Dedicated to

my

Loving Parents

..... ***Pandurang***

VALIDATION OF GROWTH AND DEVELOPMENT SUBROUTINES OF CERES-SORGHUM MODEL

A thesis submitted to the
MAHATMA PHULE AGRICULTURAL UNIVERSITY
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in partial fulfilment of the
requirements for the
degree

of

MASTER OF SCIENCE (AGRICULTURE)

in

AGRICULTURAL METEOROLOGY

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1991

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by

SHELKE PANDURANG BHANUDAS

A thesis submitted to the
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1991

CANDIDATE'S DECLARATION

I hereby declare that the thesis entitled, "VALIDATION OF GROWTH AND DEVELOPMENT SUBROUTINES OF CERES-SORGHUM MODEL" or part there of, has not been submitted by me or any other person to any other University or Institute for a Degree or Diploma.

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C E R T I F I C A T E

This is to certify that the thesis entitled, "VALIDATION OF GROWTH AND DEVELOPMENT SUBROUTINES OF CERES-SORGHUM MODEL" submitted to the Faculty of Agriculture, Post Graduate Institute, Mahatma Phule Agricultural University, Rahuri, District: Ahmednagar, Maharashtra State, in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE (AGRICULTURE) in Agricultural Meteorology, embodies the results of a piece of bona fide research work carried out by Shri. P.B. Shelke, under my guidance and supervision and that no part of the thesis has been submitted for any other degree or publication.

The assistance and the help received during the course of this investigation and sources of literature referred to have been acknowledged.

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CERTIFICATE

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Date : 28 JAN 1992

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P.B. Shelke

Place : Pune

Date :

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ABBREVIATIONS

cm	Centimeter
C.P.S.	Counts per second
d	Day
D	Degree of agreement
DAS	Days after sowing
DOS	Disk operating system
g	Gram
h	Hour
kg ha^{-1}	Kilogram per hectare
m	Meter
MAE	Mean absolute error
MBE	Mean bias error
M ha	Million hectare
mg	Milligram
MJ $m^{-2}d^{-1}$	Mega joules per meter square per day
Mt	Million tonnes
N	Number of data points
nbs	Number
RMSE	Root mean square error
So	Standard deviation of observations
Sp	Standard deviation of predictions
V	Version
r	Correlation coefficient
µg	Micro gram
µg g^{-1}	Microgram per gram
@	At the rate of
°C	Degree centigrade
%	Per cent

ACRONYMS

BIOM	Biomass
CARBO	Actual biomass produced in any given day
CUMDTT	Cumulative daily thermal time
CUMPH	Cumulative number of fully expanded leaves
DEC	Solar declination in radian
DLV	Day length variation
DLAYR	Soil layer thickness
DOY	Day of the year
DTTAN	Thermal time for anthesis
DTTPD	Thermal time for flowering after PI
DTT	Daily thermal time
DTTPI	Thermal time for panicle initiation
DUL	Drained upper limit of soil water availability
G_1	Scaler for relative leaf size
G_2	Scaler for relative head size
GPP	Grain per plant
GPSM	Grain per square meter
GRNWT	Grain weight
GROLF	Mass growth rate of leaf
GROPAN	Mass growth rate of panicle
GRORT	Mass growth rate of root
GROSTM	Mass growth rate of panicle and stem together
HRLT	Day length

I	Solar radiation received at any place in the canopy
INTPAR	Intercepted PAR
I_o	Solar radiation received at top of the canopy
JDATE	Jullian date
$LAI_{(max)}$	Maximum leaf area index
LAT	Latitude
LFWT	Leaf weight
LL	Lower limit of plant extractable soil water
$NDEF_1$	Nitrogen deficiency factor affecting early growth stage
$NDEF_2$	Nitrogen deficiency factor affecting late growth stage
O	Observed value
P	Predicted value
P1	Thermal time from seedling emergence to end of juvenile stage
P_2O	Optimal photoperiod
P_2R	Photoperiod sensitivity coefficient
P_3	Thermal time to complete leaf development
P_4	Thermal time from end of leaf growth to beginning of grain filling
P_5	Thermal time from beginning of grain filling to end of physiological maturity
PAF	Panicle aging factor
PANWT	Panicle weight
PAR	Photosynthetically active radiation

PC	Temporal variable
PCARB	Potential daily biomass production
Pg	Thermal time from germination to seedling emergence
PGC	Panicle growth constant
PHINT	Phylocron interval
Phys. mat.	Physiological maturity
PI	Panicle initiation
PLA	Plant leaf area
PLAG	Daily leaf area growth rate
PLAS	Plant leaf area senesced
PLAN	Cumulative leaf area of a plant
PRFT	Non optimal temp. factor
RATEIN	Rate of floral initiation
RGFILL	Relative panicle filling rate
RTDEP	Root depth
SDEPTH	Sowing depth
SENLA	Leaf area senesced due to unfourable conditions
SIND	Temporal variable
SLFW	Water deficit factor for leaf senescence
SLFC	Factor for leaf senescence caused by mutual shading
SLFT	Factor for leaf senescence caused by low temperature
SLW	Specific leaf weight
SOLRAD	Solar radiation
STMWT	Stem weight

SUMDTT	Sum of daily thermal time
SW	Soil water
SWCON	Drainage coefficient
$SWDF_1$	Soil water deficit factor affecting early growth stage
$SWDF_2$	Soil water deficit factor affecting later growth stage
SWSD	Weighted average water content of soil
TBASE	Base temperature
TEMPMN	Minimum temperature
TEMPMX	Maximum temperature
TMFAC	Temperature correction factor
TT	Thermal time
TTMP	Interpolation of air temperature
TEMF	Temperature reduction factor
U	Stage 1 evaporation constant
WR	Root weighting factor

ABSTRACT

VALIDATION OF GROWTH AND DEVELOPMENT SUBROUTINE OF CERES-SORGHUM MODEL

by

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1991

Research Guide	:	Prof. M.C. Varshneya
Department	:	Agricultural Meteorology

A simulation study on growth and development of sorghum (*Sorghum bicolor* (L.) Moench) was carried out during 1989-90 at CASAM Pune, India. The CERES-Sorghum model used in this study was designed to simulate the effects of cultivar, planting density, weather, soil water and nitrogen on crop growth, development and yield. Input values required include daily climatic data on solar radiation, maximum and minimum temperatures and precipitation; crop data on cultivar name, planting date, plant population and genotype specific coefficients; soil data on drained upper limit of soil water availability, lower limit of plant extractable soil water, saturation water content, initial soil water content, drainage rate content, stage I evaporation coefficient, soil albedo and runoff curve number. Two sorghum genotypes, M-35-1 and SPV-504 were taken up for study.

Initial testing of the model showed that the model needed modifications. The results of the modified model indicate that the simulated values compared well with measured data. The sensitivity analysis showed that careful considerations should be given to the water balance. The study reveals that growth, development and yield of sorghum can be simulated correctly, provided that the accurate soil characteristics parameters are used and calibration of waterbalance subroutine is done for the given region. The modified model remains to be tested against a truly independent data set to further increase the model accuracy.

(106 pages)

1. INTRODUCTION

1. INTRODUCTION

Agriculturists are always faced with risk because of the uncertainties associated with the production and marketing of crops. Strategy evaluation allows a decision maker to rank crop management practices with respect to uncertainties in crop production indicators such as yield and associated economic risk in response to different weather sequences. Decisions, in selecting long term strategies are always based on imperfect or incomplete information. Agricultural research is designed to provide information that will help the farmers in making decisions. However, it is impossible for researchers to provide specific answer, because field experiments can not include all possible soil types and weather sequences. Experiences guide the farmer in decision making. However, a complete understanding of any decision is unknown. It is difficult for any person to gain sufficient experience to enable them to minimize the risk in their decision making because combinations of weather, pests and economic uncertainties are too numerous. Optimum practices selected from agricultural experimental information are some times unattractive because of time and expense required and difficulty in adopting to other regions.

Crop models that use specific weather, soil, genetic and management information offer a good opportunity for assisting farm manager in several aspects of decision making to attain their goals. Crop models are useful in :

1. Identification of physiological and phenological attributes of cultivar needed to exploit climate and soil environment maximumally to produce higher yields;
2. Evaluation of agronomic strategies such as planting date and plant population;
3. Evaluation of irrigation strategies interms of depth and frequency of irrigation;

4. Evaluation of various fertilizer strategies such as timing, rate and depth of incorporation at a site;
5. Large area yield estimation;
6. Planning breeding programme;
7. Making drought assessment; and
8. Developing agriculture weather advisories.

The Crop Environment Resource Synthesis (CERES) models are designed to simulate the effects of cultivar, planting density, weather, soil water and nitrogen on crop growth, development and yield. These models are user friendly and require a minimum of readily available crop, soil and weather data. They are computationally efficient. They are developed to be useful for predictions and control at the farm and regional level. In addition, they are designed to be applicable globally. The productive purpose of CERES models is for evaluating potential alternative management practices that affect yield and intermediate steps in yield formation process. Because of the emphasis placed by International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT) on user-friendliness, the CERES models were adopted as prototype. But before the model could be used with confidence it has to be validated for the conditions of the area where it could be used. Validation is necessary to test the suitability of the model for its intended purpose.

In view of the above the study "Validation of Growth and Development subroutines of CERES-Sorghum model" was conducted to test the applicability of CERES-Sorghum model for Pune (Maharashtra) conditions. In present study CERES-Sorghum model is selected because sorghum (*Sorghum bicolor* (L.) Moench.) is a staple food and fodder crop in semi-arid-tropics. It is the third major cereal crop. The area under sorghum was 14.8 Mha with annual grain production of 10.5 Mt. This low production does not commensurate with the area under production. Also the yields of rainfed sorghum in semi-arid-tropics are in general low and vary from year to year. As regards Maharashtra, sorghum is main cereal crop. The area under sorghum in the state during 1989 during monsoon and post monsoon was 2.73 and 3.45 Mha, respectively with grain production of 2.46 and 1.82 Mt during respective seasons. Though sorghum is a major food crop in India, its production level has remained low as compared with Europe and America.

The present experiment was conducted during 1988-89 at Centre of Advanced Studies in Agricultural Meteorology, Pune (Maharashtra) with the following objectives:

1. To validate the growth and development subroutines of CERES-Sorghum model for crop monitoring and yield forecasting;

2. To estimate the soil characteristic parameter inputs required to run the CERES-Sorghum model.

Details of procedure employed for making observations and results obtained in the study are described in this thesis.

Chapter Opener Page

2. REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

The general aspects of crop modeling are fairly well-known. Specific literature on crop modeling is seldom available. However, the available literature has been scanned and a brief review is presented below.

2.1 DEFINITION OF THE MODEL:

The term "model" is used "to provide an explanation for certain phenomena and to postulate underlying processes which give rise to the observations under inspection" (Yarraton, 1971). It may be defined as a functional relationship between dependent observable plant response such as growth, weight change, photosynthate change, etc. and the pertinent variable influencing the plant (Walker and Splinter, 1971). Thornley (1976) defined a mathematical model as an equation or set of equations which represents the behaviour of a system.

A dynamic model is a model in which variation with time is an essential feature (Thornely, 1976).

2.2 TYPES OF MODEL:

An attempt has been made to classify selected types of crop model on the basis of the predominant approach as proposed by some authors. Explanations provided by various authors are given below.

The models based on mathematically formulated relationships with empirical constants is called as deterministic models and the models involving statistical regression technique for fitting statistically the best possible empirical relationship between climatological variables and crop production statistics is called as stochastic models (Newman, 1974).

Baier (1979) proposed a classification based on time scale, data source, approach, purpose and application of selected crop-weather models. Using these features three groups of models are suggested:

i. crop growth simulation models that consider the impact of meteorological variables on specific plant processes which can be adequately simulated by means of a set of mathematical equations that are based on available knowledge of the particular process or experiment;

ii. Crop-weather analysis models, producing a running account of the accumulated daily crop response to selected agrometeorological variables as a function of time (crop development); and

iii. Empirical statistical models in which one or several variables representing weather or climate, soil characteristics or time trend are statistically related mostly to seasonal yield or crop production statistics.

