growing seasons. Crop coefficients, phenology clock, and yield parameters are contained in data files to facilitate addition of new crops without reprogramming. The CRPSMW model assumes that, the only process influencing plant yield directly is the ratio of transpiration (T) to potential transpiration (T_p). Evaporation and drainage have an indirect influence on the available water and thus transpiration, but the model assumes these processes do not directly affect yield (Hill,1997). To estimate yield where conditions during one stage of growth are more critical than others, the method of Jensen (1968) was used in the CRPSMW model.

2.2 The Concept of growing season

It is essential to distinguish clearly between the length of a growing season, as determined by the climate at a site, and the duration of the growth period for a specific crop growing on that site. The distinction is particularly important for understanding how crop yields are for instance related to temperature (Monteith and Scott, 1981).

When the development of a crop from germination to maturity is limited physiologically rather than by bad weather, the length of the growth period is simply the sum of time spent in each development phase. In temperate climates, the length of the growing season is often identified as the average length of the period without frost. Even for crops which can survive frost, growth in the winter is severely inhibited by low temperature, lack of light or a combination of both unfavourable factors. In the semi-arid tropics, the length of the growing season is determined by the balance between rainfall and evaporation (Monteith and Scott, 1981).

Franquin (1981) defined the growing season in terms of the probability of obtaining a favourable period for non-irrigated crops between two given dates of the year. He developed a frequency model which shows all possible durations and positions of the period during which the facts of the cropping schedule, as well as the phenological phases of crop development occur. This model was designed in terms of statistical rainfall and evapotranspiration (PET) terms.

Kassase (1992) and Kingamkono (1993) defined the growing season as the duration between the start and the end of the rain season.

A number of approaches based on some specific criteria such as rainfall criterion, rainfall and evapotranspiration criterion, soil-water balance criterion, and modelling criterion, have been proposed in analysing rainfall data for the purpose of developing the start and end of the growing season and hence its length (Alusa and Mushi, 1974). Kassase (1992) used a series of thirty years duration daily weather data (1960-1990) for seventeen stations in Tanzania to determine the start, end, and effective length of the growing season. On the other hand, Kingamkono (1993) used daily historical weather data for another fifteen stations not considered by Kassase (1992). The duration of data used per station ranged from 30 to 37 years. Two criteria, the rainfall criterion and the rainfall and evapotranspiration criterion, were used by both Kassase (1992) and Kingamkono (1993) to determine the start, the end, and the length of the growing season. The rainfall criterion provided better estimates of the start and end of the growing season than the rainfall and evapotranspiration criterion.

Kassase (1992) and Kingamkono (1993) noted that, there were no discernible trends in both the start and end dates of the growing season as the characteristics of the growing season depend on local rainfall patterns which are influenced by geographical location, altitude, sun movement and presence of large water masses.

Results of the analysis by Kassase (1992) to determine the probable start and end of the growing season by using rainfall criterion for the two stations selected in this study namely Morogoro and Arusha are shown in Table 2.1.

Table 2.1: The probable dates for start and end of the growing season at three levels of probability for Morogoro and Arusha

Criterion	Station	Rainy season	Percent points 20%		50%		80%	
			S*	E*	S	E	S	E
Rainfall	Morogoro	Short	23oct	06Jan	12Nov	18Jan	01Dec	29Jan
		Long	02Mar	04May	15Mar	19May	27Mar	02Jun
	Arusha	Short	27oct	13dec	07Nov	01Jan	17nov	19Jan
		Long	18Feb	08May	09Mar	19May	28Mar	29May

S* Start of growing season..
E* End of growing season..
Source: Kassase, (1992).

Statistical studies (Runge and Odell, 1960) of the relationship between long-term weather data and soybean yields in Illinois showed that precipitation and daily maximum temperature explained about 70 percent of variation in yield and that the soybean plant is particularly sensitive to water stress occurring during the grain filling period. In field studies where water stress was imposed on soybeans at various stages of development, limiting water to early flowering reduced yields by about 3%, whereas limiting water from flowering to maturity reduced yield by about 50% (Doss *et al.*, 1974).

In examining the effect of environmental factors on yield, it is essential that the stage of development be established, in as much as the same environmental factor may have different effects at different stages of development (Shaw, 1980). Even before planting, there are factors occurring that may be important in determining final yield (Shaw, 1980).

Of particular importance in the Western part of the Corn Belt in the U.S.A is the soil-moisture reserve. Shaw (1980) measured yield increase of 600 to 1000 kg/ha for each additional 25 mm of soil moisture available in mid-April. Wet conditions during the spring, however, may delay planting. In many areas, delayed planting can reduce yields.

There is little relation between moisture stress during the early vegetative growth period and the final yield of maize unless the weather becomes so severe that the crop is killed. If the weather is relatively dry during this period, better root development will occur (Shaw, 1980).

Sopher *et al.* (1973) found that excess moisture and cool temperatures early in the season were important factors in reducing yields in soils of the South Atlantic Coastal Plains. This indicates that excess moisture can be limiting to yields in many years, although the major yield reductions are attributed to moisture deficits. The reduction associated with excess moisture could be a result of late planting, poor rooting, etc.

Moisture stress during the period of late vegetative growth to tasseling will cause maize yield reduction (Claassen and Shaw, 1970a). During the late vegetative stage, a moderately severe stress may reduce yield nearly 3% per day (Shaw, 1980). Claassen and Shaw (1970b) found that if a water stress was imposed when 6% of the maize plants had silked, yield was reduced by only 3% per day but, if applied when 75% of the plants had silked, the reduction was 7% per day. With severe stress, silking may be delayed until after all or much of the pollen has shed, increasing the number of barren stalks and poorly filled ears. Shaw (1980) indicated that very severe moisture stress around silking will result in a complete crop failure, and also he found that yield reduction for maize of more than 4% per day can occur for three to four weeks moisture stress after pollination, but then, as the crop moves closer to maturity, the yield reduction will decrease.

Monteith and Scott (1981) observed that, within the growth period, the rate of crop growth C (in units such as g/m^2 or kg/ha/day) usually increases while the canopy is closing, achieves an almost constant maximum value C_m for several weeks during the grand period of growth and then decreases to zero during a final senescent phase. A representative mean value of the maximum growth rate C_m can usually be determined by examining a record of standing dry weight measured at regular intervals during the growing season. Therefore, the dry weight of a crop at harvest (W_m) is related to the length of the growth period from germination to harvest (tg) by the relationship:

$$W_m = C_m\,(t_g - t_l) \qquad [6]$$

where:

t_g-t_l = is the effective length of the growing period, and

t_l = is the time lost as a consequence of incomplete light interception at the beginning of growth and of senescence in the period before harvest.

Crop-weather analysis models, as their terminology implies, are practical research tools for the analysis of crop responses (e.g. grain yields, dry matter or crop yields) to climate and weather variation when only climatological data are available. By extending the current yield potential into the future, such models have some predictive value (Baier, 1981).

3. MATERIALS AND METHODS

3.1 Description of the study area

Five stations were selected from two regions of Tanzania namely Morogoro and Arusha. For Morogoro region, the stations were Ilonga Agricultural Research and Training Centre (IARTC) and Msimba Foundation Seed Farm (MFSF), and for Arusha region, the stations were Selian Agricultural Research Institute (SARI), Arusha Foundation Seed Farm (AFSF), and Tanzania Pesticides Research Institute (TPRI). The altitude and location of each station used in this study are as shown in Table 3.1. The criterion used to select these stations was the availability of sufficient data to undertake the study.

Table 3.1: Stations used in the study.

Station	Altitude (m)	Location
IARTC	495	$6^0$46'S $37^0$02'E
MFSF	575	$6^0$30'S 37^0E
SARI	1 390	$3^0$22'S $36^0$38'E
AFSF	1 550	$3^0$18'S $36^0$36'E
TPRI	1 433	$3^0$20'S $36^0$37'E

3.2 Data collection

In order to achieve the set objectives, the following data were collected: weather data, crop data, and soil data. These data were collected as elaborated in the following sections.

3.2.1 Weather data

Representative daily weather data of rainfall, radiation, temperature, relative humidity, and wind speed for Ilonga and Msimba (Morogoro) were collected from Ilonga Agrometeorological weather station, and for Selian and Arusha Foundation Seed Farm were collected from TPRI Agrometeorological weather station which is located between the two mentioned stations. The duration of data collected per station was 10 years.

3.2.2 Crop data

Crop data for maize, wheat, beans, and sorghum were collected from Agricultural Research Stations and Foundation Seed Farms. Data for actual crop yield were collected from Foundation Seed Farms. Potential crop yield data were collected from Agricultural Research Stations with similar agro-ecological zonation as the Foundation Seed Farms.

Wheat and beans data were collected from Selian Agricultural Research Station and Arusha Foundation Seed Farm. Maize data were collected from Ilonga Agricultural Research Station, Msimba Foundation Seed Farm, Arusha Foundation Seed Farm, and Selian Agricultural Research Station. Sorghum data were collected from Msimba Foundation Seed Farm, and Ilonga Agricultural Research Station.

The criteria used to select the type of crop used for this study were based on soil moisture sensitivity, availability of dependable data, and the fact that they are the main food crops in most parts of Tanzania.

3.2.3 Soil data

For Ilonga and Msimba stations, soil samples were taken from experimental field plots and farms where agricultural research and seed multiplication activities usually take place.

Five core samples were taken per station. The soil type was determined by means of particle size analysis according to the procedure described by Gee and Bauder (1986). Suction plate method was used to determine the relation between water content and matric potential for field soil samples. These results were used to plot soil moisture characteristic curves from which the soil water content at field capacity and wilting point were estimated as described by Marshall and Holmes (1988). Basic infiltration rate for the determined soil type was estimated from literature as presented by Israelson and Hanson (1962) and Rijtema, (1970).

For Selian and Arusha stations, the soil analysis data were available. The availability of soil data was made possible due to the work of McKeague *et al.* (1991) who determined soil properties in the field, using guidelines established in Canada, for volcanic soils in northern Tanzania.

3.3 Model description

Two soil water balance models namely CRPSMW and IRSIS were used for crop assessment and yield prediction. These models were selected because they do take into consideration soil characteristics, crop characteristics, and weather parameters.

3.3.1 CRPSMW model

The CRPSMW program, which is structured in modular form, is coded in FORTRAN IV. Figure 3.1 illustrates the inter-relationship of the subroutine models.

Main Program - MAIN: MAIN acts as the control link of the entire program where control data identifies which subroutine is to be active.

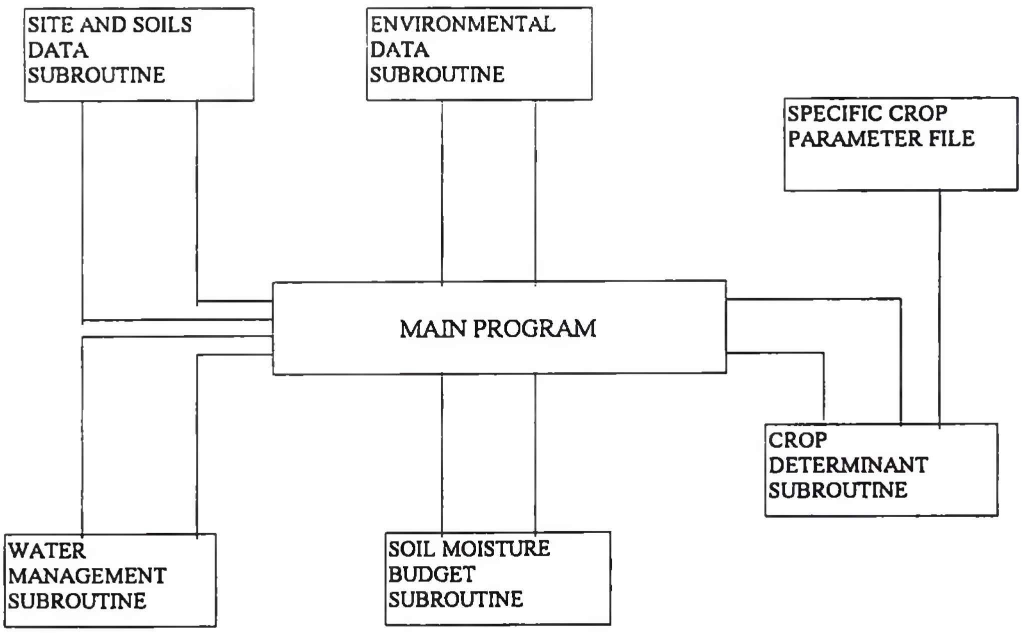


Figure 3.1 Generalized CRPSMW modular flow chart (adapted from Hill, 1997).

Site and Soils Data Subroutine - STSLDT: The purpose of this SLSLDT is to identify the site by name, elevation, latitude, longitude, and the year of the experiment. This subroutine initializes the soil moisture content in the root zone and calculates the available water for each soil layer.

Environmental Data Subroutine - ENVRDT: Subroutine ENVRDT reads daily weather data from a specified file into arrays for use by program. ENVRDT also inputs constants for any one or all ET equations. The selection of the particular equation depends upon the extent of available data. The daily calculated values of reference crop evapotranspiration (Etr) along with other weather data are made available to other subroutines via COMMON.

Water Management Data Subroutine - MANDAT: Five different irrigation options are provided for any particular situation: (a) with a fixed amount of water to be applied in set increments during the season, (b) irrigate with a fixed depth and interval between a beginning and ending date, (c) irrigation data consisting of the month, day and depth of application, (d) the model irrigates at a specified management allowable depletion (MAD) and fixed depth, and (e) irrigate only if a specified (MAD) is equalled or exceeded on a given date of a fixed interval series. Output to a LOG file of the various irrigation schedule and corresponding crop yield from successive options in the same CRPSMW input batch file permits usage by other programs for optimisation analysis etc.

Crop Data Subroutine - CRPDAT: This subroutine is the means to get from MAIN, MANDAT or SOILBT to simulate a specific crop. Information passed to CRPDAT includes the crop and variety identity along with planting date (month, day). On the first access to CRPDAT, data describing the specific crop is read from a file (CROP.DAT). The desired crop must be included in CROP.DAT.

The three major activities for each crop are to set up the phenology dates, either from actual observations or from an empirical phenology clock, initialize the crop transpiration curve coefficients and other parameters, and to determine the season yield as a function of transpiration during the several growth stages.

Soil Moisture Budget Subroutine - SOILBD: Actual and potential transpiration are determined as affected by computed soil water content during each growth stage. Herein, information from the specific crop (the phenologic clock, the crop transpiration curve, the initial and final root depth) comes together with the Etr and rain data from ENVRDT, irrigation data from MANDAT and the soil moisture data from STSLDT. There is no data input to SOILBD other than the possible control from MAIN.

Heat Unit and ET Summing Subroutine - GRWUNT: GRWUNT is a utility subroutine which calculates growing degree days (GDD) by the 50-86 and 40-77 methods, as well assuming the zero elevation Jensen-Haise ET (ETJHO) and the Etr values stored in COMMON from the selected method in ENVRDT. There is no communication between GRWUNT and any other subroutine of logical nature.

Field Measured Soil Water Status Subroutine - NPROBE: This subroutine provides for the inclusion in SOILBD of field measured root zone total soil water content from a neutron probe (or other devices). The computed, along with measured soil water values, can thus be compared in the soil water budget calibration process and plots of the same can be generated.

Project Crop Water Use (Etr) Subroutine - CROPET: This subroutine calculates Et only for a specified set of crops as in an irrigated project area. The Et crop coefficients may be represented as polynomial equations, or constants as reported by Doorenbos and Pruitt (1977), or a set of day and coefficient value pairs.

3.3.2 IRSIS model

The structure of the Information System (IS) of IRSIS is as follows: Data is stored in members; Members are grouped in libraries; Support and Schedule libraries are distinguished. The hierarchical structure of the displays is given in Figure 3.2.

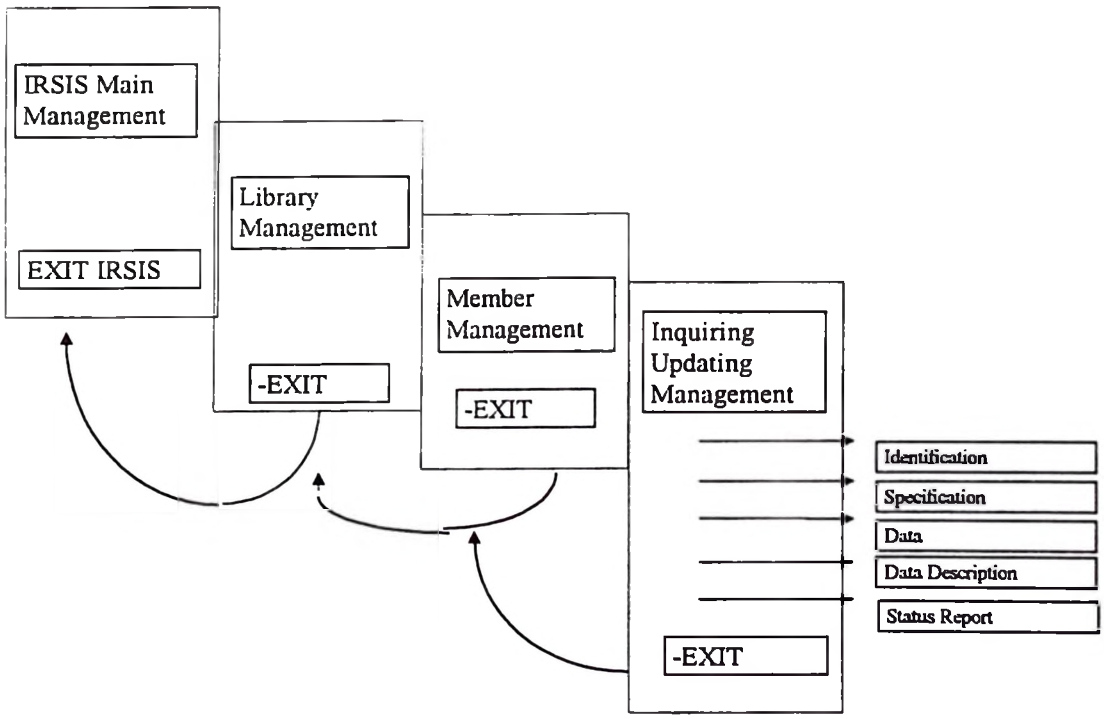


Figure 3.2. Hierarchical structure of the displays (adapted from Raes et al., 1987).

IRSIS MAIN MANAGEMENT: IRSIS model contains two parts namely Support and Schedule. The difference between them lies in the fact that the Schedule part refers to the Support part, while the Support part is self contained. The support part consists of different libraries containing information about ETo, Rain, Crop and Field. The Schedule part is divided into two libraries, a Draft and Action library. In IRSIS MAIN MANAGEMENT one selects any of the 6 libraries or else exits IRSIS.

LIBRARY MANAGEMENT: After the selection of a library, the members of the specified library are displayed in LIBRARY MANAGEMENT. The Scroll Library command, allows one to browse through the member list. By means of the Print Library command, the list of members together with the date and time on which they were last updated is printed to a file. In the LIBRARY MANAGEMENT, one may select one of the existing members or create a new member.

MEMBER MANAGEMENT: After the selection of a member or the creation of a new one, the possible operations on the member are displayed in MEMBER MANAGEMENT. One can Inquire or Update the member information. One may Print the member to a file. One may also Rename the member, Copy the information to a member which will be created at that moment, or Delete the member.

Inquire mode will be selected however if one only wants to browse through the member information. If one wants to enter or update information, the Update mode is selected.

INQUIRING/UPDATING MANAGEMENT: After the selection of the Inquire or Update mode, the categories in which member information is assorted are displayed in the INQUIRING MANAGEMENT or UPDATING MANAGEMENT. Five categories are distinguished: Identification, Specification, Data Description, Data and status Report.

Identification: The identification information represents some general member characteristics. The information is different for each type of library. The information can be regarded as a label that identifies the actual member. Apart from the altitude and latitude of the ETo-identification, the identification information is not needed in the calculations.

Specification: ETo, Rain, Draft, Action members need further specification before any data can be stored. This specification can be regarded as time situating information. By the nature of the information, Crop and Field members have no Specification.