The crop growth models are classified by Whisler et al. (1986) into various categories as follows.

Empirical or correlative models that describe the relationship between variables without referring to any underlying biological or physical structure that may exist between variables.

Mechanistic or explanatory models explicitly represents the known or hypothesized mechanism that relate variables and explains their observed behaviour. These models represent casualty between variables.

Stochastic models are based upon the probability of occurrence of some event or exogenous variable.

Physiologically, physically based simulation models are those models whose plant or soil processes can be physiologically, physically or chemically described.

Phenological models are a broad class of models that predict crop development from one growth stage to another.

Dynamic simulation crop models predict changes in crop status with time as a function of exogenous parameters.

The above distinction of models into different categories still remain elusive because of overlapping methodology between categories.

2.3 MODEL BUILDING:

It is necessary to divide the cropping system into its constituent parts while building a crop simulation model. The various processes involved can be modeled separately. The processes are divided into aerial processes and soil processes. The simulation models treat processes at one or two hierarchial levels, e.g. plant and organ level but not the organelle and lower levels of hierarchy (Whisler et al., 1986).

The dynamic crop growth models for sorghum and their relative merits are discussed below.

The development of user-oriented models was started after the success of a model developed by Ritchie (1972) to predict evapotranspiration from row crops. The model was more empirical and required seasonal variation in leaf area index (LAI) as a input. However, the information about LAI is not readily available from experiments. This difficulty was overcome after the development of SORGF, a Dynamic Grain Sorghum Growth Model (Arkins et al., 1976). The SORGF was able to predict LAI on the basis of principal of developmental physiology. The SORGF required number of leaves as a input along with maximum leaf size. However, the leaf number and size is based on the genotype and the environment. The processes treated in SORGF were photosynthesis, respiration, transpiration, growth and morphogenesis.

A Resource Capture (RESCAP) model was developed by Monteith et al. (1989) to predict the growth and yield of sorghum and pearlmillet. The RESCAP included genetic coefficients and appropriate environmental variables as inputs. The model assumes only three layers of soil: 0 to 10 cm, 10 cm to root front and below root front. Root senescence is not considered. The Model has no nutrient subroutine and is applicable only to areas where nutrients are not limiting. The RESCAP requires more weather data.

These limitations are overcome in the Crop Environment Resource Synthesis (CERES) model developed as a collaborative effort between International Crops Research Institute (ICRISAT), Michigan State University and International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT). Dr. Joe Ritchie has coordinated the model development. The nitrogen sub-model was primarily developed by the modelers at the International Fertilizer Development Centre (IFDC) (Alagarswamy et al., 1989).

The CERES models have potential to describe how the genetics and climate determine the duration of the vegetative growth in order to predict LAI. The CERES models have a procedure for simulating the uptake of N and its subsequent utilization by the crop (Alagarswamy et al., 1989) The nitrogen component of the model is designed to operate as a component of the CERES-models and not a stand-alone mode (Godwin, 1989). This raised the potential of the CERES-models for the geographical mapping of crop yields.

A revised version of SORGF known as SORKAM has been developed to incorporate the relevant knowledge since the introduction of SORGF (Rosentahl et al., 1989). Hammer and Vanderlip (1989) modified SORKAM to incorporate the genotype-by-environment interaction on radiation use efficiency and ontogeny found among the old and new hybrids.

2.4 MODEL TESTING:

Many crop models are published without adequate testing because model testing is difficult task. Model testing consists of validation and sensitivity analysis. In validation model predictions are compared with observations while sensitivity analysis tests how responsive model is to changes in certain variables and parameters (Whisler et al., 1986).

2.4.1 Validation:

It is, ofcourse, not possible to validate any model absolutely. For validation, the use of models must be clearly defined and the precision that is needed in order that the model may be an effective tool must be decided (Thornley, 1976).

Validation is a "comparison of verified model to the data and determination of its suitability for its intended purpose". In verified model the equations have been tested to ensure that they perform as intended by the developer. Verified model may not simulate a crop correctly (Lemon, 1977).

Validation may be defined as a "comparison of predictions of a verified model with experimental observations other than those used to build and calibrate the model, and identification and correction of errors in the model until it is suitable for its intended purpose". Crop simulation models can be validated either by using field data or controlled environment data. Validation increases our confidence in the model. It also provides an opportunity to identify its areas of weakness. Validation against data covering all aspects of a crop growth and development enables us to determine at what stages and in what aspects the model incorrectly predicts crop behaviour (Whisler et al., 1986).

The simulation model of plant growth was developed by Curry (1977) on the basis of Elementary Crop Simulation (ELCROS) model (De Wit, 1965, 1968) and the model developed by Stapleton (1968). The results of validation indicate that the model was predicting growth of the crop within the reasonable range. Curry and Chen (1971) incorporated actual daily weather and partioning of net photosynthesis in this model and concluded that with reasonable good calibration, model can be used to test various plant growth parameters (physiological and environmental) to determine which one might be key factor in increasing efficiency of production.

SORGF simulated accurately the dry matter accumulation in plant (Arkin et al., 1976). Conditional probability functions were developed by Arkin et al. (1978) to develop a scheme for forecasting crop yields. Cumulative probability functions were generated using 20 years of weather data from Temple, Texas, conditioned on two state variables (leaf area and extractable soil water). Cumulative distribution functions were used to forecast yields at selected dates over the season. Forecast accuracy improved as the season progressed.

Strategic decisions were examined by Dugas and Arkins (1980) by using SORGF and climatic data combinations. Anthesis and physiological maturity dates were always significantly different between sowing dates for a genotype. Significant differences were common between high and low under holding capacity soils; however, there were no significant differences between initially full and half full profiles of a given water holding capacity.

Formulas for the calculation of the average yield of grain sorghum and other crops were developed by Craford and Hott (1981). The formulas were based on the assumption that the crop yield is a function of the rainfall effective soil depth, the air/moisture regime within the effective depth, transpiration and grain; chaff ratios and the ability of a crop to resist drought. The formulas were tested against yield data obtained from farm and experimental plots. Reasonably consistent relationship between calculated and actual yields were obtained. The use of yield formulas provides an objective methods of relating soil profile features and rainfall to yield, upon which decision relating to land use and cultural practices may be based.

A model for the water relations, photosynthesis and expansive growth of plant was developed by Zur and Jones (1981) for studying the integrated effects of crop and climate on the expansive growth, photosynthesis and water use of crops. Authors concluded that detailed mechanistic crop models are of considerable value for exploring possible interactions between soil, plant and atmospheric parameters. Such exploration should lead to a better understanding of the dynamics of this complex system. The computed results could be investigated in agronomic research.

GOSSYM was validated by Reddy (1981) with data from Arizona, Mississippi and Israel. He concluded that the model was indeed a feasible tool for general application by making few site-specific changes to achieve realistic simulations. Reddy et al. (1985) developed and incorporated in GOSSYM new equations for estimating canopy temperatures under very hot dry Mississippi conditions. This model provided very good simulation of seasonal time of number of flower buds, bolls, main stem nodes and fruit sites. It also provided very good simulations of leaf, stem and boll dry weights as well as leaf area index and plant height.

A model of potato growth and yield was tested by Mackerron (1985) against three independent data sets. Results have shown the model to be successful in its aims of providing an estimate of potential yield of a potato crop and describing the development of crop towards that yield.

Three simple methods for calculating potential crop production from temperature and irradiance data (0 to 40° latitude) were presented by Versteeg and Ven Keulen (1986). They used 57 data sets of measured results for testing.

Coefficient of determination between measurements and predictions were 0.96 to 0.98 and did not differ between methods (in 45 data sets).

Sorghum simulation model was revised by Huda (1987) for the use in semi-arid tropics. As a result of revision in the model, the correlation coefficient between observed and simulated yields of sorghum (n = 59) increased from 0.52 to 0.86. Validation results showed that SORGF model can be used to estimate sorghum yields with reasonable accuracy before harvest.

Mass (1988) developed and verified a model by using data from 10 fields, observed in Central Texas, 1976. The model was tested using completely independent data set containing yield and satellite observations from 37 fields in South Texas. Without using initialising procedure the average yield for the 37 fields was under estimated by 3.7 %. Use of satellite derived GLAI data to initialize the same simulation result in 2 % over estimation of average yield. The results confirm the usefulness of the initializing procedure and satellite data to improve model estimates of crop yield.

A procedure for simulating maize phenology was developed by Grant (1989) as a subroutine for a maize growth model. The results showed that estimated leaf numbers were usually within one of those observed at all but one site in the phenology trial where the leaf numbers were over estimated by as much as four leaves. Estimated dates of tassel initiation and silking were usually within 5 d of observed data except of warmer site in Texas where estimated dates preceded observed dates by 5 d to 15 d. Grant suggested that high temperature acclimation might have resulted in slower rates of development than those predicted at some of the warmer sites.

CERES-Maize model estimated yield well in years with near-normal precipitation, but significantly under estimated yield in wet years. The soil water deficit index (D) was too sensitive to wetness. Model yield estimates for dry year improved when irrigation was simulated. Incorporating an excess water factor into the model improved yield estimates in wet years. The correlation coefficient between observed and estimated yield was 0.37 when the model was run without irrigation and excess water factor, 0.66 when model was run with irrigation and 0.92 when model was run with irrigation and excess water factor. The mean absolute error (MAE) for three versions were 593.3, 377.1 and 219.2 kg ha^{-1}, respectively. The results demonstrate that the CERES-Maize model, when the effect of irrigation and excess water are taken into account, may be applied for large area yield estimation under the wide range of moisture conditions in North China Plain (Wu et al. 1989).

The CERES-Maize model used by Liu et al. (1989) to simulate the growth and yield of Brazilion maize hybrid, DINA-10. The results showed that the predicted and measured dates from seedling emergence to the end of juvenile stage had a mean difference of 3 d, while dates from silking to physiological maturity had a mean difference of 0.5 d. For 5 years from 1983-1987, model estimated yields well at the extractable lower limit, except in 1985 which it over estimated by 21.4 % due to delayed germination caused by water stress. In this year advancing sowing date by one day which had soil water content above lower limit set for germination resulted in he model overestimating yield by only 3.3 %. This study showed that the CERES-Maize model can be used to estimate maize yield in Brazil.

The CERES-Sorghum model was developed and validated by Ritchie and Alagarswamy (1989) by using data from multilocation sorghum modeling experiment (Huda, 1987) in which sorghum hybrid CSH-1 was grown at several locations in India. Their results indicate that model is capable of simulating phenological stages reasonably well. Simulated and measured grain yields from three widely different growing regions (Bushland, Kununurra and ICRISAT) were compared. The results showed that in Bushland model over estimated the yield because of inability to correctly model tiller contribution to total grain yield. Poor production at Kununurra is from zero nitrogen plots over 2 years which might be due to severe N deficiency factor in the model, or incorrect initial soil N input value.

SORKAM model was modified by Hammer and Vanderlip (1989). Results demonstrate that predicted trend was not entirely consistent with field data. This suggests the need for research aimed at to understand the causes. The study demonstrated that modeling has an important role to play in linking physiological research with crop improvement. Modeling can improve relevancy of physiological research and application of that research to crop improvement.

A simulation study of the soil water balance and dry matter production of oat (*Avena sativa* L.) was carried out by Ragab et al. (1990) on a Typic Hapludalf soil, at two sites near Gottingen, West Germany during 1976, 1977, 1982 and 1983. The soil water balance and crop production model (SWACRO) developed by Feddes (1982) was used. The results of the study showed that simulated total dry matter, shoot dry matter, evapotranspiration rate, water storage in the profile, and soil water profiles compared reasonable well with the measured values in the 4 - yr study. Some of the input parameters were derived from the 4 - yr experimental data. Therefore, the model remains to be tested against an entirely independent data set.

A simulation model (McStress) was used by McCree and Fernandez (1989) for integrating ideas about physiological response to soil water deficit at the whole plant level. The results showed that McStress model is capable of simulating physiological response to water stress. Model simulations demonstrated how the assumption of a hyperbolic dependence of photosynthetic rate on internal CO_2 concentration could lead to an increase in water use efficiency as stomates close. Other simulations demonstrated how an increase in the volume of soil explore by unit mass of new roots could lead to greater amount of water uptake and C gain per cycle. Authors concluded that interactions among these and other factors can be studied in a way by using models that would not otherwise be possible.

2.4.2 Sensitivity Analysis:

Sensitivity analysis serve as indicators of environmental, crop and management effects on crop growth for other agronomic scientists (Whisler et al. 1986). For the weather and soil variables of GOSSYM a sensitivity analysis had done by Whistler et al. (1979a,b). The results showed that the model is most sensitive to changes in air temperature (either maxima or minima), next to that the model is sensitive to changes in solar radiation and least sensitive to changes in rainfall.

A sensitivity analysis of SORGF was performed by Mass and Arkins (1980) to determine the response of the model to changes in the values of important system variables. Temperature, insolation, percentage extractable soil water, plant population, row spacing, number of leaves and leaf area were selected as a system variables in the study. The SORGF responded to changes in the system variables in accordance with plant/environmental relationship theory.

The sensitivity of the calculated output from the model to changes in the functions and parameters used within the model is tested by Mackerron and Waister (1986). The results showed that model is flexible in its applications and in its scope for future development.

A sensitivity analysis of the soil water balance and crop production model (SWACRO) showed that the values of the maximum water use efficiency factor (A) and the respiration factor (Φ_r) should be either obtained from experimental data or chosen carefully from the literature for similar conditions (Ragab et al., 1990).

2.5 MODEL APPLICATIONS:

Crop models provide useful quantitative information for decision making. This helps in eliminating much of the repetitive trial and error of selecting production strategies. Arkin and Dugas (1984) have explained the utility of crop models to develop strategic and to some extent tactical production practices. They suggest that empirical statistical models can be widely used in agroclimatic analysis to develop production strategies. Their most suited applications are for predicting crop yields using a single variable, e.g. rainfall. However, they are site specific and are unable to adequately describe complex and dynamic causal relationships between crop growth and yield and environmental factors.

Crop-weather analysis models relate one or more derived parameters, such as heat units, soil moisture and transpiration to yield. They are helpful in assessing strategies (Baier 1973; Baier et al., 1976). But these models require considerable calibration with yield data that are often unavailable.

Crop growth models (CGMs) are generally considered as research tool only (Freve and Popov, 1979; Legg, 1981). Their utility in management decision making has recently been demonstrated. These models have the potential for overcoming many of the limitations attributed to the other model categories.

Chapter Opener Page

3. MATERIALS AND METHODS

3. MATERIAL AND METHODS

3.1 THE SITE:

3.1.1 Experimental Field:

The experiment was conducted during the post monsoon season of the year 1989-90 at the Centre of Advanced Studies in Agricultural Meteorology, College of Agriculture, Pune, India. The geographical location of the site is 18° 32' N, latitude; 73° 51' E, longitude and 559 m above mean sea level (MSL). The topography of the field was uniform and levelled. The soil was medium black calcarious having the depth of about one meter.

3.1.2 Climatic Conditions of the Station:

The tract is lying on the eastern side of the western ghats. Climatically, the area falls in Semi-Arid Sub-tropical zone with the annual average rainfall being 661.1 mm. The annual average maximum and minimum temperatures are 32.0° and 18.2°C, respectively. The annual average relative humidity at 07.30 h (RH-I) is 71.0 % and at 14.30 h (RH-I) is 46 %. The annual average insolation is 20.50 MJ $m^{-2}d^{-1}$. The annual average wind speed is 5.3 kmph.

The tract receives rainfall from south-west monsoon. Out of the total annual precipitation major part is received during the monsoon period from June to September. The remaining rainfall is received during post monsoon season. From December to May there is clear sky with abundant sunshine and the period is practically a dry spell.

3.1.3 Cropping History of the Experimental Plot:

Cropping history of the experimental field for pervious two years has been elaborated in the Table 3.1.

Table 3.1 Cropping history of experimental plot.

Year	Season and Crops Grown		
	kharif	*Rabi*	Summer
1987-88	Fallow	Onion	-
19888-89	Sunflower	Gram	-
1989-90	Sunflower	Sorghum (present experiment)	-

3.2 EXPERIMENTAL DETAILS:

3.2.1 Design of the Experiment:

The experiment was laid out in a split plot design with four replications consisting of four plots as main treatments and two plots as sub-treatments. The allocation of various treatments to respective plots was done by randomization. The plan of field layout is given in Fig. 3.1

3.2.2 Treatments:

Four treatments of sowing dates were allocated to main plot and two treatments of genotypes of sorghum were allocated to sub-plots. The detailed description of the treatment is given in Table 3.2.

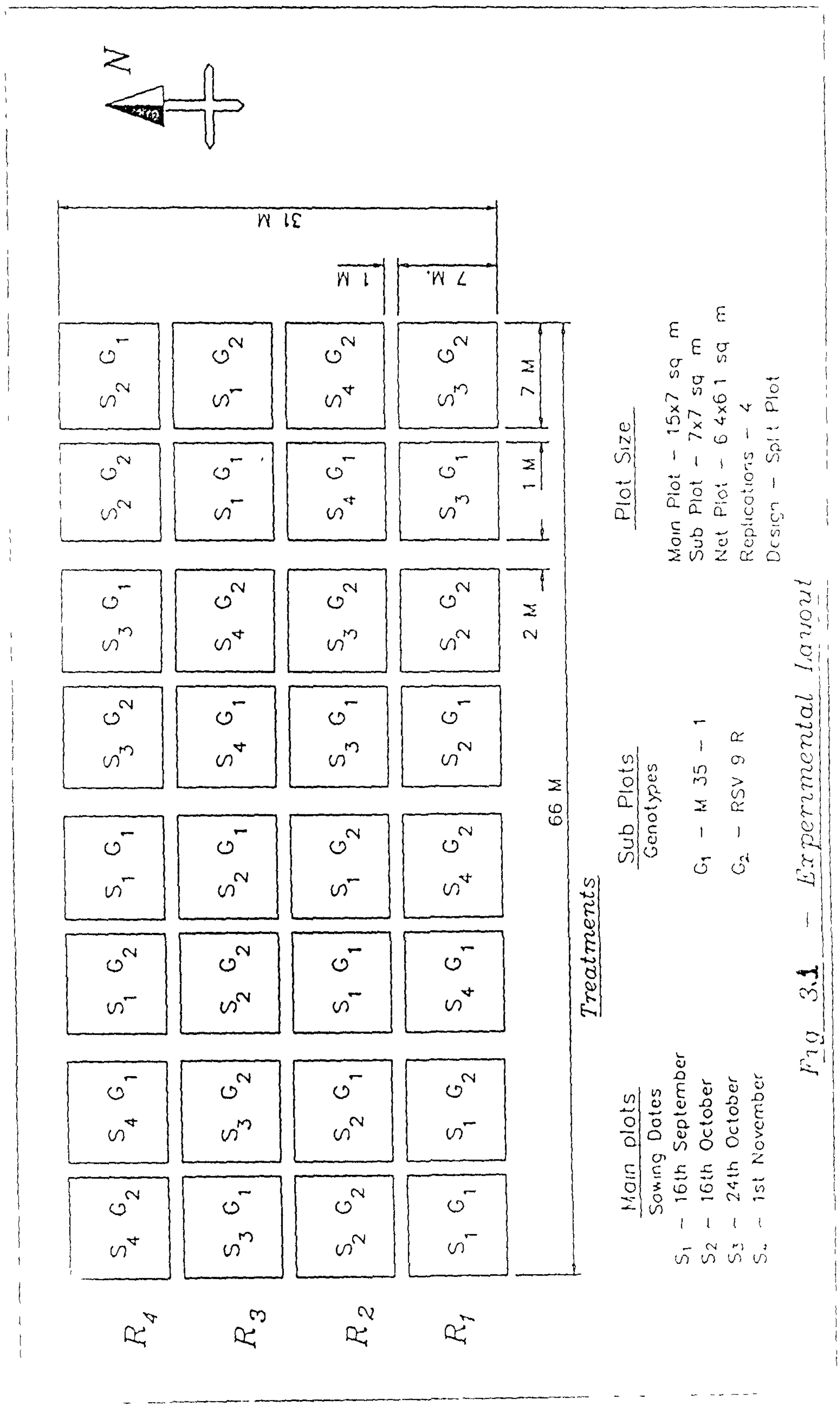

Fig. 3.1 Field layout of the experimental plot

Table 3.2 **Treatment details.**

Sr. No.	Particulars	Symbol
I.	**Main treatments (Sowing dates)**	
i.	16-09-89	S_1
ii.	16-10-89	S_2
iii.	24-10-89	S_3
Iv.	01-11-89	S_4
II.	Sub-treatments (Genotypes)	
i.	M-35-1 (Maldandi)	G_1
ii.	SPV-504/RSV 9R (Swati)	G_2
III.	Other	
i.	Main plot-size: 7 x 7 M^2	
ii.	Net plot size: 6.4 x 6.1 M^2	
iii.	No. of replications: 4	
iv.	No. of plots: 32	

3.3 FIELD OPERATIONS:

Various field operations carried out prior to sowing and during the crop growth period are given in Table 3.3.

3.3.1 Seed and Sowing:

The certified seed of sorghum was used for sowing. The seed was treated with thiram @ 4 g kg^{-1} of seed for the control of fungal diseases. Seed treatment with 300 mesh sulfur at 4 g kg^{-1} of seed was given in order to control the smuts of sorghum. The sowing was done by dibbling method in 45 cm apart rows at a

Table 3.3 Schedule of field operations.

Sr. No.	Operation	Time			
		S_1	S_2	S_3	S_4
I.	**Presowing operations**				
i.	Ploughing	02-09-89	02-09-89	02-09-89	02-09-89
ii.	Harrowing	07-09-89	07-09-89	07-09-89	07-09-89
iii.	Stuble collection	09-09-89	09-09-89	09-09-89	09-09-89
iv.	Layout of experiment	14-09-89	14-09-89	14-09-89	14-09-89
v.	Fertilizer application	16-09-89	16-10-89	24-10-89	01-11-89
II.	**Sowing by**				
	Dibbling method	16-09-89	16-10-89	24-10-89	01-11-89
III.	**Post sowing operations**				
i.	Irrigation	16-09-89	16-10-89	24-10-89	01-11-89
ii.	Gap filling	23-9-89	24-10-89	01-11-89	08-11-89
iii.	Thinning (two)	01-10-89 & 08-10-89	01-11-89 & 08-11-89	08-11-89 & 15-11-89	16-11-89 & 23-11-89
iv.	Weeding	05-10-89	07-11-89	19-11-89	26-11-89
v.	Hoeing	25-10-89	19-11-89	01-12-89	08-12-89
IV.	**Plant protection**				
i.	Spraying endosluphan @ 0.05 %	01-10-89	29-10-89	09-11-89	16-11-89
ii.	Sparying dimethoate @ 0.05 %	11-10-89	10-11-89	20-11-89	27-11-89
V.	**Harvesting**	18-01-90	20-02-90	07-03-90	14-03-90

distance of 15 cm. At one hill 3-4 seeds were dibbled. Irrigation was applied after sowing.

3.3.2 Gap Filling and Thinning:

The gap filling was done seven days after sowing. First thinning was carried out 15 days after sowing and second thinning was done 23 days after sowing.

3.3.3 Fertilizer Application:

The basal dose of N @ 50 kg ha^{-1} in the form of urea and P_2O_5 @ 25 kg ha^{-1} in the form of single superphosphate was applied at the time of sowing.

3.3.4 Plant Protection:

Two sprayings with endosufan and dimethoate @ 0.05% at an interval of 10 days were given for the control of Shoolfly.

3.3.5 Harvesting:

The border rows were separated before the harvest of plants from net plot. The earheads were nipped and kept for drying in the threshing yard. The produce from each net plot then threshed, cleaned and stored separately.