Data Description: Because climatological Data can be available under different formats, ETo and Rain Data must be described before the actual Data can be stored. Crop, field, Action and Draft Data are available under a fixed presentation.

Data: Data contains the actual data of the specific member.

Status Report: In the status report, messages concerning the status of the member are displayed. If relevant information is missing or wrongly specified, some message will occur in the Status Report. Members of Support Libraries also have a list of the members of Schedule libraries referring to their Data.

3.4 Data analysis

The collected data (climate, crop, and soil) were used as input to IRSIS and CRPSMW models. These models were used to process the collected data to get an assessment of the desired objectives.

3.4.1 IRSIS model

3.4.1.1 The input data

The IRSIS model was used to estimate the actual grain yields using the following data input:

- Weather data - daily rainfall, radiation, temperature, relative humidity, and wind speed.
- Crop data - crop type, variety, growth stages, stage lengths and corresponding crop coefficients, sensitivity stages, stage length and corresponding yield factors, rooting depth, p-factor, and planting dates.
- Soil data - initial soil moisture content, soil water content at field capacity and wilting point, basic infiltration rate, soil types, parameters corresponding to the selected Runoff Simulation Method.

Data for a particular type of crop were revised each time a new variety had to be assessed. As for maize, three varieties namely Staha - with growing period of 120 days, Kito - with growing period of 60 days, and TMV1 - with growing period of 110 days were assessed, hence, the total growing period had to be revised too. In cases where another type of crop had to be assessed, parameters such as length of the growing period, crop coefficients, yield response factors, p-factors, and rooting depths of full grown crops were changed. Growth stages and sensitivity stages were assumed to be the same for all varieties of a particular type of crop.

3.4.1.2 The output data

The output from this model comprises of: soil water balance, root zone depletion, simulated yields and rainfall application efficiency. Only yield data simulated at the maturity stage were used for subsequent analyses. Irrigation data were not considered, thus, the root zone was assumed to have gained water through rainfall only.

3.4.2 CRPSMW model

3.4.2.1 The input data

The CRPSMW model was used to estimate the actual yield of grain crops. The data used to run the model were:

- weather data - daily values of rainfall, maximum and minimum temperatures, solar radiation, and wind speed.
- crop data - planting dates, crop type (seasonal, annual etc.), variety, rooting depth, growing states, crop coefficient, maximum yield potential, growth state closest to effective cover, number of days the effective cover differs from occurrence of state, growth state closest to maximum root depth, number of days maximum root

attainment differs from occurrence of state and other specific crop parameters for each cultivar that relate phenology to the accumulated energy for evapotranspiration, days or temperature.

- soil data - number of soil layers, total soil depth, dates for initial soil moisture reading, thickness of each layer, initial soil moisture content for each layer, field capacity of each layer, and permanent wilting point for each layer.

For each variety of a particular type of crop assessed, corresponding parameters such as maximum yield potential, number of days effective cover differs from occurrence of state, and phenology clock value for each growth state were changed accordingly. As for maize, the maximum yield potential for Staha, Kito, and TMV1 varieties were taken to be 2.4, 1.5, and 2.4 tons/ha respectively and the number of days effective cover differs from occurrence of state were estimated to be -18, -10, and -16 days respectively. The phenology clock values in days for each growth state were estimated to be 0,7,22,70,93,120 for Staha, 0,4,10,20,46,60 for Kito, and 0,7,12,60,85,110 for TMV1 variety.

When another type of crop had to be assessed, parameters such as number of growth states starting with planting or beginning growth to physiologic maturity (maize-6, wheat-7, beans-6 and sorghum-6), maximum root depth, maximum yield potential, growth state closest to effective cover, and the number of days effective cover differs from occurrence of state were revised accordingly.

Crop parameters such as phenology clock type (days), crop coefficient input for third order polynomial equations, and temperature below which transpiration is reduced due to cold effect were the same for all types of crops.

Daily weather data and soil data were location specific. Apart from dependence on weather data, soil data, and site, the start of the growing season depended on the type of crops too. For the same year, 1994, for Ilonga and Msimba stations (Morogoro) the start of the planting activities for maize was from January to March and for sorghum was from March to April, whereas for Arusha, the same year, the planting activities for wheat started in early April to May and for beans in early March to April.

3.4.2.2 The output data

The output from this model includes the reference crop evapotranspiration, potential and actual transpiration, potential and actual evaporation, seasonal soil water budget, and the predicted grain yields.

3.4.3 IRSIS and CRPSMW Models

The initial soil moisture, by percent of total available water, was assumed to be the same for all sites by both CRPSMW and IRSIS models. The same planting dates for each year and type of crop were used by both models to simulate the crop yields.

For those data which were not available from the respective stations such as initial soil moisture content during planting time, crop coefficients, p-factors, number of days effective cover differs from an index of growth state closest to effective cover, and number of days maximum root attainment differs from an index of growth state closest to maximum root growth were either estimated based on the judgement from those illustrated in sample examples found in both IRSIS and CRPSMW software user manuals or estimated from data obtained through literature.

Parameters such as number of days effective cover differs from an index of growth state closest to effective cover; number of days maximum root attainment differs from an index of growth state closest to maximum root growth; the phenology clock value in days/degree days for each growth state; weighting factors for yield calculation for each growth state; the growth state for use of seasonal length yield factor and an exponent to be used in seasonal length yield factor need accurate location specific determination in order to achieve better prediction of grain yields.

Three different planting dates for each year and each type of crop and variety were used to simulate crop yields: (1) actual planting dates which were considered as the initial planting dates; (2) planting date three days after the initial planting dates (this was based on the assumption that planting activities took more than one day); and (3) planting dates as determined by Kassase (1992) for Morogoro and Arusha

For Ilonga and Msimba stations, planting dates for different years ranged from January to March for maize and from March to April for sorghum. For Selian and Arusha Foundation Seed Farm stations, planting dates ranged from March to April for beans and from April to May for wheat.

Each of the crop yield results simulated by both IRSIS and CRPSMW models, were compared with the actual crop yield data obtained from the fields. The t-Test statistic was used for comparison.

Two independent samples (actual and model simulated crop yields) with means $\bar{X}_1$ and $\bar{X}_2$ that are estimates of their population means μ_1 and μ_2 were used for comparison. Test of significance and confidence intervals concerning the population difference, $\mu_1 - \mu_2$, was based on the t- distribution at 5% level of significance. In examining whether the two samples came from the same population, the null hypothesis was set such that $\mu_1 = \mu_2$. The actual yields were used as the reference yields.

4. RESULTS AND DISCUSSION

4.1 Comparison of observed against model predicted grain yield

Table 4.1 shows the yield data analysis for maize (variety: Staha) for Ilonga and Msimba stations (Morogoro) where actual maize yields were compared with simulated maize yields by CRPSMW and IRSIS models. Similar results for other varieties of maize and sorghum for the same stations are shown in Appendix A.

Table 4.1: Yield data analysis for maize (variety: Staha) for Ilonga and Msimba stations, Morogoro.

Year	Actual yield	CRPSMW Predicted yields for respective planting dates*			Average yield**	IRSIS Predicted yields for respective planting dates*			Average yield**
	Y_a (Kg)	Y_1 (Kg)	Y_3 (Kg)	Y_{GSs} (Kg)	Y_{avg} (Kg)	Y_1 (Kg)	Y_3 (Kg)	Y_{GSs} (Kg)	Y_{avg} (Kg)
1989	1 864	1 800	1 780	1 510	1 697	2 352	2 400	2 400	2 384
1990	1 504	1 670	1 610	1 080	1 453	2 160	2 016	1 368	1 848
1991	1 400	1 470	1 420	1 170	1 353	2 057	2 107	1 512	1 892
1992	1 585	1 860	1 760	1 390	1 670	2 400	2 400	2 184	2 328
1993	895	1 020	940	870	943	1 454	1 394	1 340	1 396
1994	895	1 590	1 510	960	1 353	2 230	1 505	1 416	1 717
1995	1 440	1 580	1 560	1 210	1 450	2 304	2 256	1 488	2 048
1996	1 470	1 710	1 630	1 460	1 600	2 400	2 400	2 400	2 400

t-Test (Comparison of two samples).

	Y_1 vs Y_a	Y_3 vs Y_a	Y_{GSs} vs Y_a	Y_{avg} vs Y_a	Y_1 vs Y_a	Y_3 vs Y_a	Y_{GSs} vs Y_a	Y_{avg} vs Y_a
Significance	Ns	Ns	Ns	Ns	S	S	Ns	S

* Actual planting date (Y_1), planting date three days later (Y_3), and planting date falling on or after the most probable date for start of the growing season (Y_{GSs}) (i.e. 02 March for Morogoro for long rain season at 20% probability level, (Kassase 1992)).

** Average of Y_1, Y_3, and Y_{GSs}.

Ns = Not significant at $P \leq 0.05$.

S = Significant at $P \leq 0.05$.

GSs = Start of the growing season.

For Ilonga and Msimba stations (Morogoro), the statistical analysis carried out for actual yield data against CRPSMW model simulated yield data for maize (Staha) for different events of planting dates showed that, all of the computed t-values (t-statistic) were not significant at 5% level (Table 4.1). These results indicate that, on the basis of the chosen statistic and level of significance, there is no sufficient evidence to show that the actual and simulated maize yields came from two different populations. Hence, the null hypothesis that the population means were equal was not rejected at the 5% level of significance. When the average values of the predicted yields were analyzed, similar observations were also realized. For Kito and TMV-1 (maize varieties) and Tegemeo (Sorghum variety), similar observations were also noted. (Tables A.1, A.2, and A.3 in Appendix A).

For Arusha Foundation Seed Farm (AFSF) and Selian Agricultural Research Institute (SARI) stations in Arusha, similar results as those for Ilonga and Msimba were observed for wheat (Mbayuwayu and Mbuni varieties) and Beans (Lyamungu 85 and Lyamungu 90 varieties) as shown in Tables 4.2 to 4.4.

On estimating the crop yield, the CRPSMW model assumes that the only process influencing plant yield directly is the ratio of transpiration (T) to potential transpiration (T_p). Generally, the observed results attest the assumption because they do agree with the observations made by Jensen (1968) and Hanks (1974) and others that, models relating yield to transpiration are more sound than those relating yield to evapotranspiration because they account for water that goes through the plant. These models are more readily transferable to different locations and years because the E part of ET is corrected for.

When actual and IRSIS model simulated maize yield data for Staha variety with different planting dates as shown in Table 4.1 were analyzed, all of the computed t-values (t-statistic), except for planting dates falling on or after the probable date for start of the growing season as determined by Kassase (1992), were observed to be significant at 5% level. Also, when the average of the predicted maize yields were compared with the actual maize yield from the field, the computed t-value was found to be significant at 5% level (Table 4.1). Similar results were observed when sorghum yield data were analyzed (Table A.3 in Appendix A). For Kito and TMV-1 maize varieties (Table A.1 and A.2 in Appendix A) the computed t-values were significant at 5% level. Generally, these results indicate that, on the basis of the chosen statistic and level of significance, there is sufficient evidence to show that the actual grain yield data and simulated grain yield data were significantly different, and hence, the null hypothesis that the population means were equal was rejected.

The case was a bit different when yield data for Arusha Foundation Seed Farm and Selian were analyzed. When actual and IRSIS model simulated yield data for wheat (Mbayuwayu and Mbuni varieties) with 16 degrees of freedom were analyzed, the computed t-value was observed to be significant at 5% level indicating that the actual and predicted yield data came from two different populations (Table 4.2). When yield data for beans (Lyamungu 85 and Lyamungu 90) with 4 degrees of freedom were analyzed, the computed t-values were found to be not significant at 5% level (Tables 4.3 and 4.4) which implies that, on the basis of the chosen statistic and level of significance, there was no sufficient evidence to show that the actual and simulated yield data came from two different populations, hence, the null hypothesis that the population means were equal was not rejected.

Table 4.2: Yield data analysis for wheat (varieties: Mbayuwayu and Mbuni combined) for Selian and Arusha Foundation Seed Farm stations, Arusha.

Year	Actual yield Y_a (Kg)	CRPSMW Predicted yields for Respective planting dates* Y_1 (Kg)	Y_3 (Kg)	Y_{GSs} (Kg)	Average yield** Y_{avg} (Kg)	IRSIS Predicted yields for respective planting dates* Y_1 (Kg)	Y_3 (Kg)	Y_{GSs} (Kg)	Average yield** Y_{avg} (Kg)
1987	1 022	1 320	1 110	970	1 133	1 950	1 959	1 962	1 957
1988	1 642	1 220	1 240	1 270	1 243	1 587	1 566	1 557	1 570
1989	1 846	1 150	1 110	1 080	1 113	1 740	1 683	1 644	1 689
1990	1 051	1 510	1 250	1 070	1 277	2 622	2 460	2 331	2 471
1991	1 752	1 850	1 750	1 700	1 767	3 000	3 000	3 000	3 000
1992	1 946	2 080	1 920	1 770	1 923	3 000	3 000	2 991	2 997
1993	1 129	1 000	910	710	873	1 569	1 563	1 548	1 560
1994	1 859	1 840	1 370	1 090	1 433	1 683	1 647	1 626	1 652
1995	1 350	1 490	1 240	1 050	1 260	1 770	1 746	1 716	1 744

t-Test (Comparison of two samples).

	Y_1 vs Y_a	Y_3 vs Y_a	Y_{GSs} vs Y_a	Y_{avg} vs Y_a	Y_1 vs Y_a	Y_3 vs Y_a	Y_{GSs} vs Y_a	Y_{avg} vs Y_a
Significance	Ns	Ns	Ns	Ns	S	S	S	S

* Actual planting date (Y_1), planting date three days later (Y_3), and planting date falling on or after the most probable date for start of the growing season (Y_{GSs}), (i.e. 18 February for Arusha for long rain season at 20% probability level).

** Average of Y_1, Y_3, and Y_{GSs}.

Ns = Not significant at $P \leq 0.05$.

S = Significant at $P \leq 0.05$.

Table 4.3: Yield data analysis for beans (variety: Lyamungu85) for Selian and Arusha Foundation Seed Farm stations, Arusha.

Year	Actual yield Y_a (Kg)	CRPSMW Predicted yields for respective planting dates* Y_1 (Kg)	Y_3 (Kg)	Y_{GSs} (Kg)	Average yield** Y_{avg} (Kg)	IRSIS Predicted yields for respective planting dates* Y_1 (Kg)	Y_3 (Kg)	Y_{GSs} (Kg)	Average yield** Y_{avg} (Kg)
1994	1 066	1 390	1 370	1 340	1 367	2 500	2 500	2 500	2 500
1995	1 929	1 250	1 220	1 190	1 220	2 500	2 500	2 500	2 500
1996	822	1 000	920	830	917	1 632	1 065	1 042	1 246

t-Test (Comparison of two samples).

	Y_1 vs Y_a	Y_3 vs Y_a	Y_{GSs} vs Y_a	Y_{avg} vs Y_a	Y_1 vs Y_a	Y_3 vs Y_a	Y_{GSs} vs Y_a	Y_{avg} vs Y_a
Significance	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns

* Actual planting date (Y_1), planting date three days later (Y_3), and planting date falling on or after the most probable date for start of the growing season (Y_{GSs}), (i.e. 18 February for Arusha for long rain season at 20% probability level).

** Average of Y_1, Y_3, and Y_{GSs}.

Ns = Not significant at $P \leq 0.05$.

S = Significant at $P \leq 0.05$.

Table 4.4: Yield data analysis for beans (Lyamungu90) for Selian and Arusha Foundation Seed Farm stations. Arusha.

Year	Actual yield Y_a (Kg)	CRPSMW: Predicted yields for respective planting dates* Y_1 (Kg)			Average yield** Y_{avg} (Kg)	IRSIS: Predicted yields for respective planting dates* Y_1 (Kg)			Average yield** Y_{avg} (Kg)
		Y_1 (Kg)	Y_6 (Kg)	Y_{GS1} (Kg)		Y_1 (Kg)	Y_6 (Kg)	Y_{GS1} (Kg)	
1994	2 600	1 660	1 640	1 610	1 637	3 000	3 000	3 000	3 000
1995	867	1 300	1 270	1 230	1 267	3 000	3 000	3 000	3 000
1996	1 154	1 280	1 130	1 030	1 147	2 061	1 311	1 356	1 576

t-Test (Comparison of two samples).

	Y_1 vs Y_a	Y_6 vs Y_a	Y_{GS1} vs Y_a	Y_{avg} vs Y_a	Y_1 vs Y_a	Y_6 vs Y_a	Y_{GS1} vs Y_a	Y_{avg} vs Y_a
Significance	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns

* Actual planting date (Y_1), planting date three days later (Y_3), and planting date falling on or after the most probable date for start of the growing season (Y_{GS1}), (i.e. 18 February for Arusha for long rain season at 20% probability level).

** Average of Y_1, Y_3, and Y_{GS1}.

Ns = Not significant at $P \leq 0.05$.

S = Significant at $P \leq 0.05$.

The above results (by IRSIS model) attest what was observed by Hanks and Hill (1980) that, a major problem with the evapotranspiration (ET) models which relate the crop yield to ET by linear regression lies in the amount of soil evaporation E part of ET, which varies from year to year, and from site to site. IRSIS uses the ET model as a sub-model which estimates the crop yield.

The values of the probability (P) of obtaining the computed t-values (T) less or equal to t-critical (two-tail) for beans are shown in Table 4.5 below.

Table 4.5 The probability of computed t-values less or equal to critical t-value for beans.

Variety	$P(T \leq t)$ two-tail: CRPSMW	IRSIS
Lyamungu 85	0.786 494	0.205 431
Lyamungu 90	0.749 412	0.241 015

It is worthwhile noting that, for any of the computed t-values (t-statistic) which is equal to or less than the critical t-value is considered to have fallen in the non-rejection region (Not significant at the selected level of significance). In comparing the values of $P(T \leq t)$ two-tail obtained from the analysis of the actual field yield data with average of the simulated yield data for beans varieties, by IRSIS and CRPSMW, it was noted that, the $P(T \leq t)$ values for Lyamungu85 and Lyamungu90 varieties computed by IRSIS model were 0.205 431 and 0.241 015 and by CRPSMW model were 0.786 494 and 0.749 412 respectively (Table 4.5). These results indicate that, yields simulated by CRPSMW model are relatively better than those simulated by IRSIS model for the probabilities of obtaining the computed values of T less than t-critical were greater for CRPSMW than for IRSIS model.

However, the sample size (n=3) for beans yield data was considered too small to give a reliable analysis which can be used to compare which model simulates better, IRSIS or CRPSMW.

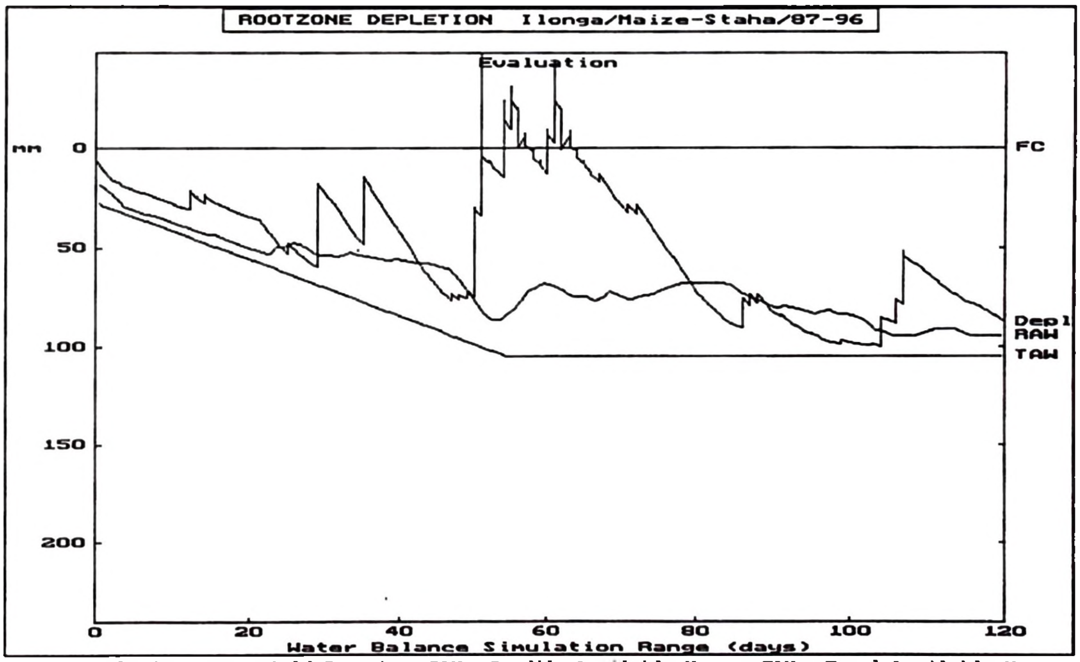
Table 4.6 and Figure 4.1 show the results for root zone depletion for Maize (Staha). From Figure 4.1, it can be noted that, the depletion of soil water by maize takes place even for water which is above the field capacity (runoff). Since the runoff was considered by the IRSIS model and the type of crops grown were not that of flooded type such as rice, then, it was expected that the depletion of soil water would start just at or after the field capacity, as it was the case for the runoff which occurred on day 58 (Table 4.6). At the beginning of this day, 1.7mm of water were above the field capacity, and at the end of the day, 1.9mm of water were below the field capacity. The depletion of soil water for day 58 started after the field capacity (Figure 4.1). Figure 4.1 also shows that before day 58 there were no surface runoff, whereas, Table 4.6 (whose data were used to plot graphs on Figure 4.1) shows that there were runoff events on day 55, 56 and 57. The remaining runoff events in Figure 4.1 show that the grown crops do consume part of the runoff. Further more, Figure 4.1 shows that the consumption of runoff water between successive periods of rain storms takes place for more than a day. But from experience, runoff can hardly survive for the few hours after rain stops. Similar events for other years, varieties, and type of crops are shown in sample figures presented in Appendix B.

Table 4.6 Daily root zone depletion for maize (Staha)-1991, IRSIS model

	Day	Rainfall (mm)	Ir Depth (mm)	TAW (mm)	RAW (mm)	D begin (mm)	D end (mm)
Global		484.3	0.0	87.4	66.8	46.8	49.9
06/02/1991	1	0.0	0.0	28.0	18.3	5.6	11.1
07/02/1991	2	0.0	0.0	29.4	20.8	11.4	15.0
08/02/1991	3	0.0	0.0	30.9	24.7	15.3	17.6
09/02/1991	4	0.0	0.0	32.3	29.0	17.8	19.3
10/02/1991	5	0.0	0.0	33.7	30.3	19.5	20.7
11/02/1991	6	0.0	0.0	35.1	31.6	21.0	22.1
12/02/1991	7	0.0	0.0	36.6	32.9	22.4	23.5
13/02/1991	8	0.0	0.0	38.0	34.2	23.8	24.9
14/02/1991	9	0.0	0.0	39.4	35.5	25.2	26.4
15/02/1991	10	0.0	0.0	40.8	36.7	26.7	27.8
*							
13/03/1991	36	33.9	0.0	77.9	54.2	15.0	20.4
14/03/1991	37	0.0	0.0	79.3	54.8	20.7	26.0
15/03/1991	38	0.0	0.0	80.8	55.9	26.3	31.4
16/03/1991	39	0.0	0.0	82.2	56.6	31.7	37.0
17/03/1991	40	0.0	0.0	83.6	55.5	37.3	42.8
18/03/1991	41	0.0	0.0	85.0	56.3	43.1	48.7
19/03/1991	42	0.0	0.0	86.5	56.8	49.0	54.5
20/03/1991	43	0.0	0.0	87.9	57.6	54.8	60.2
21/03/1991	44	0.0	0.0	89.3	57.9	60.5	65.3
22/03/1991	45	0.0	0.0	90.7	58.7	65.6	69.5
23/03/1991	46	0.0	0.0	92.2	59.7	69.8	73.3
24/03/1991	47	0.0	0.0	93.6	60.7	73.6	76.6
25/03/1991	48	3.6	0.0	95.0	63.6	73.3	75.9
26/03/1991	49	2.3	0.0	96.4	69.0	73.8	75.7
27/03/1991	50	4.4	0.0	97.9	74.0	71.6	74.7
28/03/1991	51	45.1	0.0	99.3	79.1	31.3	34.0
29/03/1991	52	82.1	0.0	100.7	83.6	3.7	6.9
30/03/1991	53	1.3	0.0	102.1	86.1	5.9	10.4
31/03/1991	54	0.0	0.0	103.6	86.7	10.7	15.1
01/04/1991	55	40.2	0.0	105.0	83.5	-14.9	-9.7
02/04/1991	56	22.3	0.0	105.0	80.8	-24.3	-19.5
03/04/1991	57	1.0	0.0	105.0	77.0	-0.7	-5.8
04/04/1991	58	1.8	0.0	105.0	71.8	-1.7	1.9
05/04/1991	59	1.8	0.0	105.0	70.3	5.3	8.0
06/04/1991	60	2.2	0.0	105.0	68.3	8.5	12.7
07/04/1991	61	22.6	0.0	105.0	69.0	-6.9	-2.8
08/04/1991	62	53.2	0.0	105.0	69.9	-24.1	-20.2
09/04/1991	63	0.1	0.0	105.0	72.8	0.3	-7.0
10/04/1991	64	2.0	0.0	105.0	75.0	-0.1	0.4
11/04/1991	65	0.0	0.0	105.0	74.6	4.5	8.1
12/04/1991	66	2.1	0.0	105.0	75.1	8.1	12.3
13/04/1991	67	0.0	0.0	105.0	76.9	13.4	16.5
14/04/1991	68	3.5	0.0	105.0	75.2	13.5	18.5
15/04/1991	79	0.0	0.0	105.0	72.4	18.8	23.8
16/04/1991	70	0.0	0.0	105.0	73.2	24.0	28.5
*							

* Data (16/02 - 12/03/1991 and 17/04 - 05/06/1991) omitted for brevity in text.

D = Day.
Ir = Irrigation.
RAW = Readily Available Water.
TAW = Total Available Water.



Depl = Depletion; FC = Field Capacity; RAW = Readily Available Water; TAW = Total Available Water.

Figure 4.1: Root zone depletion graph for Maize(Staha)-1991, IRSIS model.

These observations do agree with observations of Raes *et al.* (1987) that, the runoff calculated using the SCS - Curve Number Method (as was used in IRSIS) might give a poor estimate because factors such as the hill slope and the rain intensity are not taken into account. Curve Number (CN) method is applicable to larger basins up to several thousand hectares (Smedema and Rycroft, 1983). In contrast, fields from where data were collected for this study do not measure to such size. The CRPSMW model, however, assumes that irrigation water and rain water infiltrate instantaneously, that is, the surface runoff is not accounted for by the model. The model also assumes instantaneous drainage of excess soil water.

The above observations clearly show that the IRSIS model considers part of runoff as water available to plants. This also shows why the IRSIS model over-estimates the crop yields for it assumes that the soil water content is relatively high for days with runoff which coincide with growth stages having high kc-values during the growing period and that this runoff is being consumed by crops. This is evidenced by the yield response of maize (Table 4.8) and the corresponding rainfall application efficiency (Table 4.9), where the ratio of actual yield to maximum yield for maize (Kito) for growth stages 1 and 2 were both 100% and many of the rainfall application efficiencies during these growth stages were around 100%. Their corresponding kc-values are shown in (Table 4.7). Similar observations for growth stages 3 and 4 are shown in Appendix D.1. In addition, during the growth stages 1 and 2 (amounting to about 41 days) (Table 4.7), the corresponding root zone depletion graph (Figure 4.2) shows that runoff was dominant. Similar observations were noted for wheat (Table

D.2 and Figure B.7). This can also be supported by comparing actual maize yield data for Staha in 1990 and 1992 (Table 4.10) with root zone depletion graphs (Figures 4.3 and 4.4) respectively. For year 1990, the actual grain yield was 1 504 kg whereas IRSIS simulated grain yield was 2 160 kg, and for 1992, the actual grain yield was 1 585 kg whereas IRSIS simulated grain yield was 2 400 kg. This indicates that IRSIS is not sensitive to water logging whereas CRPSMW model uses a simple function to reduce yields as a result of excessive water.

Table 4.7 Daily soil water balance for maize (Kito) during growth stages 1 and 2, IRSIS model.

Date	ETo (mm)	ETcrop (mm)	kc	ETa (mm)	ETa/ETm	Rainfall (mm)
Global	427.9	398.7		384.2		506.5
03/03/1990	4.6	5.3	1.16	5.3	1.00	0.0
04/03/1990	2.2	2.7	1.24	2.7	1.00	20.3
05/03/1990	4.0	2.5	0.63	2.5	1.00	0.0
06/03/1990	4.3	2.0	0.46	2.0	1.00	0.0
07/03/1990	5.7	1.4	0.25	1.4	1.00	0.0
08/03/1990	4.6	2.8	0.60	2.8	1.00	1.3
09/03/1990	4.2	5.0	1.17	5.0	1.00	15.8
10/03/1990	5.2	5.9	1.14	5.9	1.00	1.7
11/03/1990	3.8	4.5	1.18	4.5	1.00	9.1
12/03/1990	5.0	5.7	1.15	5.7	1.00	0.3
13/03/1990	5.7	6.4	1.12	6.4	1.00	85.3
14/03/1990	3.9	4.6	1.18	4.6	1.00	6.4
15/03/1990	5.5	3.1	0.57	3.1	1.00	0.0
16/03/1990	5.6	6.3	1.12	6.3	1.00	20.5
17/03/1990	5.6	6.3	1.12	6.3	1.00	2.8
18/03/1990	5.9	4.0	0.67	4.0	1.00	3.7
*						
19/03/1990	5.9	4.0	0.68	4.0	1.00	0.0
20/03/1990	5.1	3.6	0.70	3.6	1.00	2.5
21/03/1990	4.5	5.2	1.16	5.2	1.00	7.5
22/03/1990	5.4	6.1	1.13	6.1	1.00	21.7
23/03/1990	4.7	3.5	0.74	3.5	1.00	0.0
24/03/1990	5.8	4.3	0.75	4.3	1.00	0.0
25/03/1990	5.7	4.3	0.76	4.3	1.00	0.0
26/03/1990	5.1	3.9	0.78	3.9	1.00	0.0
27/03/1990	5.1	5.8	1.14	5.8	1.00	42.0
28/03/1990	4.6	5.3	1.16	5.3	1.00	25.6
29/03/1990	4.9	5.6	1.15	5.6	1.00	22.9
30/03/1990	5.9	6.6	1.11	6.6	1.00	0.4
31/03/1990	4.6	5.4	1.16	5.4	1.00	2.6
01/04/1990	4.6	5.3	1.16	5.3	1.00	2.6
02/04/1990	5.5	6.2	1.13	6.2	1.00	4.1
03/04/1990	4.5	3.9	0.88	3.9	1.00	0.0
04/04/1990	4.9	4.3	0.89	4.3	1.00	2.9
05/04/1990	4.5	5.2	1.16	5.2	1.00	17.7
06/04/1990	4.1	4.8	1.17	4.8	1.00	11.6
07/04/1990	3.3	4.0	1.20	4.0	1.00	28.4
08/04/1990	3.8	4.5	1.18	4.5	1.00	0.2
09/04/1990	4.5	5.3	1.16	5.3	1.00	6.7
10/04/1990	4.6	5.3	1.16	5.3	1.00	22.4
11/04/1990	2.7	3.3	1.22	3.3	1.00	17.3
12/04/1990	4.3	4.3	1.00	4.3	1.00	11.2
**						

* End of growth stage 1.
** End of growth stage 2.
ETa = Actual evapotranspiration
Etcrop = Crop evapotranspiration.
ETm = Maximum evapotranspiration.
ETo = Reference evapotranspiration.

Table 4.8 Yield response for maize (Kito)-1990, IRSIS model.

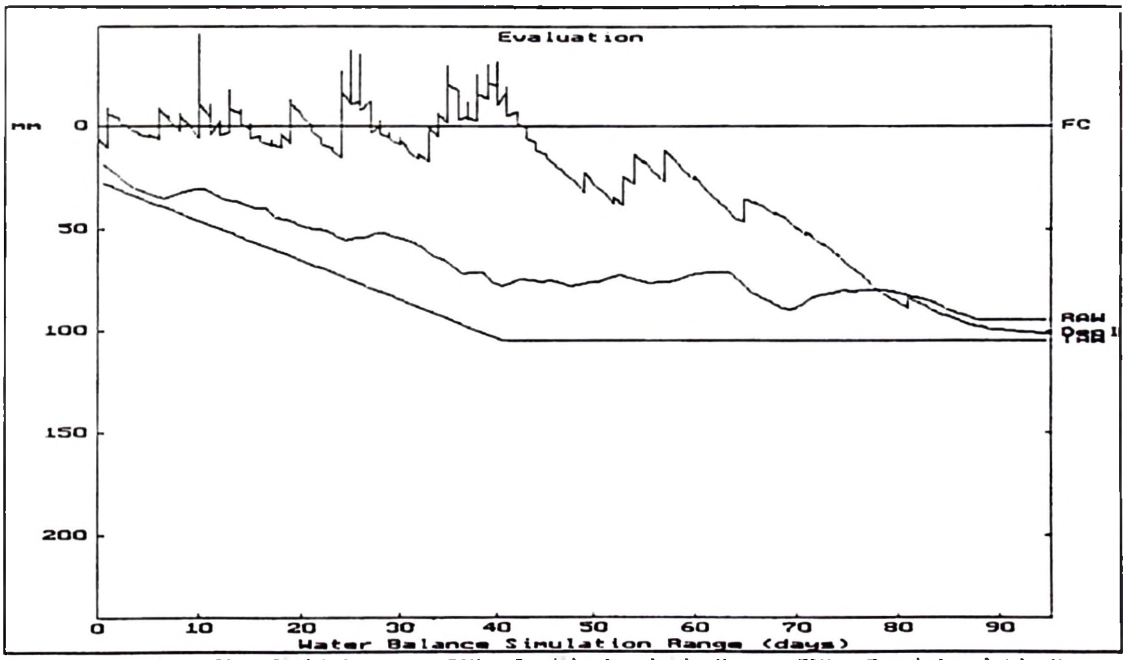
	Growth stage	ETa/ETm	Rainfall (mm)	Ir Depth (mm)	N Ir	ky	Ya/Ym (%)
Global			506.5	0.0			
03/03/1990	1	1.00	163.5	0.0	0	0.20	100.0
18/03/1990	2	1.00	242.8	0.0	0	0.20	100.0
12/04/1990	3	1.00	91.0	0.0	0	0.55	100.0
13/05/1990	4	0.75	9.2	0.0	0	0.44	91.8

Ir = Irrigation.
N Ir = Number of irrigation days.
Ky = Yield response factor.
Ya =Actual yield.
Ym = maximum yield.

Table 4.9 Application efficiency for maize (Kito) during growth stages 1 and 2, IRSIS model.

	Rainfall (mm)	Ir Depth (mm)	Rain Eff (%)	Ir Eff (%)
Global	506.5	0.0		
04/03/1990	20.3		100.0	
08/03/1990	1.3		100.0	
09/03/1990	15.8		100.0	
10/03/1990	1.7		100.0	
11/03/1990	9.1		100.0	
12/03/1990	0.3		100.0	
13/03/1990	85.3		26.9	
14/03/1990	6.4		48.5	
16/03/1990	20.5		21.7	
17/03/1990	2.8		100.0	
18/03/1990	3.7		100.0	
*				
20/03/1990	2.5		100.0	
21/03/1990	7.5		100.0	
22/03/1990	21.7		72.5	
27/03/1990	42.0		75.9	
28/03/1990	25.6		2.1	
29/03/1990	22.9		1.7	
30/03/1990	0.4		94.9	
31/03/1990	2.6		100.0	
01/04/1990	2.6		100.0	
02/04/1990	4.1		100.0	
04/04/1990	2.9		100.0	
05/04/1990	17.7		100.0	
06/04/1990	11.6		98.1	
07/04/1990	28.4		45.3	
08/04/1990	0.2		0.0	
09/04/1990	6.7		48.0	
10/04/1990	22.4		57.3	
11/04/1990	17.3		0.0	
12/04/1990	11.2		0.0	
**				

* End of growth stage 1
** End of growth stage 2
Ir Eff = Irrigation efficiency.

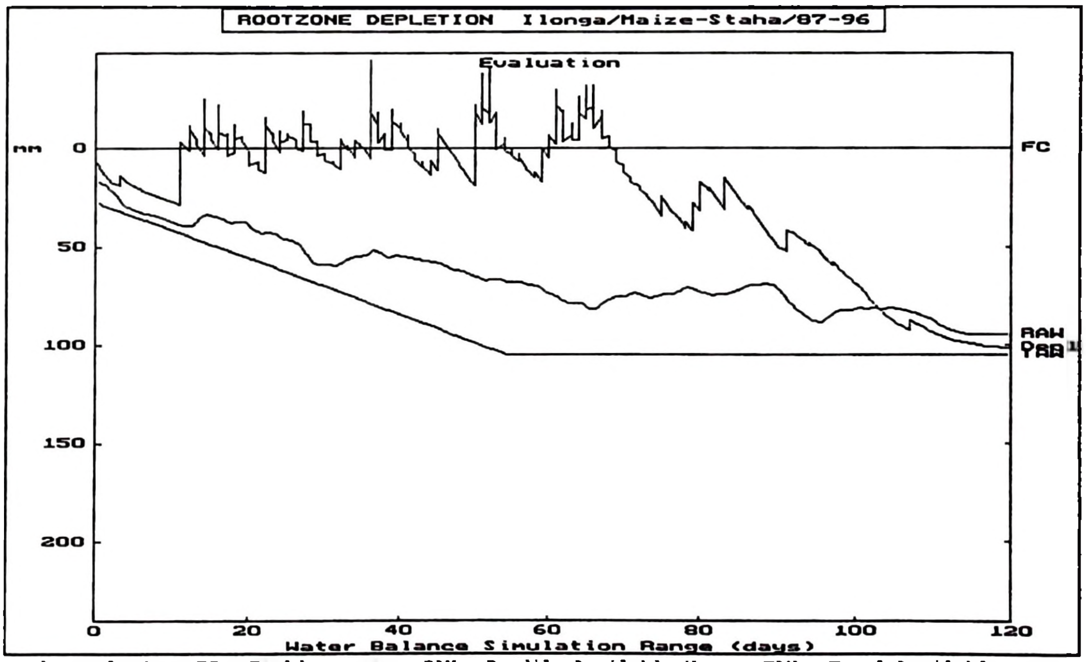


Depl - Depletion; FC - Field Capacity; RAW - Readily Available Water; TAW - Total Available Water.

Figure 4.2: Root zone depletion graph for maize (Kito)-1990, IRSIS model

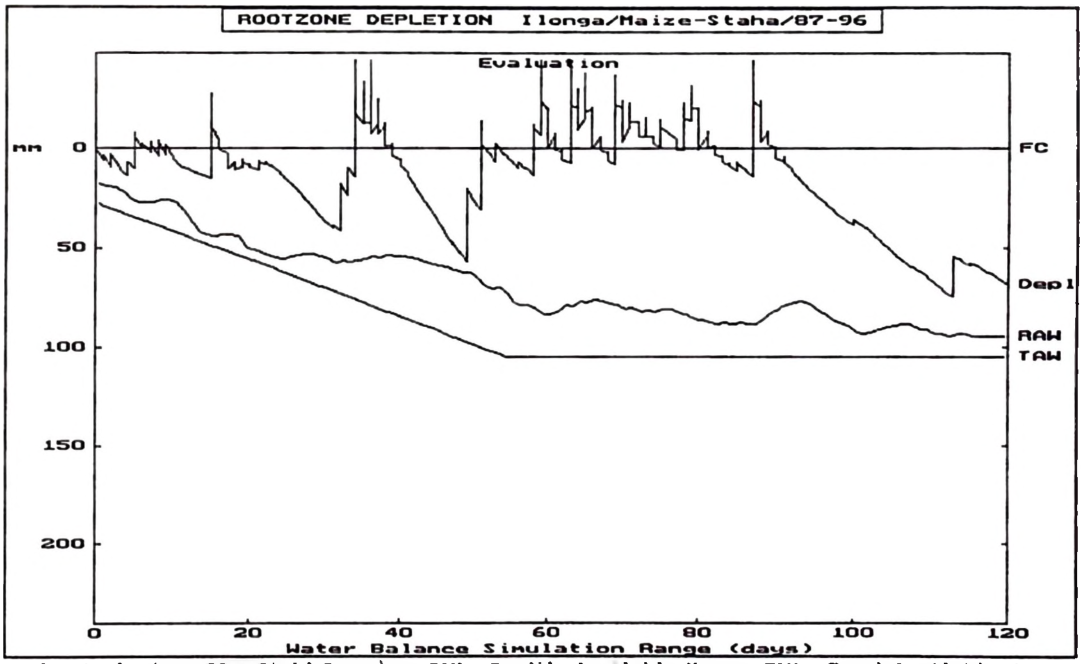
Table 4.10 Actual and IRSIS simulated yield for maize (Staha)

	Yield (Kg/ha)	
Year	Actual yield	IRSIS simulated yield
1990	1 504	2 160
1992	1 585	2 400



Depl= Depletion; FC = Field capacity; RAW = Readily Available Water; TAW = Total Available Water.