3.4 THE MODEL:

The CERES-Sorghum model consists of various subroutines, viz., phenology subroutine, growth subroutine, water balance subroutine and nitrogen subroutine. The objective of the present study is to validate the growth and development subroutines of the CERES-Sorghum model. Therefore, only these subroutines are described below. A flow diagram of the entire model is given in Fig. 3.2.

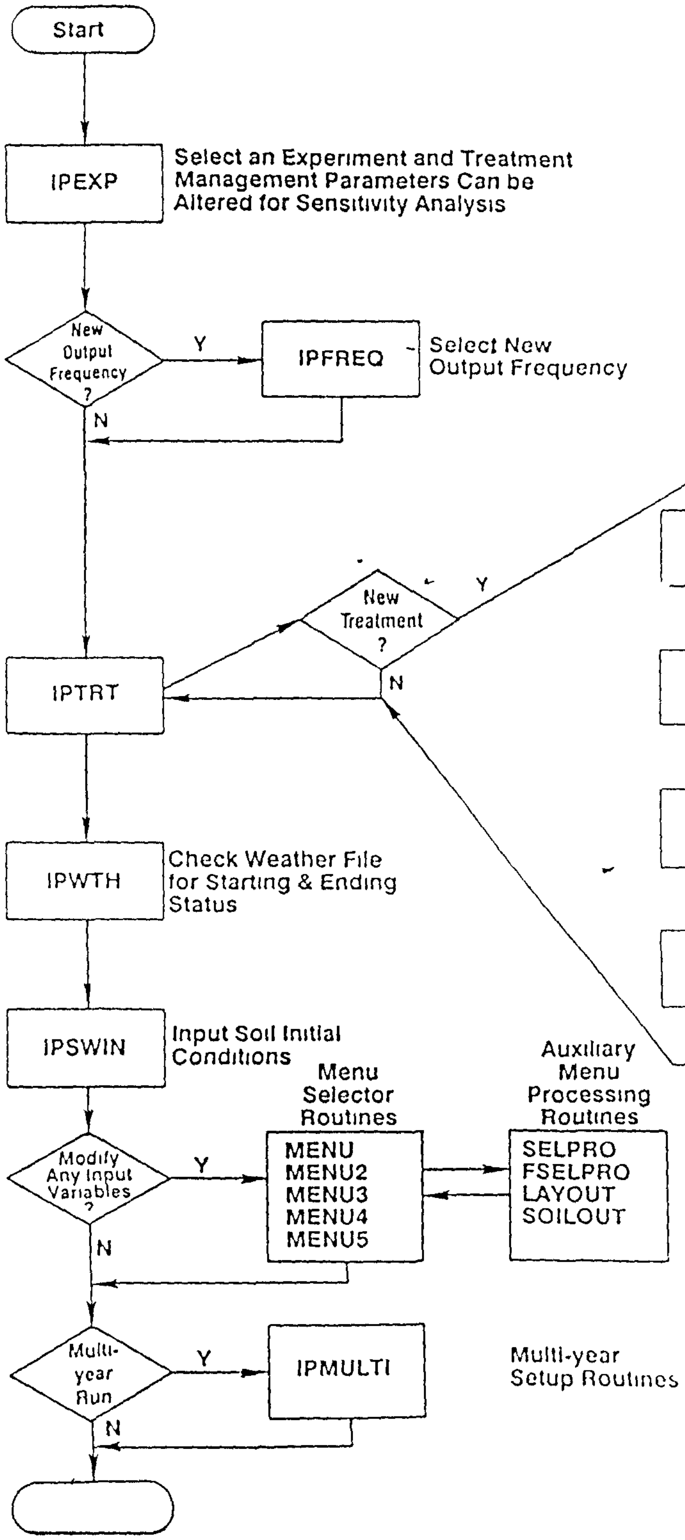

Fig. 3.2 **Flow chart of CERES-Sorghum Model**

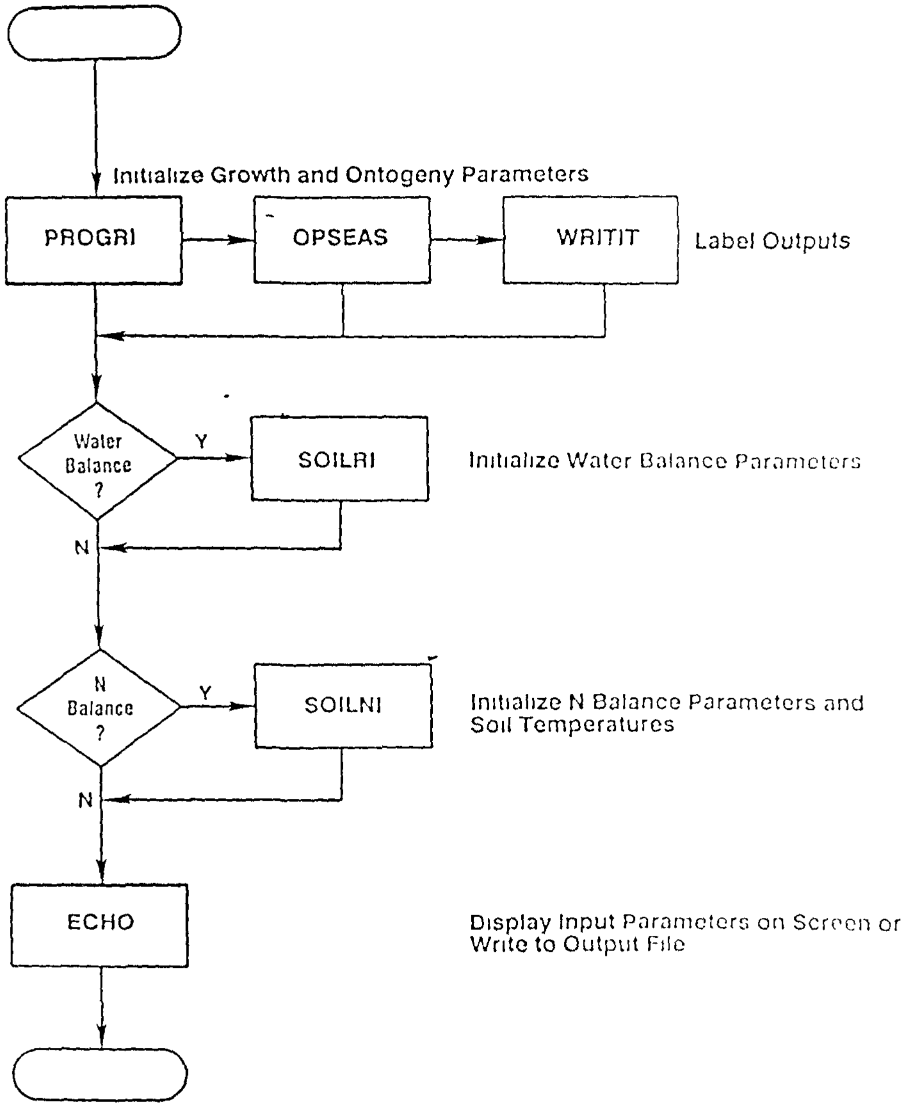

Fig. 3.2 Continued .....

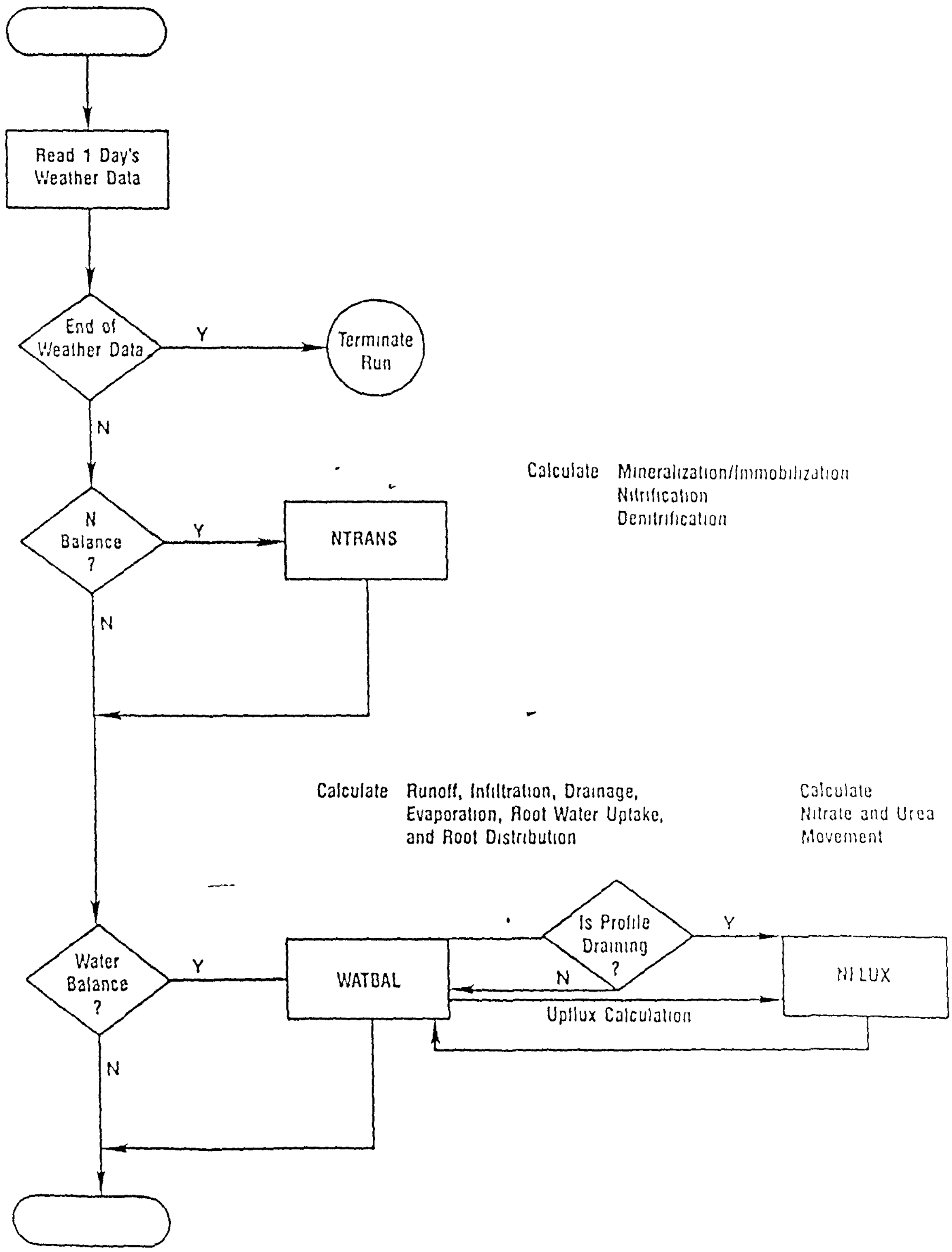

Fig. 3.2 Continued .....

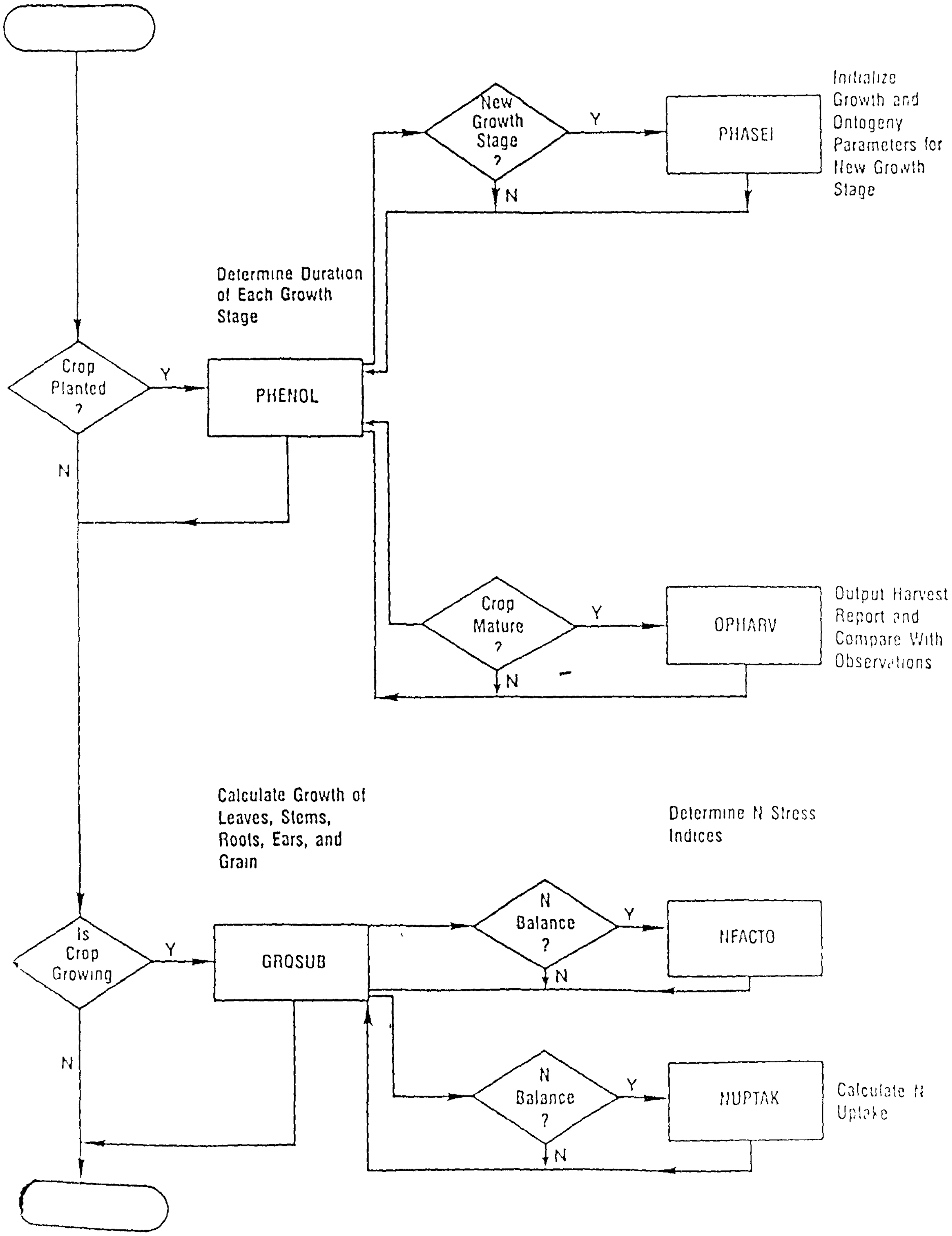

Fig. 3.2 Continued .....

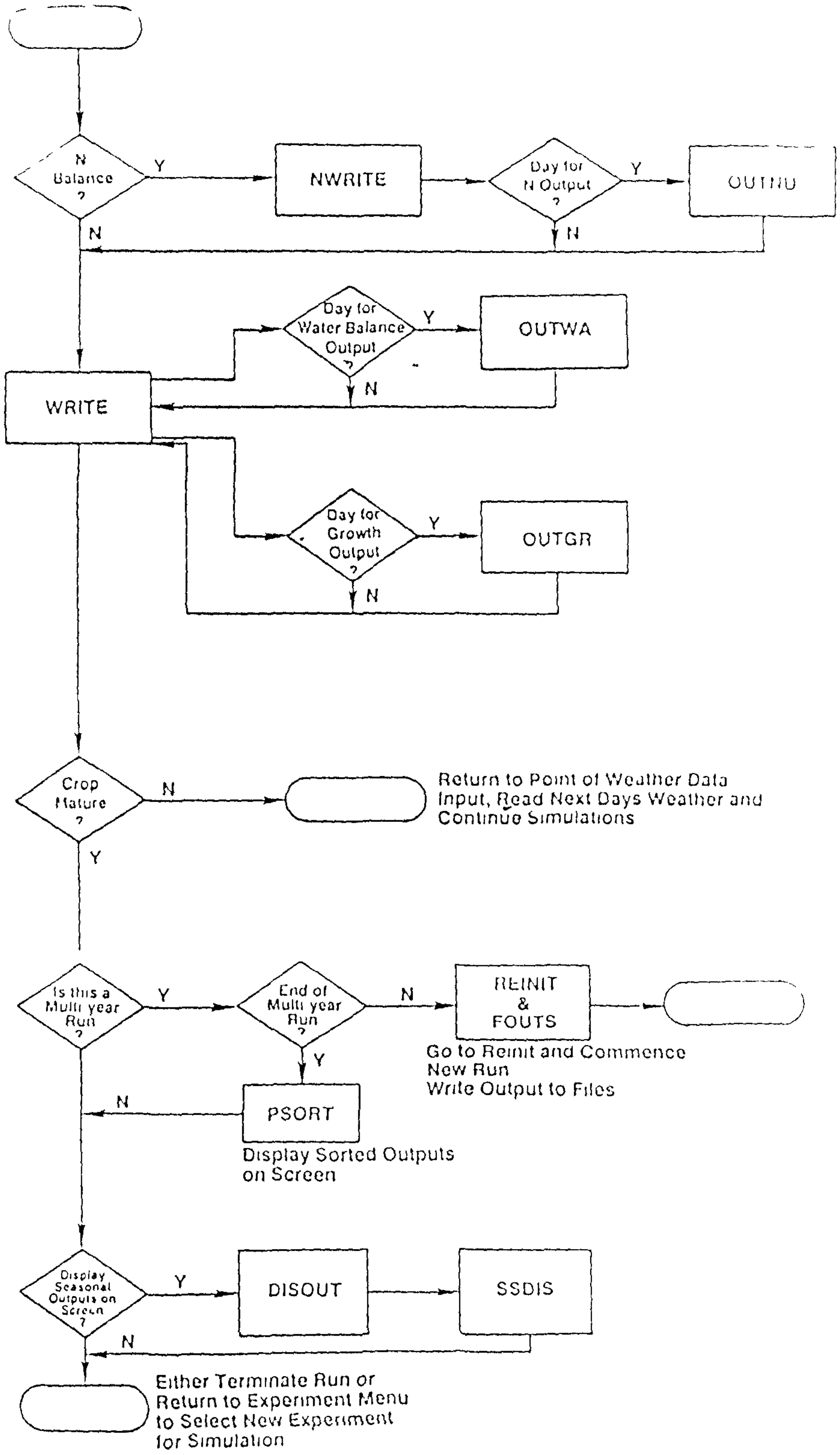

Fig. 3.2 **Continued .....**

3.4.1 Simulation of Sorghum Phenology:

Phasic development in CERES-Sorghum model describes the duration of several growth stages in the crop. Partitioning of assimilates is done entirely between leaves and roots prior to panicle initiation (PI). After PI various simultaneously growing organs begin to compete for the assimilates. Immediately prior to anthesis, the rapidly growing panicle become the active sink for assimilates. During post anthesis developing grain is the major sink for the assimilates. Thus, plant dynamically partitions assimilates among plant organs temporarily. Accordingly, various growth stages are organized around times when partitioning of assimilates change among the plant organs.

Daily progression of plant development has been precisely described by growing degree day approach. This approach relates developmental rates to the air temperature. Below a certain minimum temperature (base temperature) no plant development takes place and above some optimum temperature plant development decreases drastically. Between these two defined temperatures, plant development increases linearly with the increase in temperature. The base temperature for sorghum is 8°C and 34°C is the optimum temperature beyond which plant development rate decreases drastically.

The above principles are used in modelling the growth and development in sorghum.

3.4.1.1 Estimation of thermal time:

When the daily minimum temperature (TEMPMN) is above base temperature (TBASE, 8°C) and daily maximum temperature (TEMPMX) is below 34°C, daily thermal time (DTT) accumulation in the model is calculated as:

$$DTT = (TEMPMX + TEMPMN) / 2.0 - TBASE$$

where,

$$\text{TEMPMN} < 8^\circ\text{C} \qquad \text{TEMPMX} > 34^\circ\text{C}$$

Then eight three hourly interpolations of air temperature (TTMP) are calculated using 3 hour temperature correction factor (TMFAC).

$$\text{TMFAC (I)} = 0.931 + 0.114 * \text{I} - 0.0703 * \text{I} ** 2 + 0.0053 * \text{I} ** 3$$

where,

$$\text{I} = 1,8$$

$$\text{TTMP} = \text{TEMPPMN} + \text{TMFAC (I)} * (\text{TEMPMX} - \text{TEMPMN})$$

For each value of TTMP, a three hour value of DTT is calculated. If TTMP is between TBASE and 34°C then:

$$\text{DTT} = \text{DTT} + (\text{TTMP} - \text{TBASE}) / 8.0$$

When TTMP is inbetween 34 and 52°C then,

$$\text{DTT} = \text{DTT} + (34.0 - \text{TBASE}) * \{[1.0 - (\text{TTMP}-34)]/10.0\} / 8.0$$

There are two variables SUMDTT and CUMDTT that give accumulated DTT. The value of SUMDTT is used to determine the duration of various phenological stages whereas value of CUMDTT is used to indicate the accumulated DTT since seedling emergence at any given time.

3.4.1.2 Organization of developmental stages:

In CERES-Sorghum model, the growth stages of sorghum are numerically coded from 1 to 9 (Table 3.4) to route the control through the major growth and phenology subroutines of the model. Various plant organs actively grow between

Table 3.4 Growth stages of sorghum as defined in CERES-Sorghum model

Stage	Event	Plant parts growing
7	Fallow or presowing	-
8	Sowing to germination	-
9	Germination to seedling emergence	Roots, coleoptile
1	Seedling emergence to begining of juvenile stage	Roots, leaves
2	End of juvenile stage to panicle initiation	Roots, leaves
3	Panicle initiation to end of leaf growth	Roots, leaves, stem
4	End of leaf growth to begining of effective grain filling	Roots, stem, panicle
5	Effective grain filling to physiological maturity	Roots, stem, panicle
6	Physiological maturity to harvest	-

stages 1 and 5. Stages 7 through 9 are used to describe events occurring during sowing to seedling emergence.

STAGE 7: Presowing

On the sowing date subroutine PHENOL is called by MAIN programme. A day counter is created (initial value zero). Soil layer thickens (DLAYR), sowing depth (SDEPTH) are used to determine soil layer depth (L_0) in which seed is sown. This stage in the model could also be used to run the soil-water balance. When the initial soil water conditions at the time of sowing is unknown.

STAGE 8: Sowing to germination

If the minimum temperature is greater than 10°C and if soil moisture in seedling zone [SW (L_0)] is greater than lower limit of plant extractable water (LL), seed germinates. If soil moisture in that layer is less than LL, a weighted average water content of first and the next layer is calculated to determine if seed can germinate or not

$$SWSD = [SW(L_0) - LL(L_0)] * 0.65 + [SW(L_0 + 1) - LL(L_0 + 1)] * 0.3$$

If SWSD ≥ 0.02 then germination will occur.

The initial rooting depth (RTDEP) is set to SDEPTH.

STAGE 9: Germination to seedling emergence

Seedling emerges when the thermal time reaches the value of the coefficient + P_9 (base temperature for germination 10°C).

$$P_9 \quad 20.0 + 6.0 * SDEPTH$$

Where,

SDEPTH = sowing depth (inches)

Prior to seedling emergence root depth (RTDEP, cm) increases linearly with DTT.

$$RTDEP = RTDEP + 0.15 * DTT$$

STAGE 1: Seedling emergence to end of juvenile stage

The juvenile stage ends when the cumulative DTT equals or exceeds the value of P_1 a genotype-specific coefficient.

STAGE 2: **End of juvenile to end of panicle initiation (PI)**

The day length (HRLT) is calculated as a function of solar declination (DEC in radians), sine and cosine of latitude (LAI) and angle of sun at civil twilight. DEC is a sine function of the day of the year (JDATE). Thermal time from seedling emergence to PI could be expressed in two photoperiod response ranges, insensitive and sensitive.