Figiure 4.3: Root zone depletion graph for Maize (Staha)-1990, IRSIS model.



Depl = Depletion; FC = Field Capacity; RAW = Readily Available Water; TAW = Total Available Water.

Figure 4.4: Root zone depletion graph for Maize (Staha)-1992, IRSIS model.

From the yield data analysis for maize (Staha), Table 4.1, and other varieties of maize and types of crop shown in Appendix A, the simulated grain (CRPSMW model) for planting dates falling on or after the probable date for start of the growing season as determined by Kassase (1992) (i.e. 18 February for Arusha and 02 March for Morogoro) (Table 4.11), were not significantly different from their corresponding actual grain yield.

Table 4.11 Actual planting dates for maize and the start of the growing season.

Year	Station			
	IARTI and MFSF	SARI and AFSF	Morogoro	Arusha
	Actual planting date		Start of growing season (analysis of 30 years old data)	
1960-1990			02 Mar.	18 Feb.
87	-	10 Mar.		
88	-	10 Feb.		
89	04 Jan.	24 Jan.		
90	05 Feb.	01 Mar.		
91	06 Feb.	04 Mar.		
92	13 Feb.	05 Feb.		
93	16 Mar.	03 Mar.		
94	29 Jan.	09 Mar.		
95	24 Jan.	04 Mar.		
96	19 Feb.	09 Feb.		

AFSF = Arusha Foundation Seed Farm.
IARTI = Ilonga Agricultural Research and Training Institute.
MFSF = Msimba Foundation Seed Farm.
SARI = Selian Agricultural Research Institute.

However, the probable start dates of the growing season for Morogoro and Arusha as determined by Kassase (1992) do not exactly match the actual planting dates for the stations under study. Nevertheless, it should be noted that this is the probability of an event occurring on or after the stated date which could slightly explain the case of Arusha stations (Table 4.11). The other explanation, more so for the case of Morogoro stations, is that the location of the weather stations from which data were collected and used to determine the start of the growing season is different. For Morogoro, Kassase (1992) used weather data from Morogoro agrometeorological weather station which is about 90 Kilometers from Ilonga and Msimba stations. For Arusha, Kassase (1992) used weather data from Arusha Airport which is about 0.5 kilometers from Selian Agricultural Research Institute (SARI) and about 15 kilometers from Arusha Foundation Seed Farm (AFSF).

Thus, weather data for Arusha Airport were more appropriate for SARI and AFSF than those of Morogoro agrometeorological weather station for Ilonga and Msimba. This indicates that, good estimates of the probable dates for start of the growing season for a certain site can reliably be achieved if location specific weather data are used for analysis.

5. CONCLUSIONS AND RECOMMENDATIONS

From this study the following conclusions and recommendations can be made:

1. There is a fairly good agreement between actual and simulated grain yields for CRPSMW model. When the t-Test was performed for yield data of selected crops used in this study, the computed t-values (t-statistic) were found to be not significant at 5% level. A relatively poor agreement between actual and simulated grain yields was observed for IRSIS model. The computed t-values were found to be significant at 5% level for yield data of selected crops used in this study except beans. The disagreement between the actual and IRSIS predicted grain yields could largely be attributed to failure for the model to accurately estimate the surface runoff, as a result of which, it was considered as part of soil water consumed by crops.

2. Effective methods which consider factors such as hill slope, rain intensity, and size of catchment area in estimating surface runoff have to be incorporated as sub-models in the IRSIS model. This sub-model will help to exclude the surface runoff from being considered as part of soil water.

3. Despite the fact that there is a good agreement between the actual and CRPSMW model simulated grain yield, the average values of the predicted grain yields were consistently smaller than for actual grain yields for most of the analyzed data. These differences could be attributed to: (a) the fact that some of the parameters

required as inputs to the model such as available soil water fraction at start of stress, index of growth state closest to effective cover, number of days effective cover differs from occurrence of state, the phenology clock value in days/degree days for each growth state, weighting factors for yield calculation for each growth state, the growth state for use of seasonal length yield factor and an exponent to be used in seasonal length yield factor were estimated from either sample examples illustrated in CRPSMW software user manual or from data obtained through literature, and (b) some of the estimates of potential yields were acquired from other sources, hence, the accuracy with which they are estimated may greatly influence prediction by the model.

4. The use of location specific parameters for input in CRPSMW model for weather, crops, and soil data is necessary to achieve better prediction of grain yields.

5. Generally, the CRPSMW model predicted grain yields better than the IRSIS model, thus, it is considered suitable for adoption. However, more research work in determining location specific parameters as input to the model and the influence of moisture stress (as exemplified by length of dry spells) on different growth stages and hence yields under tropical conditions may contribute to further development of the model.

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APPENDIX A

YIELD DATA ANALYSIS SIMULATED BY IRSIS AND CRPSMW MODELS

Table A.1: Yield data analysis for maize (variety: Kito) - Ilonga and Msimba stations, Morogoro.

Year	Actual yield	CRPSMW: Predicted yields for respective planting dates*			Average yield**	IRSIS: Predicted yields for respective planting dates			Average yield**
	Y_a (Kg)	Y_1 (Kg)	Y_3 (Kg)	Y_{GSa} (Kg)	Y_{avg} (Kg)	Y_1 (Kg)	Y_3 (Kg)	Y_{GSa} (Kg)	Y_{avg} (Kg)
1987	450	770	780	800	783	1 346	1 358	1 500	1 401
1989	1 200	660	690	710	687	1 007	1 014	1 500	1 174
1990	1 100	800	810	800	803	1 500	1 500	1 185	1 394
1991	900	690	710	720	707	1 056	1 121	1 500	1 226
1992	450	860	830	820	837	1 500	1 500	1 493	1 498
1994	850	850	810	780	813	1 500	1 500	1 326	1 442

t-Test (Comparison of two samples).

	Y_1 vs Y_a	Y_3 vs Y_a	Y_{GSa} vs Y_a	Y_{avg} vs Y_a	Y_1 vs Y_a	Y_3 vs Y_a	Y_{GSa} vs Y_a	Y_{avg} vs Y_a
Significance	Ns	Ns	Ns	Ns	S	S	S	S

* Actual planting date (Y_1), planting date three days later (Y_3), and planting date falling on or after the date for start of the growing season (Y_{GSa}) (i.e. 02 March for Morogoro for long rain season at 20% probablity level (Kassase, 1992)).

** Average of Y_1, Y_3, and Y_{GSa}.

Ns = Not significant at $P<0.05$.

S = Significant at $P<0.05$

Table A.2: Yield data analysis for maize (variety: TMV-1) - Ilonga and Msimba stations, Morogoro.

Year	Actual yield	CRPSMW: Predicted yields for respective planting dates*			Average yield**	IRSIS: Predicted yields for respective planting dates*			Average yield**
	Y_a (Kg)	Y_1 (Kg)	Y_3 (Kg)	Y_{GSa} (Kg)	Y_{avg} (Kg)	Y_1 (Kg)	Y_3 (Kg)	Y_{GSa} (Kg)	Y_{avg} (Kg)
1989	1 800	1 810	1 790	1 540	1 713	2 304	2 369	2 400	2 358
1990	1 069	1 020	940	880	947	1 354	1 322	1 308	1 328
1991	1 775	1 810	1 820	1 270	1 633	2 400	2 400	1 896	2 232
1992	1 400	1 910	1 460	1 500	1 623	2 400	2 400	2 400	2 400
1993	1 690	1 980	1 910	1 710	1 867	2 400	2 400	2 400	2 400
1994	1 100	1 260	1 200	1 080	1 180	1 632	1 546	1 440	1 539
1995	895	1 160	1 110	1 080	1 117	1 800	1 704	1 464	1 656
1996	1 960	1 830	1 740	1 550	1 707	2 400	2 400	2 400	2 400

t-Test (Comparison of two samples).

	Y_1 vs Y_a	Y_3 vs Y_a	Y_{GSa} vs Y_a	Y_{avg} vs Y_a	Y_1 vs Y_a	Y_3 vs Y_a	Y_{GSa} vs Y_a	Y_{avg} vs Y_a
Significance	Ns	Ns	Ns	Ns	S	S	S	S

* Actual planting date (Y_1), planting date three days later (Y_3), and planting date falling on or after the date for start of the growing season (Y_{GSa}) (i.e. 02 March for Morogoro for long rain season at 20% probablity level (Kassase, 1992)).

** Average of Y_1, Y_3, and Y_{GSa}.

Ns = Not significant at $P<0.05$.

S = Significant at $P<0.05$.

Table A.3: Yield data analysis for Sorghum (Variety: Tegemeo) - Ilonga and Msimba stations, Morogor

		CRPSMW				IRSIS			
Year	Actual yield	Predicted yields for respective planting dates*			Average yield**	Predicted yields for respective planting dates*			Average yield**
	Y_a (Kg)	Y_1 (Kg)	Y_3 (Kg)	Y_{GSs} (Kg)	Y_{avg} (Kg)	Y_1 (Kg)	Y_3 (Kg)	Y_{GSs} (Kg)	Y_{avg} (Kg)
1987	1 000	1 100	1 070	1 000	1 057	1 425	1 425	1 380	1 410
1988	900	920	920	900	913	1 500	1 500	1 455	1 485
1989	800	760	750	720	743	1 410	1 305	1 245	1 320
1990	1 600	910	860	810	860	1 215	1 125	1 068	1 136
1991	700	840	810	790	813	1 410	1 425	1 356	1 397
1993	433	770	720	670	720	1 140	1 065	1 005	1 070
1994	800	750	730	700	727	1 110	1 050	990	1 050

t-Test (Comparison of two samples).

	Y_1 vs Y_a	Y_3 vs Y_a	Y_{GSs} vs Y_a	Y_{avg} vs Y_a	Y_1 vs Y_a	Y_3 vs Y_a	Y_{GSs} vs Y_a	Y_{avg} vs Y_a
Significance	Ns	Ns	Ns	Ns	S	S	Ns	S

* Actual planting date (Y_1), planting date three days later (Y_3), and planting date falling on or after the date for start of the growing season (Y_{GSs}) (i.e. 02 March for Morogoro for long rain season at 20% probablity level (Kassase, 1992)).

** Average of Y_1, Y_3, and Y_{GSs}.

Ns = Not significant at P<0.05

S = Significant at P<0.05.

APPENDIX B

ROOT ZONE DEPLETION GRAPHS -AN OUTPUT OF IRSIS MODEL

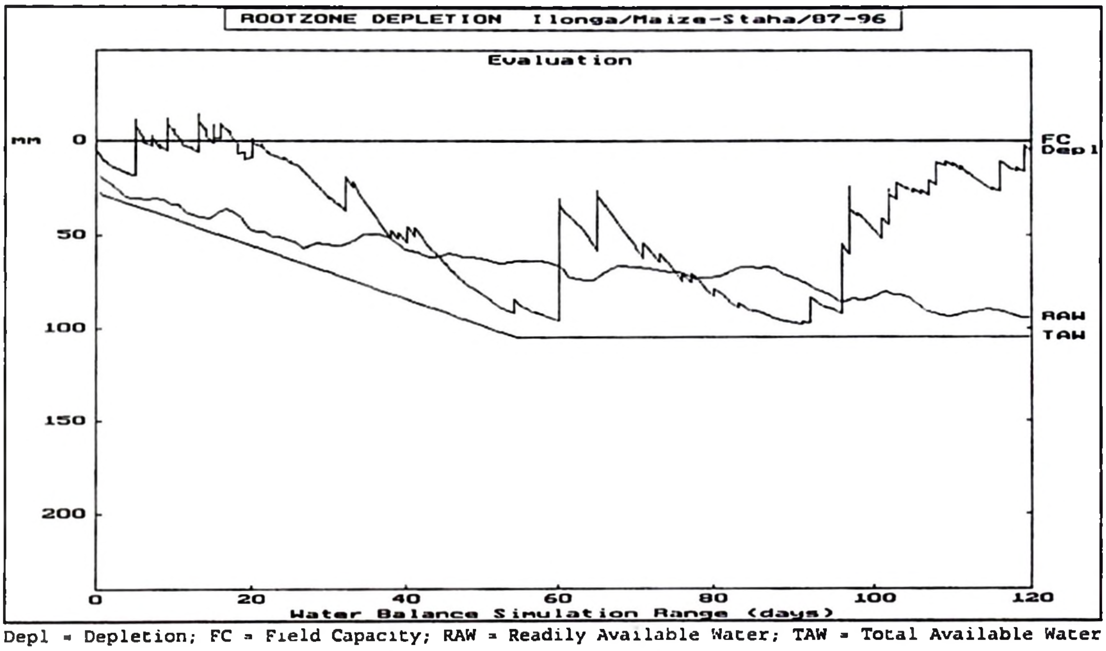


Figure B.1: Root zone depletion graph for Maize (Staha)-1989, IRSIS model.

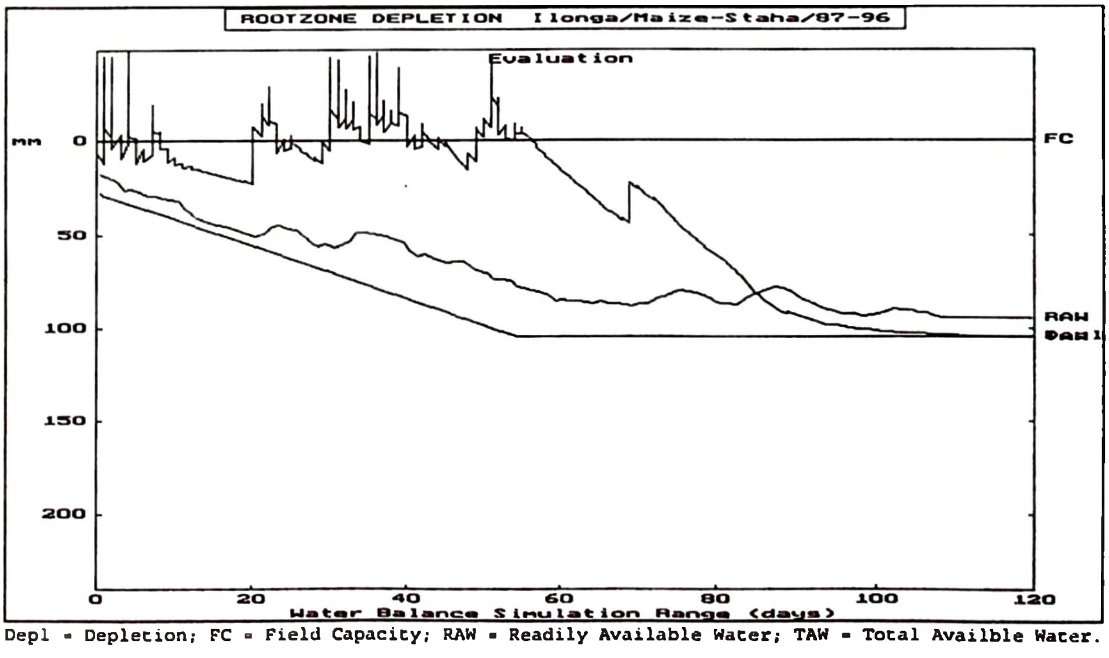
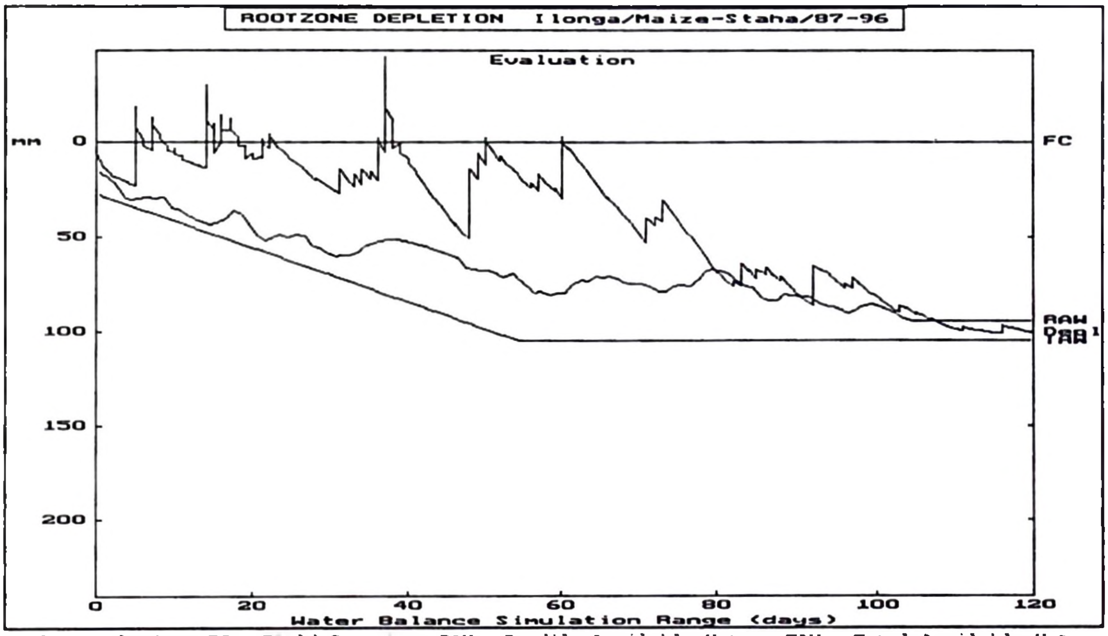
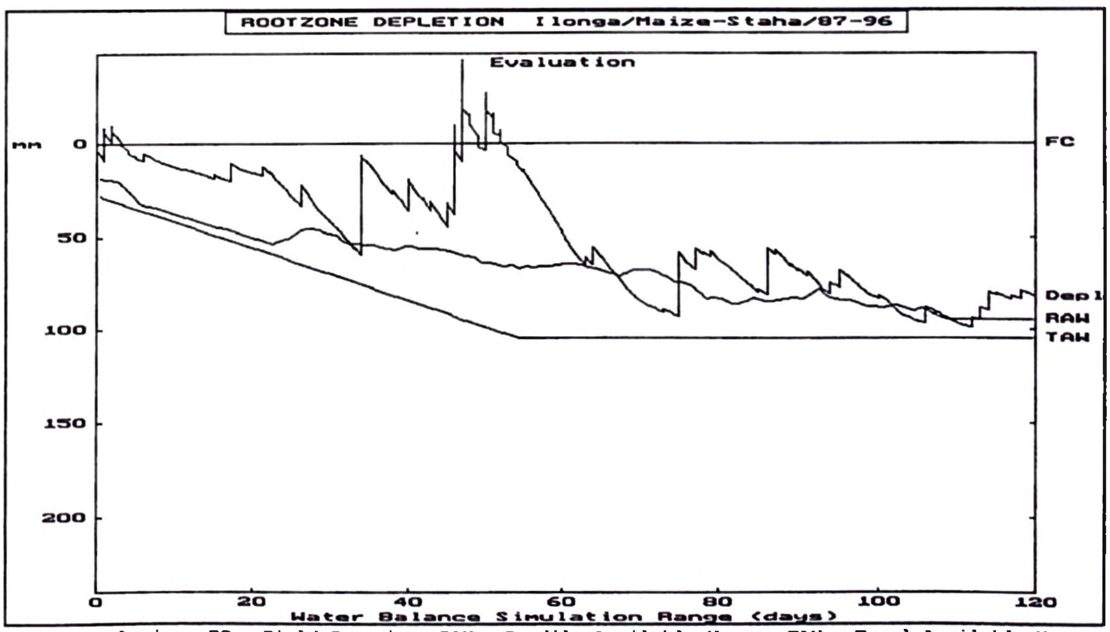


Figure B.2: Root zone deplition graph for Maize (Staha)-1993, IRSIS model.