In the insensitive range, changes in day length have no effect on thermal time for PI (DTTPI). There is a threshold photoperiod (P_2O) above which DTTPI increases linearly with increasing photoperiod. The slope (DTTPD) per hour increase in day length) is termed the photoperiod sensitivity coefficient (P_2R). The duration of this stage is dependent upon daylength above P_2O and P_2R.

Rate of floral initiation (RATEIN) is calculated as,

$$RATEIN = 1.0/[102.0 + P_2R * (HRLT - P_2O)]$$

$$SIND = SIND + RATEIN * DTT$$

SIND = Temporary variable

When sind value reaches unity stage 2 is completed.

Calculation of HRLT (daylength)

$$HRLT = 7.639 * ACOS (DLV)$$

As boundary conditions minimum value of DLV is set to -0.87.

DLV = daylength variation

$$DLV = (-SIN (LAT) * SIN (DEC) - 0.104/[COS (LAT)] * COS (DEC))$$

DEC = solar declination

$$DEC = 0.4093 * SIN (0.01) 2 * (JDATE - 82.2)$$

STAGE 3: Panicle initiation to end of leaf growth

Thermal time for flowering (DTTAN) is directly related to thermal time for PI (DTTPI)

$$DTTAN = 1.199 * DTTPI + 450.0$$

$$DTTAN = DTTPI + DTTPD$$

Where,

$$DTTPD = \text{thermal time for flowering after PI.}$$

$$DTTPI = DTTPD + 1.199 * DTTPI + 450.0$$

$$DTTPD = 0.199 * DTTPI + 450.0$$

Thermal time from flag leaf expansion until flowering in several sorghum genotypes was estimated to be 150 degree days.

Thermal time to complete leaf development (P_3) could be calculated as:

$$P_3 = 0.199 * DTTPI + 300.0$$

STAGE 4: End of leaf growth to begining of grain filling

Duration of this stage is 270 degree days, and flowering occurs after 150 degree days.

STAGE 5: Effective grain filling to phyusiological maturity

Duration of this stage is determined by genetic coefficient (P_5). Most of the commonly grown genotypes require about 550 degree days to reach physiological maturity.

3.4.2 Simulation of Growth and Development in CERES Model:

3.4.2.1 Leaf Area Development:

The number of leaves that appear can be calculated using the leaf appearance interval (PHINT).

The PHINT value (in degrees per leaf) is 49 for sorghum.

The cumulative number of fully expanded leaves (CUMPH) in sorghum is calculated from the daily thermal time (DTT).

$$\text{CUMPH} = \text{CUMPH} + \text{DTT} / \text{PHINT} * \text{PC}$$

When five or more leaves appear value of PC will be unity, otherwise,

$$\text{PC} = 0.66 + 0.068 * \text{CUMPH}$$

Cumulative leaf area of a plant (PLAN) on a given day is calculated by using Gomepertz funtion:

$$\text{PLAN} = A\ e^{be^{(-k\ *\ \text{CUMPH})}}$$

Where,

A = maximum leaf area at infinite time

b,k = constants

Leaf expansion growth is sensitive to unfourvalbe temperatures. Therefore temperature reduction factor (TEMF) is calculated to reduce leaf expansion growth when unfavourable temperatures are encountered.

When TEMPMX is below 8°C value of TEMF is set to zero. Then eight interpolations of air temperature (TTMP) are calculated using three hour temperature correction factor [TMFAC (I)].

$$TTMP = TEMPMN + TMFAC (I) * (TEMPX - TEMPMN)$$

When 14°C < TTMP > 32°C

$$TEMF = TEMF + 1.0/8.0$$

For TTMP < 14°C and TTMP > 40° C, TTMF value will respectively be,

$$TEMF = TEMF + 0.021 * (TTMP -8.0)$$

$$TEMF = TEMF + 0.0125 * (42.0 - TTMP)$$

The daily leaf area growth rate is then multiflied by the minimum value of TEMF and $SWDF_2$ (soil water deficit).

$$PLAG = (PLAN - PLAO) * AMIN1 (SWDF_2, TEMF)$$

Total plant leaf area is then updated:

$$PLA = PLA + PLAG$$

Cumulative leaf area is thus calculated in stage 1 to 3. However, the area of last three leaves is progessively smaller compared to previous leaves. To account for such differences in the area of last three leaves, calculated PLAG is reduced nonlinearly by 20 % as follows:

$$PLAG = PLAG * (0.8 + 0.2 * [(P_3 - SUMDTT)/147.0] ** 2)$$

3.4.2.2 Assimilate Production:

The input variable solar radiation (SOLRAD) is first converted into PAR.

$$PAR = 0.5 * SOLRAD$$

Using Bouger-Lambert law the amount of light intercepted (I/I_0) by the canopy is calculated as:

$$I/I_0 = e^{(-k * LAI)}$$

Where,

K = extinction coefficient

LAI = Leaf area index

Once the amount of PAR intercepted by canopy (INTPAR) is computed, potential daily biomass production (PCARB) is calculated:

PCARB = 4.0 * INTPAR

It is assumed that 4.0 g of total biomass are produced for every MJ of PAR intercepted.

The actual biomass produced is generally well below the potential amount because both biotic and abiotic factors reduce the potential amount. Therefore, in the model potential biomass production is constrained by non-optimal temperature factor (PRFT), nitrogen deficiency factor ($NDEF_1$) and water deficit ($SWDF_1$) factor. Values for those factors range form zero to unity.

Actual biomass produced in any given day is calculate as follows:

CARBO = PCARB * $AMIN_1$ (PRFT, $SWDF_1$, $NDEF_1$)

3.4.2.3 Assimilate Allocation:

STAGE 1: Leaves and roots constitute the growing organs

Leaf area growth rate (PLAG) is converted to mass growth rate (GROLF) using specific leaf weight (SLW). The remainder of the daily assimilate supply (CARBO) is allowed to the root growth (GRORT). If GRORT is less than 25 % of CARBO, then GROLF is reduced to 75 % of CARBO and the rest is allocated to roots.

STAGE 2: Leaves and roots constitute to be the major growing organs

In some cases the stem also starts to grow and is about 10 % of leaf growth. Root growth is never allowed to fall below 25 % of CARBO.

STAGE 3: Leaves, stems and roots are the major growing organs

Leaf growth is completed at this stage. Leaf weight is derived from PLAG using SLW. Stem growth increases linearly with DTT. Minimum value for GRORT is set at 30 % of CARBO. If GRORT value fall below the minimum value, growth of other organs is reduced to set GRORT at the minimum value. Finally STMWT, LFWT, and PLA values are updated.

STAGE 4: Stem, panicles, and roots are the major growing organs

Combined weight of panicle and stem (GROSTM) is a linear function of DTT and influenced by the minimum of two factors.

$$GROSTM = 0.07 * DTT * AMIN_1 (SWDF_2, TEMF)$$

GRORT is set to a minimum of 20 % of CARBO. Leaf senescence due to normal development becomes a major cause of reduction in leaf area. It is calculated as a nonlinear function of DTT.

STAGE 5: Panicles are the major growing organs

Panicle weight (PANWT) is an integral part of stem weight (STMWT) and is calculated as

$$PANWT = 0.3 * STMWT$$

The rate of biomass production during stage 5 is lower than that of in earlier stages. Post-anthesis decline in the efficiency of conversion is accounted for in the model by reducing the calculated value of CARBO.

Growth of whole panicle (GROPAN) is modeled in CERES-Sorghum rather than individuals grain as in CERES-Maize and Wheat.

In modeling panicle growth, a relative panicle filling rate (RGFILL) is calculated first as a function of temperature (Optimum 20 to 25°C). Its value ranges from zero to unity. Panicle size at the time of anthesis influences the rate of its growth during grain filling. Panicle growth constant (PGC) accounts for the influence of panicle size on its rate of growth.

As the panicles approach physiological maturity, their growth rate slows down and is accounted for a panicle aging factor (PAF). When there is a water deficit, $SWDF_2$ is used to reduce the GROPAN.

$$GROPAN = RGFILL * PGC * PAF * SWDF_2$$

If all the CARBO is not utilized to support GROPAN, which happens under adequate moisture, the remainder of CARBO is equally partitioned to grow stems and roots. Under severe water deficit, stored materials from the stem are known to support the panicle growth. In the model when CARBO is less than GROPAN, stored material from stems is translocated to the panicle to support its growth.

Besides normal senescence due to development, adverse conditions also promote leaf senescence. To account for this, three factors, caused by water deficit (SLFW), mutual shading (SLFC) and low temperature (SLFT) were computed.

Plant leaf area senescence (PLAS) is calculated by using leaf area senescence due to unfavourable conditions (SENLA) and minimum of above three factors:

$$PLAS = [PLA - SENLA) * (1.0 - AMIN_1 (SLFW, SLFC, SLFT)]$$

Total amount of leaf area senesced is updated.

SENLA = SENLA + PLAS

When physiological maturity occurs, grain weight (GRNWT) is calculated using a threshing percentage of 80 %.

GRNWT = PANWT * 0. 8

Single kernel weight (SKERWT) is calculated using grains per plant (GPP). The value of GPP is calculated in the beginning of stage 5 as a linear function of growth rate between PI and flowering.

3.5 THE CERES-SORGHUM MODEL INPUTS:

The CERES models are designed to run with minimum of soil and climate data. These data are summarized in the Table 3.5.

More data are needed to evaluate the accuracy of the various components of the model. These data are given in Table 3.6.

3.6 DATA ACQUISITION:

The data required for the validation can be divided into crop data (management, genetic and biometric), soil data and climatic data. Themethodology followed in collecting and recording the required data is described below.

3.6.1 Crop Data:

3.6.1.1 Phenology:

The growth of the sorghum were identified according to the method described by Vanderlip and Reeves (1972). The dates of planning, plant population, irrigation dates and amount, cultivar name and the dates of occurrence of various phenological stages were recorded. The description of various phenological stages is given in Table 3.6.

Table 3.5 Minimum data set needed to run the CERES-Sorghum model

Type of data	Data
Management	Cultivar name Planting date Plant population Irrigation dates and amounts
Climate	Longitude and Latitude Daily solar radiation Daily maximum minimum temperature Daily precipitation
Soil (by layers)	Initial soil water content Drained upper limit of soil Water availability and lower limit of plant extract soil water; or 0.33 and 15 bar water content Soil texture pH
Crop	
A. Genetic parameters	TT from seedling emergence to end of juvenile stage (P_1) Optimal photoperiod (P_2O) Photoperiod sensitivity coefficient (P_2R) TT from begining of grain filling to physiological maturity (P_5) Scalar for relative leaf size (G_1) Scalar for relative head size (G_2)
B. Other	Planting date (DOY) Sowing depth (cm) Plant population (plants m^{-2})

Table 3.6 Minimum data set needed to evaluate CERES model

Type of data	Data
CROP	Dates of emergence, anthesis and physiological maturity Leaf area index several times during the season Shoot weight several times during the year Yield components
SOIL	
A. For each layer	Layer depth (cm) Lower limit of plant extractable soil water (cm cm^{-1}) Drained upper limit of soil water availability (cm cm^{-1}) Saturation moisture content Initial moisture content
B. For the whole profile	Soil surface albedo First stage evapotranspiration (cm d^{-1}) Soil runoff curve number Whole profile drainage rate constant (inch d^{-1})
SOIL NITROGEN	
A. For each layer	Layer depth (cm) Initial extractable nitrate (NO_3) Initial extractable ammonium (NH_4) Bulky desnity (g cm^{-2}) pH
B. crop residue information	An estmate of the amount of crop residue present its depth of incorporation and its C:N ratio or state of decay
c. Fertilizer	Fertilizer application date, rate and depth of all applictions and the type of fertilizer.

3.6.1.2 Leaf area dry matter:

The plant were sampled from 1 m^2 area at the growth stages given in Table 3.7.

The leaf area was measured by using area meter (LI-1800 A). Leaf area index was calculated by dividing total leaf area by the area of the ground surface represented by the sample (1 m^2).

For the determination of dry matter the leaves, stem, and panicles were separated. Leaves and stems were chopped in fine pieces. From these representative samples of known weight were taken for drying. The samples were dried in hot air oven at 65°C until dry weight ceased to change. Then total dry weight per meter square was calculated.

Table 3.7 Growth stages of sorghum

Sr. No.	Crop growth stages	Description
1	Emergence	Coleoptile visible at soil surface
2	Panicle Initiation	Growing point differentiation, approximately 8^{th} leaf stage by previous criterion
3	Flag Leaf	Final leaf visible in whorl
4	Boot	Head extended into flag leaf
5	Anthesis	50 % flowering completed
6	Soft Dough	Grain green, milky exudes on pressing grains
7	Hard Dough	Grains hardened but still green coloured
8	Physiological Maturity	Maximum dry matter accumulation, appearance of black spot at the hylum region of grain

3.6.1.3 Genetic coefficients:

Determination of the genetic coefficients, viz., thermal time for juvenile period (P_1), optimal photoperiod (P_2O), photoperiod sensitivity coefficients (P_2R) was done in an experiment carried out at the Centre of Advanced Studies in Agricultural Meteorology, Pune. The sorghum genotypes can be ranked on a 1 to 15 scale for their relative leaf size (G_1). Rank 1 represented the narrow leaved genotype and 15 being broader leaved genotype. The scaler for relative head size (G_2) representing small and large head size.

3.6.2 Soil Data:

The soil profile was divided into eight different layer. The depths of the top two layers were 10 cm each and depths of the successive layers were 15 cm each.

The mechanical analysis of soil was carried out by the international pipette method (Piper, 1966). The initial extractable nitrate and ammonium were analysed by stem distillation method. The bulk density of the soil was determined by Core Sampler method. Drained upper limit of soil water availability (DUL) which is equivalent to field capacity or 0.33 bar soil water content was determined by gravimetric method (field method). The lower limit (LL) of plant extractable soil water which is equivalent to permanent wilting percentage or 15 bar soil water was determined by sunflower technique (Black, 1965). The pH of the soil was determined by 1 : 2.5 soil water ratio by pH meter (Piper, 1966). The organic carbon and organic matter were determined by Walkley and Black Rapid Titration Method (Piper, 1966).

The measurements on soil albedo, stage 1 evaporation constant (U) and drainage coefficient (SWCON) were not available. These parameters were approximated from soil classification information. The values of soil albedo range from 0.09 for soil to about 0.18 for light soils. The values of U range from about 5 mm for coarse textured and self mulching clay soils to 15 mm for clay loams. The values of SWCON can vary from 0.85 for very rapid 0.01 for very slow permeability.

The root weighing factor (WR) is needed to determine the root distribution for new growth each day. A value of WR between zero and unity is calculated for each depth by incrementing in equation that reduces WR exponentially with depth (Ritchie and Godwin, 1989).

3.6.3 Climatic Data:

The data on daily maximum temperature, minimum temperature, precipitation and solar radiation were collected from Agromet Observatory located at College of Agriculture Farm, Pune. Missing radiation data was estimated from sunshine hours by using the equation provided by Mani and Rangarajan (1982).

If long-term weather records are not available, a computer simulation model (WGEN) developed by Richardson and Wright (Godwin, 1989) to generate daily weather parameter, viz., maximum temperature, minimum temperature, precipitation and solar radiation can be used.

3.7 INSTRUMENTATION:

3.7.1 Leaf Area Measurements:

The LI-COR model LI-3000A Portable Area Meter (Plate 3.1) was used to measure the leaf area. The area meter utilizes an electronic method of rectangular approximation to measure the leaf area of plants. It consists of Scanning Head and the Readout Console. As the leaf is passed through the scanning head the area data is logged by Readout Console.

Plate 3.1 Leaf Area Meter

Plate 3.2 Neutron Probe

The function of the LI-3000A Portable Area Meter is to use electronic method to simulate grid pattern on the leaf. The scanning head uses a row of 128 narrow band red light emitting diodes (LED_s), spaced 1 mm apart to examine 128 grid size across the width of the leaf. The LED_s are sequentially pulsed to examine a particular grid cell in the row. The LED_s are located along a line 0.62 cm from the edge of the upper section of the scanning head. The base of the scanning head contains a lens-photodiode system which responds only to the collimated, pulsed LED light. The narrow band red LED_s and associated digital circuitry provide measurements which are unaffected by leaf transmission properties. The scanning head is calibrated to the readout console, at the factory using LI-3000A's built in autocalibration routine. Transparent belt conveyor accessory can be used to measure small objects and detached leaves.

3.7.2 Soil Moisture Measurements:

Neutron soil moisture probe (make type DIDCOT - Plate 3.2) was used to measure the soil moisture. It consists of a memory rate scaler and a probe. The probe is lowered in the access tubes spaced in the field and the mean count rate (counts per second, CPS) is recorded electronically by ratescaler. The volumetric water content of the soil was calculated by using the following equation:

$$\theta = m \frac{R}{R_w} + C$$

where,

θ = Volumetric soil water content expressed as a fraction ($cm^3\ cm^{-3}$);

R = Count rate in soil (CPS);

R_w = Count rate in water (Standard);

m = Slope of calibration curve; and

c = Intercept.

Either before or after the use of probe, a "Standard count", R_w is taken in water. The standard count rate is used to normalize the field counts.

3.8 PROCEDURE FOR RUNNING THE MODEL:

CERES-Sorghum V1.99 is a process-oriented management level model of sorghum (*Sorghum bicolor* L. Moench) crop growth and development. CERES-Sorghum model is a member of a family of models that use a minimum data set as specified by IBSNAT (1988) and the input and output structures described in Technical Report No. 5 (IBSNAT, 1986a).

The CERES-Sorghum package consists of three main componets.

Simulation Model

Program and data diskettes provide the following options:

1. Single year simulation (Single or multitreatment)
2. Multiple year simulation
3. Sensitivity analysis
4. Display of detailed outputs on the screen

Graphics Program

The graphics diskette allows the following model outputs to be plotted on the screen and thus facilitates interpretation of these outputs.

1. Crop variables
2. Harvest variables
3. Soil and plant nitrogen variables
4. Weather and soil variables

Input Program

The Input Editor may be used to create input files for the model. CERES-Sorghum can be run in either a stand alone mode or as a component of IBSNAT's Decision Support System for Agrotechnology Transfer (DSSAT).

An example of model run is presented in appendix .

3.8.1 System Requirements:

CERES-Sorghum V1.99 was developed using an IBM AT microcomputer, DOS 3.2, Microsoft FORTRAN V4.01, and Microsoft Quick BASIC V4.0. Both the FORTRAN and BASIC section of the CERES-Sorghum model require DOS V2.00 or higher. The graphics display component requires a personal computer (PC) with either a Color Graphic Adapter (CGA) or a Enhanced Graphics Adapter (EGA) and colour or monochrome graphics monitor. The graphics section of the model will not operate with a Hercules graphics card. The model will operate effectively on PCs that do not have graphics adapters if graphics display option is not required.

The model runs fastest on AT-equivalent machines. The model also runs on an IBM or IBM-compatible personal computer that uses dual floppy disk drive and has a minimum memory capacity of 256 K.

We have successfully run CERES-Sorghum on IBM PC/XT computer that meets the minimum requirements described above.

3.8.2 Creation of Input Files:

There are three ways that input data files can be created for running CERES-Sorghum V2.00. The recommended procedure is to create the files directly from IBSNAT minimum data set after the experiment data have been entered. The files can also be created by using a text editor on the PC or interactively by using the INPUT program. The IBSNAT Data Base Management

System (DBMS) is a powerful system that provides the user with other applications in addition to the creation of the files for thesè crop models. IBSNAT's DBMS program also provides the capacity for recording all experimental details (by plot), some statistical analysis, and plotting the experimental results (Alagarswamy et al. 1989). Inputs files were created by using DSSAT V 2.1 programme.

3.9 VALIDATION:

There are several statistical measures available to evaluate the association between predicted and observed values. Among them are the correlation coefficient (r) and its square, the coefficient of determination (r^2). Willmott (1982) has pointed out that the main problem with his analysis is that the magnitudes of r and r^2 are not consistently related to the accuracy of prediction where accuracy is defined as the degree to which model predictions approach the magnitude of their observed counterparts.

Test criteria have been separated into two groups, called summary measures and difference measures. Summary measures include the mean of observed values ($\bar{O}$) and predicted values ($\bar{P}$), the standard deviations of observations (S_0) and the predictions S_p), the slope (b) and intercepted (a) of the least square regression ($P_i = a + b * O_i$).

In addition, an index of agreement (D) (Willmott, 1982) was calculated as follows:

$$D = [1 - \sum_{i=1}^{n} (p_i - O_i)^2 / \sum_{i=1}^{n} (IP_iI + IO_iI)^2]$$

Where,

$$P_i' = P_i - \bar{P} \text{ and } O_i' = O_i - \bar{O}$$

The value of D is mainly used to determine the relative superiority of alternative models. The value of D can be used as a descriptive parameter of model performance. More the D approaches 1, more accurate the model.

The summary measures describe the quality of simulation while the difference measures try to locate and quantify errors. The later includes the mean absolute error (MAE), the mean bias error (MBE) and the root mean square error (RMSE). They are calculated according to Willmott (1982) as follows and based on the terms $(P_i - O_i)$:

$$MAE = \sum_{i=1}^{n} (IP_iI - IO_iI) / n$$

$$MBE = \sum_{i=1}^{n} (P_i - O_i) / n$$

$$RMSE = [\sum_{i=1}^{n} (P_i - O_i)^2 / n]^{\frac{1}{2}}$$

MAE and RMSE indicate the magnitude of the average error, but provide no information on the relative size of the average difference between (P) and (O). MBE describes the direction of the error bias. The value of MBE is related to the magnitude of the values under investigation. A negative MBE occurs when predictions are smaller than observations.

The parameters examined in the statistical evaluation were panicle initiation date, anthesis date, physiological maturity date, leaf are index (LAI) total above ground dry matter, straw yield, weight at number of grains per m^2 number of grains per plant and kernel weight.

Chapter Opener Page

4. RESULTS AND DISCUSSION

4. RESULTS AND DISCUSSION

In order to test the validity of the CERES-Sorghum model, data on sorghum was taken from the present experiment carried out during the post rainy season of 1989-90. The results of the simulation study on growth and development of sorghum carried out at the Centre of Advanced Studies in Agricultural Meteorology, College of Agriculture, Pune have been presented in this chapter.

4.1 WEATHER DURING EXPERIMENTAL PERIOD:

During the experimental period (Sept. 1989 - March 1990) the total rainfall received was 162.9 mm. This was 24.6 % of the annual average rainfall. Of the total rainfall received during the experimental period, 141.4 mm was received during the second fortnight of September and remaining 21.5 mm was received during early October. The rainfall received during September was more than the annual average rainfall of that month (123.3 mm) and the rainfall received during October was very much less than the annual average rainfall of that month (91.9 mm). Thereafter no rain was received. The total number of rainy days were 13 only.

The average maximum temperature was 31.3°C varying between 26.2°C and 35.3°C. The average minimum temperature was 13.8°C varying between 6.2°C and 22.7°C. The average maximum temperature was less than the optimum temperature of sorghum (34°C) and the average minimum temperature was more than the base temperature of sorghum (8°C) (Alagarswamy, 1989). The average maximum temperature was slightly less than annual average, however, average minimum was less than annual average by 4.4°C.

The average relative humidity at 7.30 h (RH-I) was 86.69 % and at 14.30 h (RH-I) was 36.97 %. The Value of average RH-I was higher than the value of annual average (71.0 %) and that of RH-I was lower than the annual average (46.0 %)

The average solar radiation received was 18.72 MJ $m^{-2}d^{-1}$ and was lower than the annual average 20.5 MJ $m^{-2}d^{-1}$. The average pan evaporation was 4.9 mm d^{-1}. The weekly average meteorological data for the period from April 1989 to March 1990 is given in Table 4.1 and is graphically shown in the Fig. 4.1.