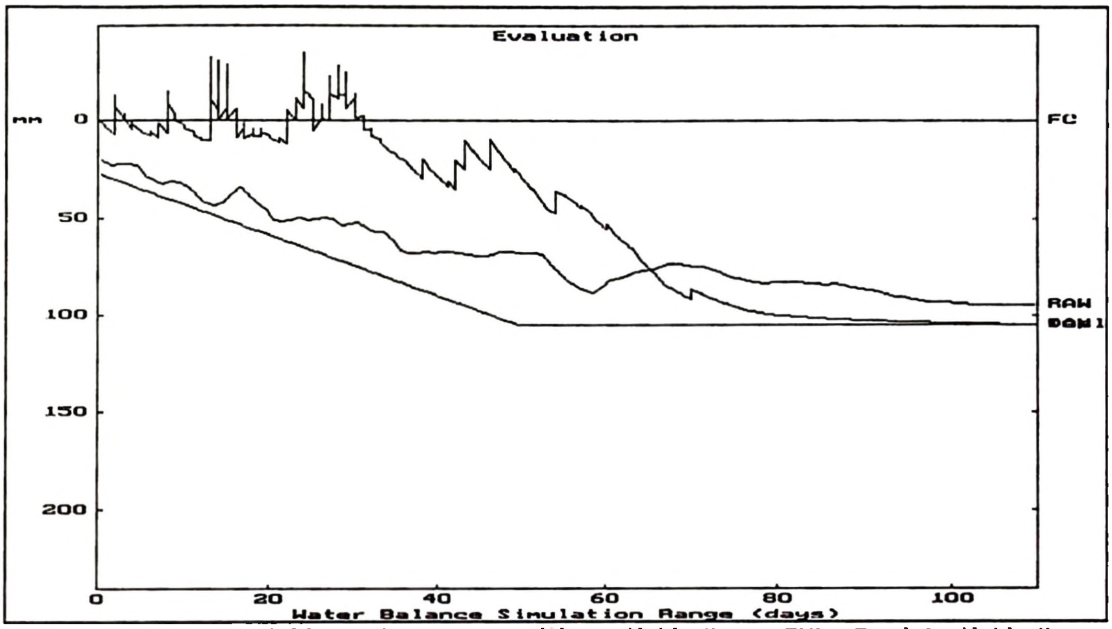
Depl = Depletion; FC = Field Capacity; RAW = Readily Available Water; TAW = Total Available Water.

Figure B.3: Root zone deplition graph for Maize (Staha)-1994, IRSIS model.



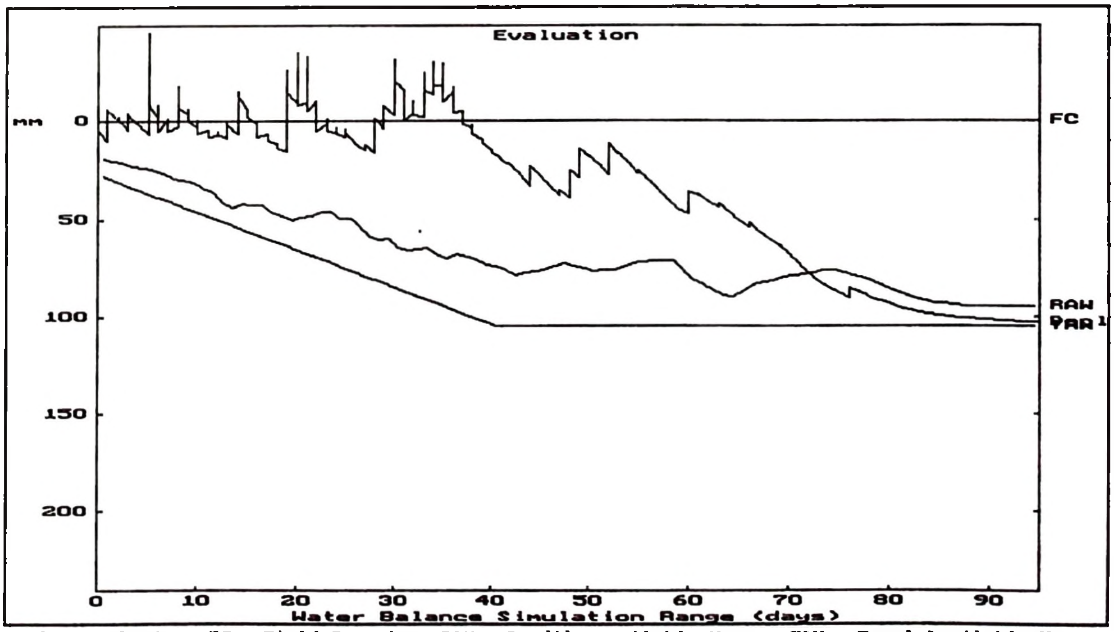
Depl = Depletion; FC = Field Capacity; RAW = Readily Available Water; TAW = Total Available Water.

Figure B.4: Root zone deplition graph for Maize (Staha)-1995, IRSIS model.



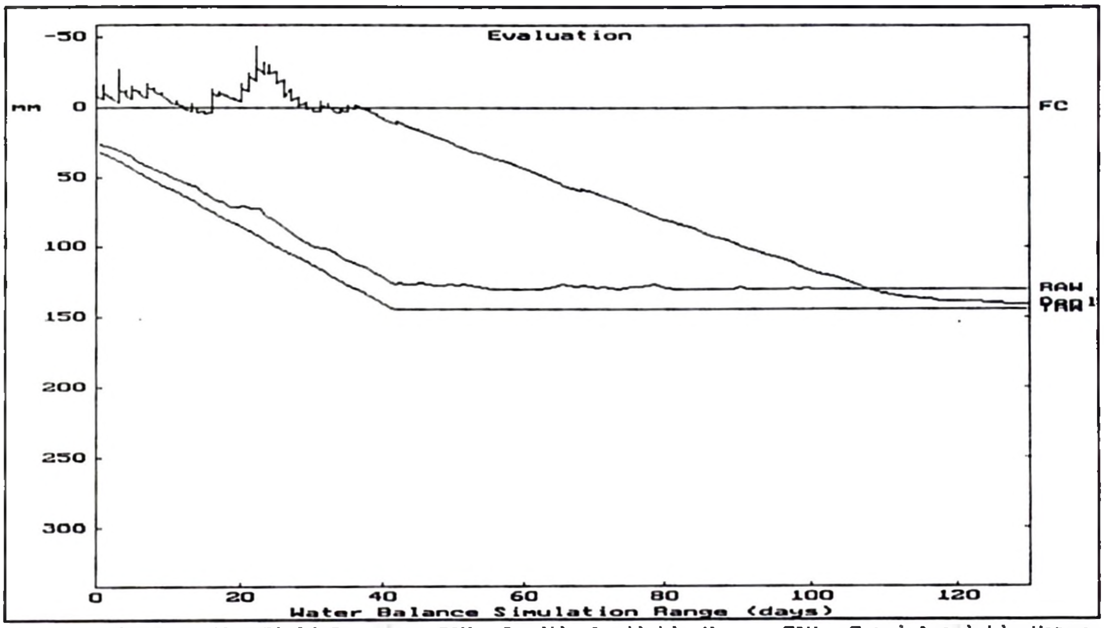
Depl =Depletion; FC = Field Capacity; RAW = Readily Available Water; TAW = Total Available Water.

Figure B.5: Root zone depletion graph for Maize (TMV-1)-1990, IRSIS model.



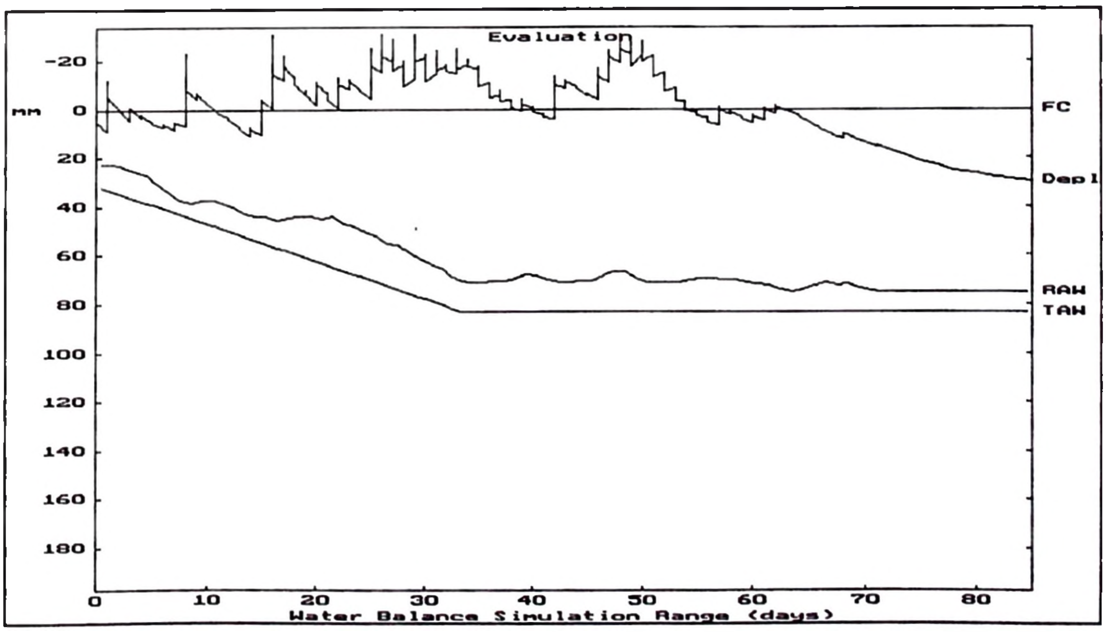
Depl = Depletion; FC = Field Capacity; RAW = Readily Available Water; TAW = Total Available Water.

Figure B.6: Root zone depletion graph for sorghum (Tegemeo)-1990, IRSIS model.



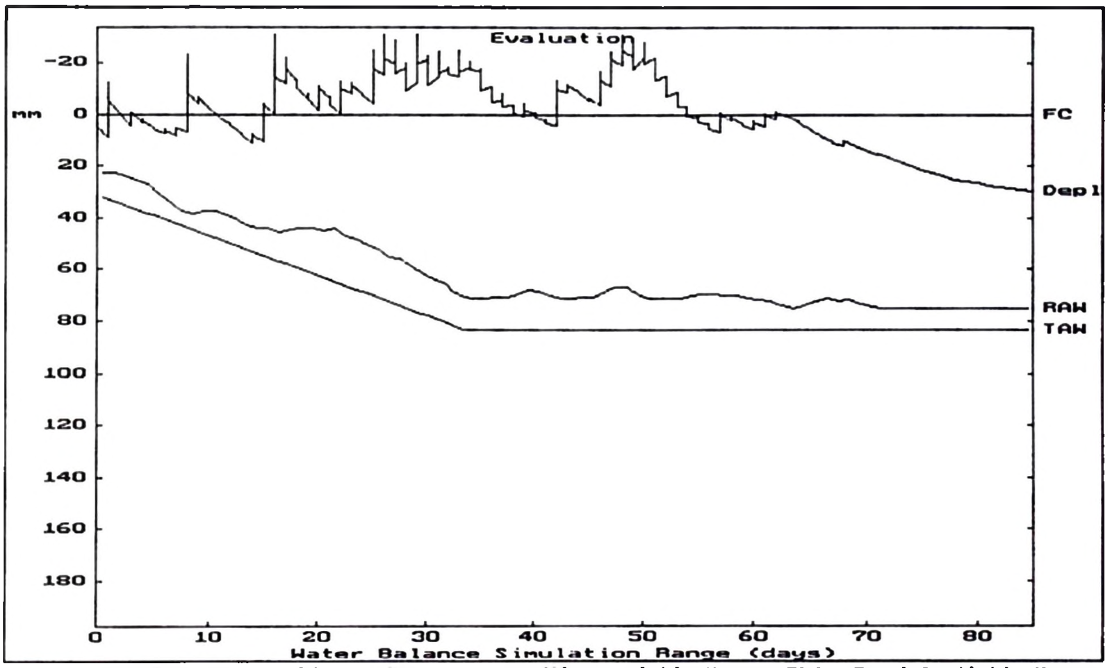
Depl = Depletion; FC = Field Capacity; RAW = Readily Available Water; TAW = Total Available Water.

Figure B.7: Root zone depletion for wheat (Mbayuwayu and Mbuni)-1990, IRSIS model.



Depl = Depletion; FC = Field Capacity; RAW = Readily Available Water; TAW = Total Available Water.

Figure B.8: Root zone depletion graph for beans (Lyamungu 85)-1994, IRSIS model.



Depl = Depletion; FC = Field Capacity; RAW = Readily Available Water; TAW = Total Available Water.

Figure B.9: Root zone depletion graph for beans (Lyamungu90)-1994, IRSIS model.

APPENDIX C

IRSIS AND CRPSMW MODEL SIMULATED GRAIN YIELDS

Table C.1: IRSIS and CRPSMW model simulated grain yields on different planting dates for different years.

Station: Ilonga-Msimba
Crop: Maize
Variety: Staha-GP*120

Planting Dates	Dates for initial SMC	Ilonga Potential yiel (Ym)- Kg/ha	Msimba Actual yield (Ya)-Kg/ha	IRSIS Predicted yield-Kg/ha	CRPSMW Predicted yield-Kg/ha	Msimba Ilonga (Ya/Ym)%	CRPSMW (Ya/Ym)%	IRSIS (Ya/Ym)%
1989								
4-Jan	4-Jan	2 400	1 864	2 352	1 800	78	75	98
7-Jan	"	"	"	2 400	1 780	"	74	100
2-Mar	"	"	"	2 400	1 510	"	63	100
1990								
5-Feb	5-Feb	2 400	1 504	2 160	1 670	63	69	90
8-Feb	"	"	"	2 016	1 610	"	67	84
2-Mar	"	"	"	1 368	1 080	"	45	57
1991								
6-Feb	6-Feb	2 400	1 400	2 057	1 470	58	61	86
9-Feb	"	"	"	2 107	1 420	"	59	88
2-Mar	"	"	"	1 512	1 170	"	49	63
1992								
13-Feb	13-Feb	2 400	1 585	2 400	1 860	66	78	100
16-Feb	"	"	"	2 400	1 760	"	74	100
2-Mar	"	"	"	2 180	1 390	"	58	91
1993								
16-Mar	16-Mar	2 400	895	1 454	1 020	37	43	61
19-Mar	"	"	"	1 394	940	"	39	58
22-Mar	"	"	"	1 340	870	"	36	56
1994								
29-Jan	29-Jan	2 400	895	2 230	1 590	37	66	93
1-Feb	"	"	"	1 505	1 510	"	63	89
2-Mar	"	"	"	1 416	960	"	40	59
1995								
24-Jan	24-Jan	2 400	1 440	2 304	1 580	60	66	96
27-Jan	"	"	"	2 256	1 560	"	65	94
2-Mar	"	"	"	1 488	1 210	"	50	62
1996								
19-Feb	19-Feb	2 400	1 470	2 400	1 710	61	71	100
22-Feb	"	"	"	2 400	1 630	"	68	100
2-Mar	"	"	"	2 400	1 460	"	61	100

* GP = Growing period.

Table C.2: IRSIS and CRPSMW model simulated grain yields on different planting dates for different years.

Station: Ilonga-Msimba
Crop: Maize
Variety: Kito-GP*60

Planting Dates	Dates for initial SMC	Ilonga Potential yiel (Ym)- Kg/ha	Msimba Actual yield (Ya)-Kg/ha	IRSIS Predicted yield-Kg/ha	CRPSMW Predicted Yield-Kg/ha	Msimba Ilonga Ya/Ym%	CRPSMW Ya/Ym%	IRSIS Ya/Ym%
1987								
25-Feb	25-Feb	1 500	450	1 346	770	30	51	100
28-Feb	"	"	"	1 358	780	"	52	100
2-Mar	"	"	"	1 500	800	"	53	100
1989								
4-Jan	4-Jan	1 500	1 200	1 007	660	80	44	94
7-Jan	"	"	"	1 014	690	"	46	91
2-Mar	"	"	"	1 500	710	"	47	100
1990								
3-Mar	3-Mar	1 500	1 100	1 500	800	73	54	92
6-Mar	"	"	"	1 500	810	"	54	85
9-Mar	"	"	"	1 185	800	"	54	79
1991								
9-Jan	9-Jan	1 500	900	1 056	690	60	46	89
12-Jan	"	"	"	1 121	710	"	47	95
2-Mar	"	"	"	1 500	720	"	48	100
1992								
16-Mar	16-Mar	1 500	450	1 500	860	30	57	100
19-Mar	"	"	"	1 500	830	"	55	100
22-Mar	"	"	"	1 500	820	"	54	100
1994								
25-Feb	25-Feb	1 500	850	1 500	850	57	57	96
28-Feb	"	"	"	1 500	810	"	54	92
2-Mar	"	"	"	1 326	780	"	52	88

* GP = Growing period.

Table C.3: IRSIS and CRPSMW model simulated grain yields on different planting dates for different years.

Station: Ilonga-Msimba
Crop: Maize
Variety: TMV-1 GP*110

Planting Dates	Dates for initial SMC	Ilonga Potential yiel (Ym)- Kg/ha	Msimba Actual yield (Ya)-Kg/ha	IRSIS Predicted yield-Kg/ha	CRPSMW Predicted Yield-Kg/ha	Msimba Ilonga Ya/Ym%	CRPSMW Ya/Ym%	IRSIS Ya/Ym%
1989								
10-Jan	10-Jan	2 400	1 800	2 304	1 810	75	75	96
13-Jan	"	"	"	2 369	1 790	"	75	99
2-Mar	"	"	"	2 400	1 540	"	64	100
1990								
14-Mar	14-Mar	2 400	1 069	1 354	1 020	45	42	56
17-Mar	"	"	"	1 322	940	"	39	55
20-Mar	"	"	"	1 308	880	"	37	55
1991								
9-Jan	9-Jan	2 400	1 775	2 400	1 810	74	76	100
12-Jan	"	"	"	2 400	1 820	"	76	100
2-Mar	"	"	"	1 896	1 270	"	53	79
1992								
26-Feb	26-Feb	2 400	1 400	2 400	1 910	58	66	100
29-Feb	"	"	"	2 400	1 460	"	61	100
3-Mar	"	"	"	2 400	1 500	"	63	100
1993								
11-Feb	11-Feb	2 400	1 690	2 400	1 980	70	83	100
14-Feb	"	"	"	2 400	1 910	"	80	100
2-Mar	"	"	"	2 400	1 710	"	71	100
1994								
21-Feb	21-Feb	2 400	1 100	1 632	1 260	46	52	68
24-Feb	"	"	"	1 546	1 200	"	50	64
2-Mar	"	"	"	1 440	1 080	"	45	62
1995								
11-Mar	11-Mar	2 400	895	1 800	1 160	37	49	75
14-Mar	"	"	"	1 704	1 110	"	46	71
17-Mar	"	"	"	1 464	1 080	"	45	61
1996								
19-Feb	19-Feb	2 400	1 960	2 400	1 830	82	76	100
22-Feb	"	"	"	2 400	1 740	"	73	100
2-Mar	"	"	"	2 400	1 550	"	65	100

* GP = Growing period.

Table C.3: IRSIS and CRPSMW model simulated grain yields on different planting dates for different years.

Station: Ilonga-Msimba
Crop: Maize
Variety: TMV-1 GP*110

Planting Dates	Dates for initial SMC	Ilonga Potential yiel (Ym)- Kg/ha	Msimba Actual yield (Ya)-Kg/ha	IRSIS Predicted yield-Kg/ha	CRPSMW Predicted Yield-Kg/ha	Msimba Ilonga Ya/Ym%	CRPSMW Ya/Ym%	IRSIS Ya/Ym%
1989								
10-Jan	10-Jan	2 400	1 800	2 304	1 810	75	75	96
13-Jan	"	"	"	2 369	1 790	"	75	99
2-Mar	"	"	"	2 400	1 540	"	64	100
1990								
14-Mar	14-Mar	2 400	1 069	1 354	1 020	45	42	56
17-Mar	"	"	"	1 322	940	"	39	55
20-Mar	"	"	"	1 308	880	"	37	55
1991								
9-Jan	9-Jan	2 400	1 775	2 400	1 810	74	76	100
12-Jan	"	"	"	2 400	1 820	"	76	100
2-Mar	"	"	"	1 896	1 270	"	53	79
1992								
26-Feb	26-Feb	2 400	1 400	2 400	1 910	58	66	100
29-Feb	"	"	"	2 400	1 460	"	61	100
3-Mar	"	"	"	2 400	1 500	"	63	100
1993								
11-Feb	11-Feb	2 400	1 690	2 400	1 980	70	83	100
14-Feb	"	"	"	2 400	1 910	"	80	100
2-Mar	"	"	"	2 400	1 710	"	71	100
1994								
21-Feb	21-Feb	2 400	1 100	1 632	1 260	46	52	68
24-Feb	"	"	"	1 546	1 200	"	50	64
2-Mar	"	"	"	1 440	1 080	"	45	62
1995								
11-Mar	11-Mar	2 400	895	1 800	1 160	37	49	75
14-Mar	"	"	"	1 704	1 110	"	46	71
17-Mar	"	"	"	1 464	1 080	"	45	61
1996								
19-Feb	19-Feb	2 400	1 960	2 400	1 830	82	76	100
22-Feb	"	"	"	2 400	1 740	"	73	100
2-Mar	"	"	"	2 400	1 550	"	65	100

* GP = Growing period.

Table C.5: IRSIS and CRPSMW model simulated grain yields on different planting dates for different years.

Station: SARI-AFSF
Crop: Wheat
Variety: Mbayuwayu & Mbuni-GP*130

Planting Dates	Dates for initial SMC	SARI otential yiel (Ym)- Kg/ha	AFSF Actual yield (Ya)-Kg/ha	IRSIS Predicted yield-Kg/ha	CRPSMW Predicted yield-Kg/ha	SARI AFSF (Ya/Ym)%	CRPSMW (Ya/Ym)%	IRSIS (Ya/Ym)%
1987								
25-Apr	25-Apr	3 000	1 022	1 950	1 320	34	44	65
28-Apr		"	"	1 959	1 110	"	37	65
1-May		"	"	1 962	970	"	32	65
1988								
3-Apr	3-Apr	3 000	1 642	1 587	1 220	55	41	53
6-Apr		"	"	1 566	1 240	"	42	52
9-Apr		"	"	1 557	1 270	"	42	52
1989								
5-Apr	5-Apr	3 000	1 846	1 740	1 150	62	38	58
8-Apr		"	"	1 683	1 110	"	37	56
11-Apr		"	"	1 644	1 080	"	36	55
1990								
3-Apr	3-Apr	3 000	1 051	2 622	1 510	35	50	87
6-Apr		"	"	2 460	1 250	"	42	82
9-Apr		"	"	2 331	1 070	"	36	78
1991								
3-Apr	3-Apr	3 000	1 752	3 000	1 850	58	62	100
6-Apr		"	"	3 000	1 750	"	59	100
9-Apr		"	"	3 000	1 700	"	57	100
1992								
17-Apr	17-Apr	3 000	1 946	3 000	2 080	65	69	100
20-Apr		"	"	3 000	1 920	"	64	100
23-Apr		"	"	2 991	1 770	"	59	100
1993								
14-Apr	14-Apr	3 000	1 129	1 569	1 000	38	33	52
17-Apr		"	"	1 563	910	"	30	52
20-Apr		"	"	1 548	710	"	24	52
1994								
9-Apr	9-Apr	3 000	1 859	1 683	1 840	62	61	56
12-Apr		"	"	1 647	1 370	"	46	55
15-Apr		"	"	1 626	1 090	"	36	54
1995								
20-Apr	20-Apr	3 000	1 350	1 770	1 490	45	50	59
23-Apr		"	"	1 746	1 240	"	41	58
26-Apr		"	"	1 716	1 050	"	35	57

* GP = Growing period.

Table C.6: IRSIS and CRPSMW model simulated grain yields on different planting dates for different years.

Station: SARI-AFSF
Crop: Beans
Variety: Lyamungu85-GP*85

Planting Dates	Dates for initial SMC	SARI otential yiel (Ym)- Kg/ha	AFSF Actual yield (Ya)-Kg/ha	IRSIS Predicted yield-Kg/ha	CRPSMW Predicted yield-Kg/ha	SARI AFSF (Ya/Ym)%	CRPSMW (Ya/Ym)%	IRSIS (Ya/Ym)%
1994								
8-Mar	8-Mar	2 500	1 066	2 500	1 390	43	55	100
11-Mar		"	"	2 500	1 370	"	55	100
14-Mar		"	"	2 500	1 340	"	54	100
1995								
7-Mar	7-Mar	2 500	1 929	2 500	1 250	77	50	100
10-Mar		"	"	2 500	1 220	"	49	100
13-Mar		"	"	2 500	1 190	"	48	100
1996								
7-Apr	7-Apr	2 500	822	1 632	1 000	33	39	65
10-Apr		"	"	1 065	920	"	37	43
13-Apr		"	"	1 042	830	"	33	42

* GP = Growing period.

Table C.7: IRSIS and CRPSMW model simulated grain yields on different planting dates for different years.

Station: SARI-AFSF
Crop: Beans
Variety: Lyamungu90-GP*85

Planting Dates	Dates for initial SMC	SARI otential yiel (Ym)- Kg/ha	AFSF Actual yield (Ya)-Kg/ha	IRSIS Predicted yield-Kg/ha	CRPSMW Predicted yield-Kg/ha	SARI AFSF (Ya/Ym)%	CRPSMW (Ya/Ym)%	IRSIS (Ya/Ym)%
1994								
8-Mar	8-Mar	3 000	2 600	3 000	1 660	87	55	100
11-Mar		"	"	"	1 640	"	55	100
14-Mar		"	"	"	1 610	"	54	100
1995								
24-Mar	24-Mar	3 000	867	3 000	1 300	29	43	100
27-Mar		"	"	"	1 270	"	42	100
30-Mar		"	"	"	1 230	"	41	100
1996								
7-Apr	7-Apr	3 000	1 154	2 061	1 280	39	43	69
10-Apr		"	"	1 311	1 130	"	38	44
13-Apr		"	"	1 356	1 030	"	34	45

* GP = Growing period.

APPENDIX D

SAMPLE OUTPUT FILE FOR IRSIS

(Water balance, root zone depletion, yield response, and application efficiency)

Table D.1: Sample OUTPUT File for IRSIS model

IRSIS Action Member Ilonga/Maize-Kito/87-96

Country : Tanzania
Site : Ilonga

Altitude : 495 m
Latitude : -6.77 ° Longitude : 37.00 °

Project :

Field : Ilonga-Msimba/Soils/1987-96
Crop : Ilonga/Kito/1987-96

Cropping Period From 03/03/1990 To 05/06/1990

----- Evaluating From 03/03/1990 To 05/06/1990

ETo : Moro-Ilonga/ETo-Daily/90-92
Rain : Moro-Ilonga/Rain-Daily/87-96

---- Forecasting From --/--/---- To --/--/----

------- Planning From --/--/---- To --/--/----

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WATER BALANCE (part 1) (Daily)

	ETo (mm)	ETcrop (mm)	kc	ETact (mm)	ETa/ETm	Rainfall (mm)
	427.9	398.7		384.2		506.5
03/03/1990	4.6	5.3	1.16	5.3	1.00	0.0
04/03/1990	2.2	2.7	1.24	2.7	1.00	20.3
05/03/1990	4.0	2.5	0.63	2.5	1.00	0.0
06/03/1990	4.3	2.0	0.46	2.0	1.00	0.0
07/03/1990	5.7	1.4	0.25	1.4	1.00	0.0
08/03/1990	4.6	2.8	0.60	2.8	1.00	1.3
09/03/1990	4.2	5.0	1.17	5.0	1.00	15.8
10/03/1990	5.2	5.9	1.14	5.9	1.00	1.7
11/03/1990	3.8	4.5	1.18	4.5	1.00	9.1
12/03/1990	5.0	5.7	1.15	5.7	1.00	0.3
13/03/1990	5.7	6.4	1.12	6.4	1.00	85.3
14/03/1990	3.9	4.6	1.18	4.6	1.00	6.4
15/03/1990	5.5	3.1	0.57	3.1	1.00	0.0
16/03/1990	5.6	6.3	1.12	6.3	1.00	20.5
17/03/1990	5.6	6.3	1.12	6.3	1.00	2.8
18/03/1990	5.9	4.0	0.67	4.0	1.00	3.7
19/03/1990	5.9	4.0	0.68	4.0	1.00	0.0
20/03/1990	5.1	3.6	0.70	3.6	1.00	2.5
21/03/1990	4.5	5.2	1.16	5.2	1.00	7.5
22/03/1990	5.4	6.1	1.13	6.1	1.00	21.7
23/03/1990	4.7	3.5	0.74	3.5	1.00	0.0
24/03/1990	5.8	4.3	0.75	4.3	1.00	0.0
25/03/1990	5.7	4.3	0.76	4.3	1.00	0.0
26/03/1990	5.1	3.9	0.78	3.9	1.00	0.0
27/03/1990	5.1	5.8	1.14	5.8	1.00	42.0
28/03/1990	4.6	5.3	1.16	5.3	1.00	25.6
29/03/1990	4.9	5.6	1.15	5.6	1.00	22.9
30/03/1990	5.9	6.6	1.11	6.6	1.00	0.4
31/03/1990	4.6	5.4	1.16	5.4	1.00	2.6
01/04/1990	4.6	5.3	1.16	5.3	1.00	2.6
02/04/1990	5.5	6.2	1.13	6.2	1.00	4.1
03/04/1990	4.5	3.9	0.88	3.9	1.00	0.0
04/04/1990	4.9	4.3	0.89	4.3	1.00	2.9
05/04/1990	4.5	5.2	1.16	5.2	1.00	17.7
06/04/1990	4.1	4.8	1.17	4.8	1.00	11.6
07/04/1990	3.3	4.0	1.20	4.0	1.00	28.4
08/04/1990	3.8	4.5	1.18	4.5	1.00	0.2
09/04/1990	4.5	5.3	1.16	5.3	1.00	6.7
10/04/1990	4.6	5.3	1.16	5.3	1.00	22.4
11/04/1990	2.7	3.3	1.22	3.3	1.00	17.3

12/04/1990	4.3	4.3	1.00	4.3	1.00	11.2
13/04/1990	5.4	5.4	1.00	5.4	1.00	2.1
14/04/1990	5.0	5.0	1.00	5.0	1.00	0.0
15/04/1990	5.2	5.2	1.00	5.2	1.00	1.0
16/04/1990	4.5	4.5	1.00	4.5	1.00	0.0
17/04/1990	3.8	3.8	1.00	3.8	1.00	0.0
18/04/1990	3.5	3.5	1.00	3.5	1.00	0.0
19/04/1990	4.7	4.7	1.00	4.7	1.00	0.2
20/04/1990	5.5	5.5	1.00	5.5	1.00	0.0
21/04/1990	5.7	5.7	1.00	5.7	1.00	10.4
22/04/1990	4.7	4.7	1.00	4.7	1.00	0.0
23/04/1990	5.0	5.0	1.00	5.0	1.00	0.0
24/04/1990	4.3	4.3	1.00	4.3	1.00	3.2
25/04/1990	4.0	4.0	1.00	4.0	1.00	14.5
26/04/1990	4.3	4.3	1.00	4.3	1.00	14.9
27/04/1990	5.0	5.0	1.00	5.0	1.00	0.8
28/04/1990	5.0	5.0	1.00	5.0	1.00	0.0
29/04/1990	5.1	5.1	1.00	5.1	1.00	15.9
30/04/1990	5.2	5.2	1.00	5.2	1.00	0.3
01/05/1990	5.4	5.4	1.00	5.4	1.00	0.0
02/05/1990	4.9	4.9	1.00	4.9	1.00	2.1
03/05/1990	5.3	5.3	1.00	5.3	1.00	0.0
04/05/1990	5.1	5.1	1.00	5.1	1.00	0.2
05/05/1990	4.9	4.9	1.00	4.9	1.00	0.0
06/05/1990	2.3	2.3	1.00	2.3	1.00	0.0
07/05/1990	2.5	2.5	1.00	2.5	1.00	11.6
08/05/1990	2.8	2.8	1.00	2.8	1.00	0.6
09/05/1990	3.5	3.5	1.00	3.5	1.00	0.0
10/05/1990	3.7	3.7	1.00	3.7	1.00	1.6
11/05/1990	4.4	4.4	1.00	4.4	1.00	0.0
12/05/1990	4.1	4.1	1.00	4.1	1.00	0.4
13/05/1990	4.6	4.6	1.00	4.6	1.00	2.4
14/05/1990	3.6	3.5	0.98	3.5	1.00	0.0
15/05/1990	4.1	3.9	0.96	3.9	1.00	0.0
16/05/1990	4.9	4.6	0.93	4.6	1.00	0.8
17/05/1990	4.8	4.3	0.91	4.3	1.00	0.0
18/05/1990	4.9	4.3	0.89	4.3	1.00	0.0
19/05/1990	5.1	4.4	0.87	4.4	1.00	0.0
20/05/1990	4.4	3.7	0.85	3.5	0.93	0.0
21/05/1990	4.3	3.6	0.83	2.9	0.82	0.0
22/05/1990	4.6	3.7	0.80	2.7	0.74	0.0
23/05/1990	4.3	3.4	0.78	3.1	0.91	5.4
24/05/1990	4.8	3.7	0.76	3.1	0.84	0.6
25/05/1990	4.2	3.1	0.74	2.4	0.78	0.0
26/05/1990	3.1	2.3	0.72	1.7	0.76	0.0
27/05/1990	3.1	2.1	0.70	1.6	0.76	0.0
28/05/1990	4.2	2.8	0.67	2.0	0.69	0.0
29/05/1990	3.4	2.2	0.65	1.4	0.66	0.0
30/05/1990	4.4	2.8	0.63	1.5	0.55	0.0
31/05/1990	3.7	2.3	0.61	1.1	0.50	0.0
01/06/1990	3.7	2.2	0.59	1.0	0.46	0.0
02/06/1990	3.1	1.8	0.57	0.7	0.42	0.0
03/06/1990	3.9	2.1	0.54	0.8	0.38	0.0
04/06/1990	3.5	1.9	0.52	0.7	0.35	0.0
05/06/1990	3.9	2.0	0.50	0.6	0.32	0.0

WATER BALANCE (part 2) (Daily)

	Runoff (mm)	Ir Depth (mm)	N Ir	Drainage (mm)	Rooting (m)
	69.8	0.0		135.3	
3/03/1990	0.0	0.0	0	0.0	0.20
04/03/1990	0.0	0.0	0	0.0	0.21
05/03/1990	0.0	0.0	0	0.0	0.23
06/03/1990	0.0	0.0	0	0.0	0.24
* Data (07 March - 01 June 1990) omited for brevity in text *					
02/06/1990	0.0	0.0	0	0.0	0.75
03/06/1990	0.0	0.0	0	0.0	0.75
04/06/1990	0.0	0.0	0	0.0	0.75
05/06/1990	0.0	0.0	0	0.0	0.75

WATER BALANCE (part 3) (Daily)

	TAW (mm)	RAW (mm)	p	D begin (mm)	D end (mm)
	88.4	67.0		28.7	31.5
03/03/1990	28.0	18.7	0.67	5.6	10.9
04/03/1990	29.9	22.2	0.74	-6.5	-3.8
05/03/1990	31.8	26.3	0.83	-2.4	0.2
06/03/1990	33.8	30.4	0.90	1.1	3.0
* Data (07 March - 01 June 1990) omited for brevity in text *					
02/06/1990	105.0	94.5	0.90	100.1	100.5
03/06/1990	105.0	94.5	0.90	100.5	100.9
04/06/1990	105.0	94.5	0.90	100.9	101.2
05/06/1990	105.0	94.5	0.90	101.2	101.6

ROOTZONE DEPLETION (Daily)

	Rainfall (mm)	Ir Depth (mm)	TAW (mm)	RAW (mm)	D begin (mm)	D end (mm)
	506.5	0.0	88.4	67.0	28.7	31.5
03/03/1990	0.0	0.0	28.0	18.7	5.6	10.9
04/03/1990	20.3	0.0	29.9	22.2	-6.5	-3.8
05/03/1990	0.0	0.0	31.8	26.3	-2.4	0.2
06/03/1990	0.0	0.0	33.8	30.4	1.1	3.0
* Data (07 March - 01 June 1990) omited for brevity in text *						
02/06/1990	0.0	0.0	105.0	94.5	100.1	100.5
03/06/1990	0.0	0.0	105.0	94.5	100.5	100.9
04/06/1990	0.0	0.0	105.0	94.5	100.9	101.2
05/06/1990	0.0	0.0	105.0	94.5	101.2	101.6

YIELD RESPONSE (Growth Stage)

	ETa/ETm	Rainfall (mm)	Ir Depth (mm)	N Ir	ky	Ya/Ym (%)
		506.5	0.0			
03/03/1990	1.00	163.5	0.0	0	0.20	100.0
18/03/1990	1.00	242.8	0.0	0	0.20	100.0
12/04/1990	1.00	91.0	0.0	0	0.55	100.0
13/05/1990	0.75	9.2	0.0	0	0.44	91.8

APPLICATION EFFICIENCY (Event)

	Rainfall (mm)	Ir Depth (mm)	Rain Eff (%)	Ir Eff (%)
	506.5	0.0		
04/03/1990	20.3		100.0	
08/03/1990	1.3		100.0	
09/03/1990	15.8		100.0	
10/03/1990	1.7		100.0	
11/03/1990	9.1		100.0	
12/03/1990	0.3		100.0	
13/03/1990	85.3		26.9	
14/03/1990	6.4		48.5	
16/03/1990	20.5		21.7	
17/03/1990	2.8		100.0	
18/03/1990	3.7		100.0	
20/03/1990	2.5		100.0	
21/03/1990	7.5		100.0	
22/03/1990	21.7		72.5	
27/03/1990	42.0		75.9	
28/03/1990	25.6		2.1	
29/03/1990	22.9		1.7	
30/03/1990	0.4		94.9	
31/03/1990	2.6		100.0	
01/04/1990	2.6		100.0	
02/04/1990	4.1		100.0	
04/04/1990	2.9		100.0	
05/04/1990	17.7		100.0	
06/04/1990	11.6		98.1	
07/04/1990	28.4		45.3	
08/04/1990	0.2		0.0	
09/04/1990	6.7		48.0	
10/04/1990	22.4		57.3	
11/04/1990	17.3		0.0	
12/04/1990	11.2		0.0	
13/04/1990	2.1		0.0	
15/04/1990	1.0		100.0	
19/04/1990	0.2		100.0	
21/04/1990	10.4		100.0	
24/04/1990	3.2		100.0	
25/04/1990	14.5		100.0	
26/04/1990	14.9		99.8	
27/04/1990	0.8		100.0	
29/04/1990	15.9		100.0	
30/04/1990	0.3		100.0	
02/05/1990	2.1		100.0	
04/05/1990	0.2		100.0	
07/05/1990	11.6		100.0	
08/05/1990	0.6		100.0	
10/05/1990	1.6		100.0	
12/05/1990	0.4		100.0	
13/05/1990	2.4		100.0	
16/05/1990	0.8		100.0	
23/05/1990	5.4		100.0	
24/05/1990	0.6		100.0	

Table D.2: Sample OUTPUT File for IRSIS model

IRSIS Action Member SARI/Crops-Yields/1987-96

Country : Tanzania
Site : SARI-AFSF

Altitude : 1390 m
Latitude : -3.37 ° Longitude : 36.63 °

Field : SARI-AFSF/Soil/1990
Crop : SARI/Wheat-Mbayuwayu/GP-130

Cropping Period From 03/04/1990 To 10/08/1990

----- Evaluating From 03/04/1990 To 10/08/1990

ETo : Arusha/TPRI/ETo/90-92
Rain : Arusha/TPRI/Daily-Rain/87-96

---- Forecasting From --/--/---- To --/--/----

------- Planning From --/--/---- To --/--/----

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WATER BALANCE (part 1) (Daily)

	ETo (mm)	ETcrop (mm)	kc	ETact (mm)	ETa/ETm	Rainfall (mm)
	262.4	250.3		239.1		205.8
03/04/1990	2.1	2.7	1.24	2.7	1.00	19.4
04/04/1990	3.2	3.8	1.20	3.8	1.00	9.5
05/04/1990	2.5	3.0	1.23	3.0	1.00	1.3
06/04/1990	1.8	2.3	1.25	2.3	1.00	24.7
07/04/1990	2.4	2.9	1.23	2.9	1.00	1.8
08/04/1990	1.8	2.2	1.25	2.2	1.00	10.0
09/04/1990	2.1	2.7	1.24	2.7	1.00	0.2
10/04/1990	2.2	2.7	1.24	2.7	1.00	10.5
11/04/1990	1.7	2.1	1.25	2.1	1.00	2.0
12/04/1990	2.7	3.3	1.22	3.3	1.00	1.2
13/04/1990	2.8	2.0	0.72	2.0	1.00	0.0
14/04/1990	2.3	2.9	1.23	2.9	1.00	2.6
15/04/1990	2.8	2.0	0.72	2.0	1.00	0.0
16/04/1990	2.9	3.5	1.21	3.5	1.00	5.4
17/04/1990	2.3	1.7	0.74	1.7	1.00	0.5
18/04/1990	1.5	1.2	0.78	1.2	1.00	0.6
19/04/1990	1.6	2.1	1.25	2.1	1.00	17.4
20/04/1990	2.8	3.4	1.22	3.4	1.00	3.3
21/04/1990	3.2	2.4	0.73	2.4	1.00	0.0
22/04/1990	2.7	3.2	1.22	3.2	1.00	1.1
23/04/1990	2.8	3.4	1.22	3.4	1.00	13.3
24/04/1990	2.8	3.4	1.22	3.4	1.00	13.4
25/04/1990	2.9	3.5	1.21	3.5	1.00	24.9
26/04/1990	1.3	1.6	1.27	1.6	1.00	7.3
27/04/1990	1.6	2.1	1.25	2.1	1.00	6.0
28/04/1990	2.5	2.0	0.83	2.0	1.00	0.0
29/04/1990	2.8	2.4	0.84	2.4	1.00	0.0
30/04/1990	2.9	2.5	0.85	2.5	1.00	0.0
01/05/1990	2.3	2.0	0.87	2.0	1.00	0.0
02/05/1990	2.0	1.8	0.88	1.8	1.00	1.2
03/05/1990	2.2	2.0	0.90	2.0	1.00	0.0
04/05/1990	2.8	3.4	1.22	3.4	1.00	7.7
05/05/1990	2.6	3.2	1.22	3.2	1.00	2.5
06/05/1990	1.7	1.6	0.94	1.6	1.00	0.0
07/05/1990	1.6	2.0	1.26	2.0	1.00	3.1
08/05/1990	1.7	2.1	1.25	2.1	1.00	4.7
09/05/1990	1.8	2.2	1.25	2.2	1.00	3.1
10/05/1990	1.7	1.7	0.99	1.7	1.00	0.0
11/05/1990	2.5	2.6	1.01	2.6	1.00	0.0
12/05/1990	2.6	2.7	1.02	2.7	1.00	0.0
13/05/1990	2.4	2.5	1.04	2.5	1.00	0.0
14/05/1990	1.4	1.4	1.05	1.4	1.00	0.0
15/05/1990	2.2	2.3	1.05	2.3	1.00	2.2

16/05/1990	1.5	1.5	1.05	1.5	1.00	0.0
17/05/1990	2.4	2.5	1.05	2.5	1.00	0.0
18/05/1990	2.1	2.2	1.05	2.2	1.00	0.7
19/05/1990	2.0	2.1	1.05	2.1	1.00	0.0
20/05/1990	1.9	2.0	1.05	2.0	1.00	0.0
21/05/1990	2.0	2.1	1.05	2.1	1.00	0.0
22/05/1990	2.0	2.1	1.05	2.1	1.00	0.0
23/05/1990	1.7	1.8	1.05	1.8	1.00	0.0
24/05/1990	2.4	2.5	1.05	2.5	1.00	0.0
25/05/1990	1.5	1.6	1.05	1.6	1.00	0.0
26/05/1990	1.4	1.4	1.05	1.4	1.00	0.0
27/05/1990	1.4	1.5	1.05	1.5	1.00	0.0
28/05/1990	1.4	1.5	1.05	1.5	1.00	0.0
29/05/1990	1.3	1.4	1.05	1.4	1.00	0.0
30/05/1990	1.3	1.4	1.05	1.4	1.00	0.0
31/05/1990	2.0	2.1	1.05	2.1	1.00	0.0
01/06/1990	1.9	2.0	1.05	2.0	1.00	0.0
02/06/1990	1.6	1.7	1.05	1.7	1.00	0.0
03/06/1990	1.9	2.0	1.05	2.0	1.00	0.0
04/06/1990	2.3	2.4	1.05	2.4	1.00	0.0
05/06/1990	2.1	2.2	1.05	2.2	1.00	0.0
06/06/1990	2.1	2.2	1.05	2.2	1.00	0.0
07/06/1990	2.6	2.7	1.05	2.7	1.00	0.0
08/06/1990	1.4	1.4	1.05	1.4	1.00	0.0
09/06/1990	1.2	1.3	1.05	1.3	1.00	0.0
10/06/1990	2.1	2.2	1.05	2.2	1.00	2.1
11/06/1990	1.5	1.6	1.05	1.6	1.00	0.0
12/06/1990	1.6	1.7	1.05	1.7	1.00	0.6
13/06/1990	2.3	2.4	1.05	2.4	1.00	0.0
14/06/1990	1.7	1.8	1.05	1.8	1.00	0.0
15/06/1990	1.9	2.0	1.05	2.0	1.00	0.0
16/06/1990	1.9	1.9	1.05	1.9	1.00	0.0
17/06/1990	2.2	2.3	1.05	2.3	1.00	0.0
18/06/1990	2.0	2.1	1.05	2.1	1.00	0.0
19/06/1990	1.8	1.9	1.05	1.9	1.00	0.0
20/06/1990	2.2	2.3	1.05	2.3	1.00	0.0
21/06/1990	1.4	1.4	1.05	1.4	1.00	0.0
22/06/1990	1.2	1.3	1.05	1.3	1.00	0.0
23/06/1990	1.1	1.2	1.05	1.2	1.00	0.0
24/06/1990	1.0	1.0	1.05	1.0	1.00	0.0
25/06/1990	2.5	2.6	1.05	2.6	1.00	0.0
26/06/1990	2.3	2.4	1.05	2.4	1.00	0.0
27/06/1990	2.1	2.2	1.05	2.2	1.00	0.0
28/06/1990	1.4	1.4	1.05	1.4	1.00	0.0
29/06/1990	1.3	1.4	1.05	1.4	1.00	0.0
30/06/1990	1.5	1.6	1.05	1.6	1.00	0.0
01/07/1990	1.4	1.5	1.05	1.5	1.00	0.0
02/07/1990	2.7	2.8	1.05	2.8	1.00	0.0
03/07/1990	1.3	1.3	1.05	1.3	1.00	0.0
04/07/1990	2.0	2.0	1.05	2.0	1.00	0.0
05/07/1990	1.7	1.8	1.05	1.8	1.00	0.0
06/07/1990	1.2	1.2	1.05	1.2	1.00	0.0
07/07/1990	1.3	1.4	1.05	1.4	1.00	0.0
08/07/1990	1.9	2.0	1.05	2.0	1.00	0.0
09/07/1990	2.2	2.3	1.05	2.3	1.00	0.0
10/07/1990	2.1	2.1	1.02	2.1	1.00	0.0
11/07/1990	2.4	2.4	1.00	2.4	1.00	0.0
12/07/1990	1.5	1.5	0.97	1.5	1.00	0.0
13/07/1990	1.2	1.2	0.95	1.2	1.00	0.0
14/07/1990	1.2	1.1	0.93	1.1	1.00	0.0
15/07/1990	2.2	2.0	0.90	2.0	1.00	0.0
16/07/1990	2.1	1.8	0.87	1.8	1.00	0.0
17/07/1990	2.4	2.0	0.85	2.0	1.00	0.0
18/07/1990	2.3	1.9	0.82	1.9	1.00	0.0
19/07/1990	2.2	1.8	0.80	1.8	1.00	0.0
20/07/1990	2.1	1.6	0.78	1.5	0.92	0.0
21/07/1990	1.6	1.2	0.75	1.0	0.84	0.0
22/07/1990	2.2	1.6	0.73	1.2	0.76	0.0
23/07/1990	2.3	1.6	0.70	1.1	0.68	0.0
24/07/1990	1.0	0.7	0.68	0.4	0.63	0.0
25/07/1990	1.9	1.2	0.65	0.7	0.59	0.0
26/07/1990	2.7	1.7	0.63	0.9	0.56	0.4
27/07/1990	1.9	1.1	0.60	0.6	0.51	0.0
28/07/1990	1.9	1.1	0.58	0.5	0.47	0.0
29/07/1990	2.4	1.3	0.55	0.6	0.43	0.0
30/07/1990	2.0	1.0	0.53	0.4	0.40	0.0
31/07/1990	2.1	1.0	0.50	0.4	0.37	0.0
01/08/1990	1.4	0.7	0.48	0.3	0.40	0.7
02/08/1990	2.5	1.1	0.45	0.5	0.40	0.4
03/08/1990	1.9	0.8	0.43	0.3	0.37	0.0

04/08/1990	2.1	0.8	0.40	0.3	0.35	0.0
05/08/1990	2.1	0.8	0.38	0.3	0.33	0.0
06/08/1990	2.5	0.9	0.35	0.3	0.31	0.0
07/08/1990	2.6	0.9	0.33	0.3	0.29	0.0
08/08/1990	2.8	0.9	0.30	0.2	0.28	0.0
09/08/1990	1.3	0.4	0.28	0.1	0.27	0.0
10/08/1990	2.6	0.6	0.25	0.2	0.26	0.0

WATER BALANCE (part 2) (Daily)

	Runoff (mm)	Ir Depth (mm)	N Ir	Drainage (mm)	Rooting (m)
	32.2	0.0		46.0	
03/04/1990	4.4	0.0	0	0.0	0.20
04/04/1990	0.7	0.0	0	0.0	0.22
05/04/1990	0.0	0.0	0	0.0	0.23
06/04/1990	9.7	0.0	0	0.0	0.25
* Data (07 April - 06 June 1990) omited for brevity in text *					
07/08/1990	0.0	0.0	0	0.0	0.90
08/08/1990	0.0	0.0	0	0.0	0.90
09/08/1990	0.0	0.0	0	0.0	0.90
10/08/1990	0.0	0.0	0	0.0	0.90

WATER BALANCE (part 3) (Daily)

	TAW (mm)	RAW (mm)	p	D begin (mm)	D end (mm)
	125.9	111.3		56.8	58.3
03/04/1990	32.0	26.7	0.83	-8.6	-5.9
04/04/1990	34.7	27.8	0.80	-10.1	-6.2
05/04/1990	37.5	30.0	0.80	-6.0	-3.0
06/04/1990	40.2	32.5	0.81	-12.2	-9.9
* Data (07 April - 08June 1990) omited for brevity in text *					
09/08/1990	144.0	129.6	0.90	140.1	140.2
10/08/1990	144.0	129.6	0.90	140.2	140.4

ROOTZONE DEPLETION (Daily)

	Rainfall (mm)	Ir Depth (mm)	TAW (mm)	RAW (mm)	D begin (mm)	D end (mm)
	205.8	0.0	125.9	111.3	56.8	58.3
03/04/1990	19.4	0.0	32.0	26.7	-8.6	-5.9
04/04/1990	9.5	0.0	34.7	27.8	-10.1	-6.2
05/04/1990	1.3	0.0	37.5	30.0	-6.0	-3.0
06/04/1990	24.7	0.0	40.2	32.5	-12.2	-9.9
* Data (07 April - 06 June 1990) omited for brevity in text *						
07/08/1990	0.0	0.0	144.0	129.6	139.6	139.9
08/08/1990	0.0	0.0	144.0	129.6	139.9	140.1
09/08/1990	0.0	0.0	144.0	129.6	140.1	140.2
10/08/1990	0.0	0.0	144.0	129.6	140.2	140.4

YIELD RESPONSE (Growth Stage)

	ETa/ETm	Rainfall (mm)	Ir Depth (mm)	N Ir	ky	Ya/Ym (%)
		205.8	0.0			
03/04/1990	1.00	89.7	0.0	0	0.20	100.0
19/04/1990	1.00	109.0	0.0	0	0.20	100.0
14/05/1990	1.00	5.6	0.0	0	0.60	100.0
09/07/1990	0.65	1.5	0.0	0	0.49	87.4

APPLICATION EFFICIENCY (Event)

	Rainfall (mm)	Ir Depth (mm)	Rain Eff (%)	Ir Eff (%)
	205.8	0.0		
03/04/1990	19.4		77.3	
04/04/1990	9.5		92.9	
05/04/1990	1.3		100.0	
06/04/1990	24.7		60.7	
07/04/1990	1.8		100.0	
08/04/1990	10.0		91.8	
09/04/1990	0.2		100.0	
10/04/1990	10.5		90.7	
11/04/1990	2.0		100.0	
12/04/1990	1.2		100.0	
13/04/1990	1.7		100.0	
14/04/1990	2.6		100.0	
16/04/1990	5.4		100.0	
17/04/1990	0.5		100.0	
18/04/1990	0.6		100.0	
19/04/1990	17.4		79.3	
20/04/1990	3.3		72.4	
22/04/1990	1.1		100.0	
23/04/1990	13.3		91.8	
24/04/1990	13.4		7.3	
25/04/1990	24.9		0.0	
26/04/1990	7.3		0.0	
27/04/1990	6.0		0.0	
02/05/1990	1.2		100.0	
04/05/1990	7.7		100.0	
05/05/1990	2.5		100.0	
07/05/1990	3.1		100.0	
08/05/1990	4.7		100.0	
09/05/1990	3.1		78.3	
15/05/1990	2.2		100.0	
18/05/1990	0.7		100.0	
10/06/1990	2.1		100.0	
12/06/1990	0.6		100.0	
26/07/1990	0.4		100.0	
01/08/1990	0.7		100.0	
02/08/1990	0.4		100.0	

APENDIX E

CRPSMW CROP DATA File list and Sample OUTPUT FILE

Table E.1

CROP.DAT File List for Ilonga and Msimba stations (Morogoro) and Selian Agricultural Research Institute (SARI) and Arusha Foundation Seed Farm stations (AFSF) (Arusha).

Definition of variables and their corresponding parameters.
Data in CROP.DAT File is read as follows:

Record 1 : NCRP, NSTS, ITYPE, IPHN, IKCT
Record 2 : AVR, BGRZ, RTMX, CKX, FAW, COLD, YLDMX, YUNIT
Record 3 : IEFC, NEFDY, IMRD, NMRDY, ISLF, ISL1, ISL2, ALPH, TPTH,FD
Record 4 Through (NSTC + 3) : ISTT, STGNM, CLOCK, YL, CKT

The following two records are required only when IKCT = 2
record (NSTS + 4) : A_0, A_1, A_2, A_3 (INPUT AS CKO (L))
record (NSTS + 5) : B_0, B_1, B_2, B_3 (INPUT AS CKO (L))

Where:

NCRP = sequential crop identification number. (to match ICRP-crop index number).
NSTS = number of growth states (<=10) starting with planting date or beginning growth.
ITYPE = crop type, i.e:

1 seasonal crops such as maize, wheat, and potatoes.
2 for annual crops, and
3 for perennial crops such as forage crops.

IPHN = phenology clock type:
1 for days
2 for 50-86 growing degree days
3 for 40-77 growing degree days

IKCT = mode of crop coefficient input :
1 for use of tabular k_{ct} values input for each growth state with linear interpolation between.
2 for use of third order polynomial equations with input A_0, ..A_3 and B_0,..B_3 on last two records for each crop.

AVR = alphanumeric name of crop/variety.

BGRZ = root zone depth (ft)
CKX = maximum crop coefficient value
FAW = available soil water fraction at start of stress
COLD = temperature (^{0}F)below which transpiration is reduced to due to cold effect
YLDMX = maximum yield potential
YUNIT = yield units

IEFC	= index of growth closest to effective cover
NEFDY	= number of days effective cover differs from occurrence of state (IEFC). (+ if after, - if prior)
IMRD	= index of growth state closest to maximum root growth
NMRDY	= number of days maximum root attainment differs from occurrence of state (IMRD). (+ if after, - if prior)
ISLF	= index for use of season yield factor (0 use. >0 do not use)
ISL1	= index of first growth state to use in sum of potential transpiration between growth states (TPSM) for SLF calculation
ISL2	= index of second growth state to use in sum of potential transpiration between growth states (TPSM) for SLF calculation
ALPH	= exponent in SLF equation
TPTH	= threshold transpiration total inn SLF equation
FD	= multiplier on potential transpiration sum in deep percolation factor (DPF)
ISTT	= index of growth state for this record must be in sequence (equivalent to k, below)
STGNM (k)	= alphanumeric description of growth state k (<= 20 characters)
CLOCK (k)	= phenology clock value at attainment of growth state k
CKT (k)	= estimated transpiration crop coefficient (k_{ct}) value at attainment of growth state k, ignored if ICK = 2
YLAM (k)	= lambda for yield calculation for the growth stage period.
A_0,..A_3	= coefficients for k_{ct} equation before effective cover
B_0,..B_3	= coefficients for k_{ct} equation after effective cover

NOTE: kct equation of form:

(Before cover) Kct $= A_0 + A_1 \times R + A_2 \times R^2 + A_3 \times R^3$

(R is proportion (%/100) time between planting and effective cover)

(After cover) Kct $= B_0 + B_1 \times D + B_2 \times D^2 \times B_3 \times D^3$

(D is days after effective cover)

A_0,...A_3 and B_0,...B_3 are determined from regression analysis of empirical ET crop coefficient data.

Table E.2: CROP.DAT file List For Ilonga and Msimba (Morogoro) crops used in CRPSMW model.

```
NCRP      1    6    1    1    2
CROP CORN (MAIZE) STAHA  .3334     4 1.05 0.65 36.0  2.4  TON/HA
IEFC           4  -18    5    0    1    3    4 0.92 11.6
GROWTH STATE      1  PLANTING                     0       0.00       0.00
GROWTH STATE      2  EMERGENCE                    7       0.00       0.00
GROWTH STATE      3  FOUR LEAF                   22       0.00       0.17
GROWTH STATE      4  SILK EMERGENCE              70       0.00       0.10
GROWTH STATE      5  DOUGH                       93       0.00       0.35
GROWTH STATE      6  PHYSIOLOGIC MATURITY       120       0.00       0.50
A0,...,A3  -.0263044    .349338  -1.19873   1.80757
B0,...,B3     .910848-.65123E-3-.24960E-4-.31643E-6

NCRP      2    6    1    1    2
CROP CORN (MAIZE) KITO   .3334     4 1.05 0.65 36.0 1.50  TON/HA
IEFC           4  -10    5    0    1    3    4 0.92 11.6
GROWTH STATE      1  PLANTING                     0       0.00       0.00
GROWTH STATE      2  EMERGENCE                    4       0.00       0.00
GROWTH STATE      3  FOUR LEAF                   10       0.00       0.17
GROWTH STATE      4  SILK EMERGENCE              20       0.00       0.10
GROWTH STATE      5  DOUGH                       46       0.00       0.35
GROWTH STATE      6  PHYSIOLOGIC MATURITY        60       0.00       0.50
A0,...,A3  -.0263044    .349338  -1.19873   1.80757
B0,...,B3     .910848-.65123E-3-.24960E-4-.31643E-6

NCRP      3    6    1    1    2
CROP CORN (MAIZE) TMV-1  .3334     4 1.05 0.65 36.0 2.40  TON/HA
IEFC           4  -16    5    0    1    3    4 0.92 11.6
GROWTH STATE      1  PLANTING                     0       0.00       0.00
GROWTH STATE      2  EMERGENCE                    7       0.00       0.00
GROWTH STATE      3  FOUR LEAF                   12       0.00       0.17
GROWTH STATE      4  SILK EMERGENCE              60       0.00       0.10
GROWTH STATE      5  DOUGH                       85       0.00       0.35
GROWTH STATE      6  PHYSIOLOGIC MATURITY       110       0.00       0.50
A0,...,A3  -.0263044    .349338  -1.19873   1.80757
B0,...,B3     .910848-.65123E-3-.24960E-4-.31643E-6

NCRP      4    6    1    1    2
CROP SORGHUM (TEGEMEO)   .3334     3  1.0 0.65 36.0 1.50  TON/HA
IEFC           4  -15    5    0    1    3    4 0.92 11.6
GROWTH STATE      1  PLANTING                     0       0.00       0.00
GROWTH STATE      2  EMERGENCE                    4       0.00       0.00
GROWTH STATE      3  SEEDLING DEVELOPMENT        15       0.00       0.17
GROWTH STATE      4  FLOWERING                   40       0.00       0.10
GROWTH STATE      5  SEED DEVELOPMENT            71       0.00       0.35
GROWTH STATE      6  PHYSIOLOGIC MATURITY        95       0.00       0.50
A0,...,A3  -.0263044    .349338  -1.19873   1.80757
B0,...,B3     .910848-.65123E-3-.24960E-4-.31643E-6
```

Table E.3: CROP.DAT File List for SARI and AFSF (Arusha) crops used in CRPSMW model.

```
NCRP      3    7    1    1    2
CROP WHEAT  MBAYUWAYU     .3334   3.0 1.05 0.65 36.0   3.0 TON/HA
IEFC             5    5    5    0    1    4    5  2.0   3.5
GROWTH STATE      1  PLANTING                      0        0.00        0.00
GROWTH STATE      2  EMERGENCE                     7        0.00        0.40
GROWTH STATE      3  BEGIN TILLERING              23        0.00        0.80
GROWTH STATE      4  BEGIN STEM EXTENSION         40        0.00        0.80
GROWTH STATE      5  HEADING                      62        0.00        2.00
GROWTH STATE      6  BEGIN RIPENING               85        0.00        0.50
GROWTH STATE      7  PHYSIOLOGIC MATURITY        131        0.00        0.00
A0,...,A3  -.0479204    .214183    .754455    .542178
B0,...,B3     2.12338 -.0737685.864345E-3-.35357E-5

NCRP      4    6    1    2    2
CROP BEAN LYAMUNGU-85     .3334   3.0 1.05 0.50 36.0   2.5 TON/HA
IEFC             4   10    5    0    1    2    5  2.2  11.8
GROWTH STATE      1  PLANTING                    0.0        0.00        0.00
GROWTH STATE      2  EMERGENCE                 100.0        0.00        0.00
GROWTH STATE      3  BEGIN RAPID GROWTH        314.0        0.00        1.40
GROWTH STATE      4  FIRST BLOOM               690.0        0.00        0.80
GROWTH STATE      5  BEGINNING MATURITY       1261.0        0.00        1.20
GROWTH STATE      6  PHYSIOLOGIC MATURITY     1414.0        0.00        0.60
A0,...,A3 -.25724E-1-.65528E-1   1.25939   -.184819
B0,...,B3    .9734551.491553E-2-.92464E-3.772695E-5

NCRP      5    6    1    1    2
CROP BEAN LYAMUNGU-90     .3334   3.0 1.05 0.50 36.0   3.0 TON/HA
IEFC             4   10    5    0    1    2    5  1.9  12.4
GROWTH STATE      1  PLANTING                      0        0.00        0.00
GROWTH STATE      2  EMERGENCE                     7        0.00        0.00
GROWTH STATE      3  BEGIN RAPID GROWTH           12        0.00        1.90
GROWTH STATE      4  FIRST BLOOM                  33        0.00        2.30
GROWTH STATE      5  BEGINNING MATURITY           66        0.00        1.30
GROWTH STATE      6  PHYSIOLOGIC MATURITY         85        0.00        0.40
A0,...,A3 -.25724E-1-.65528E-1   1.25939   -.184819
B0,...,B3    .9734551.491553E-2-.92464E-3.772695E-5
```

Table E.4: Sample OUTPUT File for CCCRPSMW model.

```
** Main **  Input File> climat90.dat  Output File> climat90.stt  Crpsm-wat version 04.97 time is 11:51:58 on 29 SEP 1997

    THE SITE IS ILONGA MSIMBA KILOSA 1990      1990 (JAN 1 is first day of year)
     AT AN ELEVATION OF 1650. FT . LATITUDE     6.77 DEGREES . LONGITUDE     37.00 DEGREES
     NLAY=  3. RTX= 6.6 FT.  INITIAL SOIL WATER ON FEB  5
      FRACTION WETTED SOIL=   1.00   WET SOIL DECAY=   1.688

                              SOILS DATA
LAYER NUMBER                   1    2    3
INITIAL SOIL MOISTURE (%)     80.0 80.0 80.0
THICKNESS OF SECTION (FEET)    .33 2.30 3.97
FIELD CAPACITY (INCHES/FOOT)   4.1  4.1  4.1
WILTING POINT (INCHES/FOOT)    2.2  2.2  2.2
AVAILABLE WATER (INCHES)        .6  4.4  7.5

** ENVRDT **
     HARGREAVES EQUATION   CNV =   .808E-04 DELTA TEMP COEF IS  .127
     THE AVERAGE MAXIMUM AND MINIMUM MONTHLY TEMPERATURES FOR THE WARMEST MONTH ARE  94 300 AND 68.200 DEG F
     JENSEN HAISE EQUATION   CONV =   .673E-03   C1 = 62.1   CH =  1 6   CT =.0121   TX =17.86   E2 = 55.5   E1 = 23.5
     PENMAN COMBINATION EQUATION   A = 1.220   B =  -.180   A1 =  .325   B1 =  -.044
         W1 =  .750   W2 =  .019   WHT = 2.000   WL1= 1.00  WL2=  .01
         A Maximum wind run limit of 100.0 mi/day at 2 meter height has been set

         REGRESSION COEFFICIENTS FOR RSO CURVE
         NRSD = 1   CRSO(1) =   .850E+00   CRSO(2) =
     FAO BL-CR EQUATION  CFEL= 1.050  (Eto is assumed to be Grass Reference ) .  FAOM= 1.000
        UDAY/UNIGHT = (default is 2.0)  2.00 2.00 2.00 2.00 2.00 2.00 2.00 2.00 2.00 2.00 2.00 2.00

     THE DATA BEGINS AT MONTH  1  DAY  1  AND ENDS AT MONTH  8  DAY 31

     TO CONVERT    MULTIPLY BY    TO OBTAIN

     SOLAR RAD       23.8800       LANGLYS/DAY (if < 0 %SS input)
          WIND         .6214       Miles/day at WHT=  2.00 meters. Mult by   1.00 to adjust to 2 m
        PRECIP         .0394       INCHES
      EVAP PAN        1.0000       INCHES/DAY
   TEMPERATURE         .0000       Temp difference (   .0 added to Tx and   .0 to Tn)
                      1.0000       DEGREES F (IF .GT. 0. CONVERT C TO F)
     DEWPOINT          .0000      Max difference between Tmin and Tdew  (Used only if non zero)
     THE FIRST AND LAST JULIAN DAYS OF DATA ARE   1 AND 243
     PNCMB ET DATA IS PUT IN COMMON.  The wind data output is not adjusted to 2 meters.
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ILONGA MSIMBA KILOSA 1990

JULIAN MONTH DAY DAY	DAILY TEMPERATURE MAX	MIN (DEGREES FAHRENHEIT)	AVG	WB	DB	DAILY RAINFALL (INCHES)	WIND (MILES/ DAY)	SOLAR RADIATION (LANGLEYS)	DAYLENTH (HOURS)	DEWPOINT (DEG F)	EVAPOTRANSPIRATION HRGDT	CALJH	PNCMB	EPAN	FAOBC
JAN AVERAGES	88.5	70.1	79.3				22.5	419.2		32.0					
OR TOTALS						2.72					6.48	6.57	5.98	.00	6.21
FEB AVERAGES	88.2	71.9	80.1				18.3	431.8		32.0					
OR TOTALS						6.13					5.89	6.15	5.46	.00	5.57
MAR AVERAGES	86.9	70.4	78.6				8.3	391.3		32.0					
OR TOTALS						10.90					6.77	6.07	5.39	.00	5.36
APR AVERAGES	86.8	75.5	81.1				12.1	396.6		32.0					
OR TOTALS						7.42					5.61	6.16	5.48	.00	5.43
MAY AVERAGES	84.6	67.7	76.1				14.9	317.9		32.0					
OR TOTALS						1.01					6.54	4.71	4.99	.00	4.57
JUN AVERAGES	83.9	62.8	73.3				13.2	353.2		32.0					
OR TOTALS						.00					6.68	4.80	4.83	.00	4.52
JUL AVERAGES	82.9	62.7	72.8				32.9	343.3		32.0					
OR TOTALS						.07					6.74	4.78	5.62	.00	4 66
AUG AVERAGES	85.0	64.6	74.8				40.6	356.4		32.0					
OR TOTALS						.53					7.11	5.15	6.21	.00	4.95

THE SEASONAL EVAPOTRANSPIRATION (KC=1.0) IS: 51.83 INCHES FOR THE HARGREAVES DELTA TEMP EQUATION
44.38 INCHES FOR A CALIBRATED JENSEN-HAISE EQUATION
43.96 INCHES FOR THE PENMAN COMBINATION EQUATION (PNCMB)
.00 INCHES FOR AN EVAPORATION PAN
41.26 INCHES FOR THE FAO BLANEY-CRIDDLE EQ.
(Eto. includes CFEL times 1.000)

CORN (MAIZE) STAHA ILONGA MSIMBA KILOSA 1990

STAGE	MONTH	DAY	JULIAN DAY	DAYS AFTER PLANTING	CLOCK
PLANTING	FEB	5	36	0	
EMERGENCE	FEB	12	43	7	7.00
FOUR LEAF	FEB	27	58	22	22.00
SILK EMERGENCE	APR	16	106	70	70.00
DOUGH	MAY	9	129	93	93.00
PHYSIOLOGIC MATURITY	JUN	5	156	120	120.00

ILONGA MSIMBA KILOSA 1990 1990 CORN (MAIZE) STAHA 1 S U M M A R Y I N F O R M A T I O N

JULIAN	DATE		C O N S U M P T I V E			U S E		PPT	WIRR	DEEP	TOTAL	NEUTRON
DAY	MONTH	DAY	ETP	TP	T	EP	E			PERC	SW	PROBE
36	FEB	5	.22	.00	.00	.22	.08	.00	.00	.00	24.47	.00
43	FEB	12	.20	.00	.00	.20	.02	.00	.00	.00	24.13	.00
58	FEB	27	.18	.01	.01	.17	.17	1.10	.00	.76	26.88	.00
106	APR	16	.18	.16	.16	.02	.00	.00	.00	.00	26.33	.00
129	MAY	9	.13	.11	.11	.02	.01	.00	.00	.00	25.56	.00
156	JUN	5	.17	.11	.08	.06	.00	.00	.00	.00	23.07	.00

ILONGA MSIMBA KILOSA 1990 1990 S E A S O N S U M M A R Y (all values in inches)
REFERENCE CROP EVAPOTRANSPIRATION = 21.31 TRANSPIRATION: POTENTIAL = 11.71 , ACTUAL = 11.31
IRRIGATION = .00 PRECIPITATION = 25.27 EVAPORATION: POTENTIAL = 9.60 , ACTUAL = 5.18

SEASONAL SOIL WATER BUDGET :
AVAILABLE SOIL MOISTURE: BEGINNING =10.03 ENDING = 8 55
EVAPOTRANSPIRATION = 16.49 ADDED WATER (PPT+IRR) = 25.27 DEEP PERCOLATON =10.26

CORN (MAIZE) STAHA 1 GROWTH STAGE SUMMARY

STAGE	JULIAN DAY	DATE MONTH	DATE DAY	C O N S U M P T I V E U S E ETP	TP	T	EP	E	PPT	WIRR	DEEP PERC	TOTAL SW
BEGIN SEASON	36	FEB	5									24.55
				.22	.00	.00	.22	.08	.00	.00	.00	
PLANTING	36	FEB	5									24.47
				1.57	.00	.00	1.57	.61	.26	.00	.00	
EMERGENCE	43	FEB	12									24.13
				2.63	.06	.06	2 57	1.58	5.65	.00	1.26	
FOUR LEAF	58	FEB	27									26.88
				8.50	5.00	5.00	3.51	2.53	15.98	.00	9.00	
SILK EMERGENCE	106	APR	16									26.33
				4.02	3.45	3.45	.58	.26	2.94	.00	.00	
DOUGH	129	MAY	9									25.56
				4.36	3.21	2.81	1.16	.12	.44	.00	.00	
PHYSIOLOGIC MATURITY	156	JUN	5									23.07

THE PREDICTED YIELD = 1.67 TON/HA OR 69.5 PERCENT OF 2.40 TON/HA POTENTIAL (without DPF included)
This yield includes the effect of an SLF of .746

CORN (MAIZE) STAHA ILONGA MSIMBA KILOSA 1990

STAGE	MONTH	DAY	JULIAN DAY	DAYS AFTER PLANTING	CLOCK
PLANTING	FEB	8	39	0	
EMERGENCE	FEB	15	46	7	7.00
FOUR LEAF	MAR	2	61	22	22.00
SILK EMERGENCE	APR	19	109	70	70.00
DOUGH	MAY	12	132	93	93.00
PHYSIOLOGIC MATURITY	JUN	8	159	120	120.00

ILONGA MSIMBA KILOSA 1990 1990 CORN (MAIZE) STAHA 1 S U M M A R Y I N F O R M A T I O N

JULIAN DAY	DATE MONTH	DAY	C O N S U M P T I V E ETP	TP	T	U S E EP	E	PPT	WIRR	DEEP PERC	TOTAL SW	NEUTRON PROBE
39	FEB	8	.25	.00	.00	.25	.25	.23	.00	.00	24.38	.00
46	FEB	15	.17	.00	.00	.17	.00	.00	.00	.00	24.10	.00
61	MAR	2	.12	.01	.01	.11	.11	.15	.00	.04	26.94	.00
109	APR	19	.17	.15	.15	.02	.00	.01	.00	.00	25.90	.00
132	MAY	12	.14	.12	.12	.03	.00	.02	.00	.00	25.25	.00
159	JUN	8	.18	.12	.07	.06	.00	.00	.00	.00	22.83	.00

ILONGA MSIMBA KILOSA 1990 1990 S E A S O N S U M M A R Y (all values in inches)

REFERENCE CROP EVAPOTRANSPIRATION = 21.81 TRANSPIRATION: POTENTIAL = 11.66 , ACTUAL = 11.08
IRRIGATION = .00 PRECIPITATION = 25.27 EVAPORATION: POTENTIAL = 10.15 , ACTUAL = 5.53

SEASONAL SOIL WATER BUDGET :
AVAILABLE SOIL MOISTURE: BEGINNING =10.03 ENDING = 8.31
EVAPOTRANSPIRATION = 16.62 ADDED WATER (PPT+IRR) = 25.27 DEEP PERCOLATON =10.37

CORN (MAIZE) STAHA 1 GROWTH STAGE SUMMARY

STAGE	JULIAN	DATE		CONSUMPTIVE USE					PPT	WIRR	DEEP	TOTAL
	DAY	MONTH	DAY	ETP	TP	T	EP	E			PERC	SW
BEGIN SEASON	36	FEB	5									24.55
				.91	.00	.00	.91	.40	.23	.00	.00	
PLANTING	39	FEB	8									24.38
				1.46	.00	.00	1.46	.31	.03	.00	.00	
EMERGENCE	46	FEB	15									24.10
				2.47	.05	.05	2.42	1.89	6.26	.00	1.47	
FOUR LEAF	61	MAR	2									26.94
				8.57	4.95	4.95	3.62	2.57	15.38	.00	8.91	
SILK EMERGENCE	109	APR	19									25.90
				3.97	3.40	3.40	.57	.26	3.01	.00	.00	
DOUGH	132	MAY	12									25.25
				4.43	3.26	2.68	1.17	.10	.36	.00	.00	
PHYSIOLOGIC MATURITY	159	JUN	8									22.83

THE PREDICTED YIELD = 1.61 TON/HA OR 67.0 PERCENT OF 2.40 TON/HA POTENTIAL (without DPF included)
This yield includes the effect of an SLF of .739

CORN (MAIZE) STAHA ILONGA MSIMBA KILOSA 1990

STAGE	MONTH	DAY	JULIAN DAY	DAYS AFTER PLANTING	CLOCK
PLANTING	FEB	28	59	0	
EMERGENCE	MAR	7	66	7	7.00
FOUR LEAF	MAR	22	81	22	22.00
SILK EMERGENCE	MAY	9	129	70	70.00
DOUGH	JUN	1	152	93	93.00
PHYSIOLOGIC MATURITY	JUN	28	179	120	120.00

ILONGA MSIMBA KILOSA 1990 1990 CORN (MAIZE) STAHA 1 SUMMARY INFORMATION

JULIAN DAY	DATE MONTH	DATE DAY	CONSUMPTIVE USE ETP	TP	T	EP	E	PPT	WIRR	DEEP PERC	TOTAL SW	NEUTRON PROBE
59	FEB	28	.20	.00	.00	.20	.12	.03	.00	.00	26.80	.00
66	MAR	7	.19	.00	.00	.19	.04	.00	.00	.00	26.79	.00
81	MAR	22	.19	.01	.01	.18	.18	.85	.00	.55	26.87	.00
129	MAY	9	.13	.12	.12	.01	.01	.00	.00	.00	25.69	.00
152	JUN	1	.17	.14	.09	.03	.00	.00	.00	.00	23.52	.00
179	JUN	28	.16	.10	.04	.06	.00	.00	.00	.00	21.93	.00

ILONGA MSIMBA KILOSA 1990 1990 S E A S O N S U M M A R Y (all values in inches)

REFERENCE CROP EVAPOTRANSPIRATION = 24.97 TRANSPIRATION: POTENTIAL = 11.20 , ACTUAL = 8.99
IRRIGATION = .00 PRECIPITATION = 25.27 EVAPORATION: POTENTIAL = 13.77 , ACTUAL = 8.10

SEASONAL SOIL WATER BUDGET :
AVAILABLE SOIL MOISTURE: BEGINNING =10.03 ENDING = 7.41
EVAPOTRANSPIRATION = 17.09 ADDED WATER (PPT+IRR) = 25.27 DEEP PERCOLATON =10.80

CORN (MAIZE) STAHA 1 GROWTH STAGE SUMMARY

STAGE	JULIAN DAY	DATE MONTH	DATE DAY	CONSUMPTIVE USE ETP	TP	T	EP	E	PPT	WIRR	DEEP PERC	TOTAL SW
BEGIN SEASON	36	FEB	5									24.55
				4.62	.00	.00	4.62	2.42	5.94	.00	1.28	
PLANTING	59	FEB	28									26.80
				.98	.00	.00	.97	.59	1.37	.00	.79	
EMERGENCE	66	MAR	7									26.79
				2.65	.06	.06	2.59	2.05	7.03	.00	4.85	
FOUR LEAF	81	MAR	22									26.87
				8.70	4.79	4.79	3.92	2.97	10.48	.00	3.89	
SILK EMERGENCE	129	MAY	9									25.69
				3.71	3.17	2.54	.54	.07	.44	.00	.00	
DOUGH	152	JUN	1									23.52
				4.32	3.18	1.59	1.14	.00	.00	.00	.00	
PHYSIOLOGIC MATURITY	179	JUN	28									21.93

THE PREDICTED YIELD = 1.11 TON/HA OR 46.3 PERCENT OF 2.40 TON/HA POTENTIAL (without DPF included)
This yield includes the effect of an SLF of .707