Table 4.1 Weekly average weather data of the period from April 1989 to March 1990

Week No.	Temperature Tmax (°C)	Tmin. (°C)	Solar radiation ($MJm^{-2}d^{-1}$)	Bright sunshine hours	Rel.humidity I (%)	II (%)	Rainfall (mm)	Evaporation (mm)
14	37.5	15.2	23.88	10.8	54	12	007.5	09.5
15	38.5	18.2	19.77	11.2	55	12	0.0	10.5
16	39.2	20.2	20.67	10.2	59	19	24.7	9.2
17	37.5	20.0	20.62	10.5	53	22	0.0	9.9
18	37.2	21.4	23.19	10.5	64	27	0.2	9.9
19	39.5	20.2	27.04	10.5	53	17	0.0	10.0
20	37.2	23.6	26.38	10.5	59	32	0.0	10.7
21	35.7	22.7	27.34	11.8	68	37	0.0	10.3
22	34.9	21.9	21.46	7.0	80	47	72.5	8.7
23	32.2	21.9	19.81	6.2	86	65	46.5	6.7
24	29.4	22.2	16.90	3.3	86	72	41.3	5.6
25	29.9	21.7	21.17	5.8	83	65	6.2	5.5
26	29.2	22.1	15.57	3.5	67	79	20.3	4.5
27	29.7	22.0	20.38	5.6	86	66	1.6	4.3
28	31.1	22.1	20.03	6.2	85	67	0.1	5.0
29	29.6	22.1	17.97	3.8	89	76	25.6	3.5
30	27.9	22.4	13.15	1.9	90	81	158.3	2.9
31	28.5	21.4	17.99	4.4	84	77	5.5	4.1
32	28.2	21.4	20.41	4.8	86	79	8.4	3.3
33	27.1	20.7	14.23	2 5	90	81	16.1	2.6

(Continued.....)

Table 4.1 (Continued.....)

Week No.	Temperature Tmax (°C)	Tmin. (°C)	Solar radiation ($MJm^{-2}d^{-1}$)	Bright sunshine hours	Rel. humidity I (%)	II (%)	Rainfall (mm)	Evapo-ration (mm)
34	26.9	21.0	13.04	1.3	93	88	41.1	4.1
35	27.9	19.9	18.12	3.7	88	71	4.7	4.1
36	29.0	19.2	17.41	6.5	90	64	12.4	4.5
37	29.6	20.6	21.21	7.2	83	59	1.0	4.5
38	31.1	21.1	16.31	4.3	92	73	36.4	3.0
39	30.5	20.3	15.51	3.7	95	85	105.0	3.3
40	30.9	19.8	19.12	5.4	93	56	21.5	4.7
41	34.0	18.3	21.93	9.2	91	30	0.0	4.2
42	33.8	15.3	22.20	10.1	88	32	0.0	4.8
43	33.1	15.8	21.28	10.2	87	29	0.0	4.6
44	32.8	14.4	20.74	10.1	85	32	0.0	4.5
45	31.6	14.1	18.23	8.8	75	34	0.0	4.3
46	31.6	17.2	19.07	9.7	84	43	0.0	3.7
47	31.5	13.0	19.13	10.0	88	33	0.0	3.9
48	30.8	11.9	18.33	9.8	80	38	0.0	4.2
49	29.4	10.3	18.20	9.6	88	35	0.0	4.5
50	28.2	9.6	10.18	9.6	91	39	0.0	4.2
51	28.2	10.3	17.49	9.4	87	38	0.0	3.9
52	28.4	14.0	15.49	6.1	86	42	0.0	3.2
1	30.8	13.5	17.06	9.2	89	39	0.0	3.4
2	30.1	10.1	18.55	9.8	87	27	0.0	4.4
3	31.9	8.3	19.81	10.0	86	22	0.0	4.1
4	31.7	9.1	19.90	10.0	84	24	0.0	4.7
5	33.7	10.1	19.05	9.8	83	21	0.0	4.7
6	33.1	12.1	19.51	9.8	78	29	0.0	4.9
7	32.6	12.9	19.77	9.9	85	27	0.0	5.3
8	30.1	8.5	20.28	10.4	85	19	0.0	6.0
9	31.9	12.1	22.22	10.1	79	29	0.0	6.8
10	31.7	13.1	23.18	10.1	74	27	0.0	7.8
11	35.4	15.7	23.50	10.2	81	27	0.0	7.7
12	35.6	16.4	22.47	9.6	87	23	0 0	9 6
13	34.8	15.6	25.16	10.3	69	20	0.0	8.5

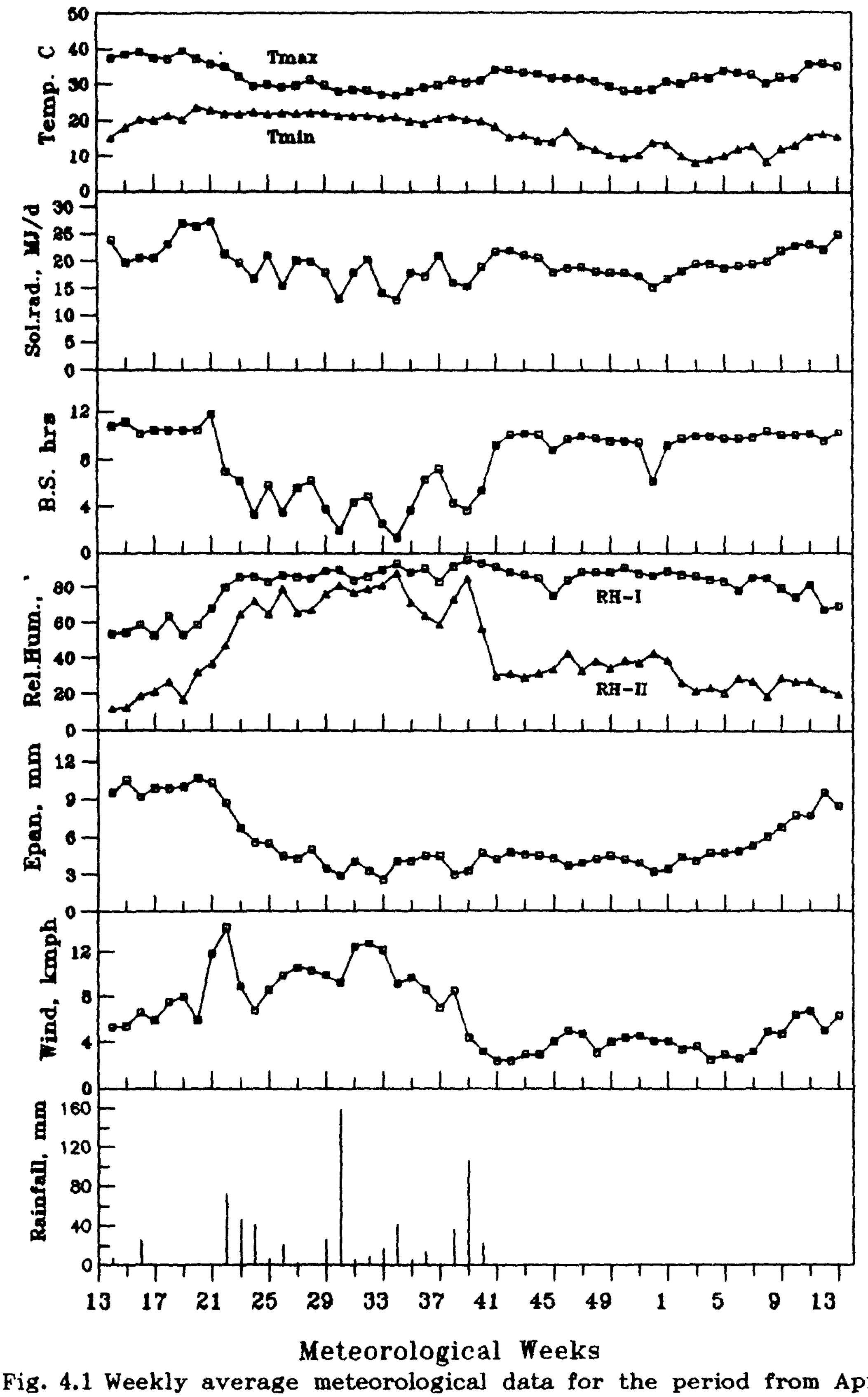

Fig. 4.1 Weekly average meteorological data for the period from April 1989 to March 1990

4.2 SOIL CHARACTERISTICS PARAMETERS:

The soil of the experimental field was medium black calcarious. The clay, silt, fine sand and coarse sand content of the soil was 42.65, 29.72, 18.70 and 4.93 per cent, respectively. The pH (1:2.5) of the soil was 8.4 indicating alkaline nature of the soil. The organic carbon and the organic matter content was 0.48 and 0.84, respectively. The bulk density of the soil was 1.05 g cm^{-3}.

The initial soil moisture content of the experimental plot was 23.9, 31.7, 30.9 and 27.6 per cent at the time of first, second, third and fourth sowing dates, respectively. The soil characteristics parameters for the study area are given in the Table 4.2.

Table 4.2 Estimated soil characteristics parameters for the study area

Soil characteristics	Parameter estimated
1. Soil albedo	0.17
2. Coefficient for the upper limit of stage 1 evaporation (U)	6.00 mm
3. Whole profile drainage rate constant (SWCON)	0.15
4. Runoff curve number	85.00
5. Lower limit of plant extractable soil moisture (LL)	17.90 %
6. Drained upper limit of soil water availability (DUL)	39.60 %
7. Saturation soil water content (SATSW)	43.30 %
8. Soil layer thickness	100.00 cm

The layerwise data on lower limit of extractable soil water (LL) drained upper limit of soil water availability (DUL), saturation water content, root weighing factor (WR), extractable nitrate (NO_3) and ammonium (NH_4) of soil are given in the Table 4.3.

Table 4.3 Layerwise soil characteristics parameters

Depth (cm)	LL (cm^3 cm^{-3})	DUL (cm^3 cm^{-3})	SATSW (cm^3 cm^{-3})	WR (μg g^{-1})	NO_3 (μg g^{-1})	NH_4 (μg g^{-1})
0-5	0.148	0.371	0.429	1.000	10.2	5.6
5-10	0.149	0.385	0.420	0.897	10.9	5.5
10-25	0.151	0.391	0.433	0.789	9.6	4.5
25-40	0.155	0.398	0.434	0.598	5.4	2.2
40-55	0.162	0.392	0.432	0.387	5.0	1.7
55-70	0.185	0.399	0.434	0.212	5.4	2.7
70-85	0.220	0.399	0.434	0.212	5.6	2.5
85-100	0.220	0.409	0.434	0.212	5.6	2.5
Total 100	17.90	39.6	43.3	-	*70	*32

* Note: Units are in kg ha^{-1}.

4.3 GENETIC COEFFICIENTS:

The length of the growing season is determined by type of genotype and the climatically influenced factors. For the correct simulation of the crop phenology and growth the genetic coefficient are incorporated in the CERES-Sorghum model.

The juvenile phase varies with genotype. The genotype specific coefficient P_1 (TT from seedling emergence to end of juvenile stage) determines the duration of juvenile phase. The optimal photoperiod and the photoperiod sensitivity of the crop depends on the genotype. Therefore, optimal photoperiod P_2O and photoperiod sensitivity coefficient P_2R (Increase in thermal time for panicle initiation per hour increase in photoperiod above the optimal photoperiod) are incorporated in the model. The physiological maturity of the crop is determined by the genotype specific coefficient P_5. For most of the sorghum varieties P_5 is found to be 550 TT. The genotype specific coefficient G_1 (scaler for relative leaf size) and G_2 (scaler for relative head size are used for the determination of leaf area and panicle weight, respectively. The genetic coefficients of two sorghum cultivars (M-35-1 and SPV-504) are given in Table 4.4.

Table 4.4 Genetic coefficients of two varieties of sorghum

Genetic specific coefficient	Cultivar	
	M-35-1	SPV-504
1. TT from seedling emergence to end of juvenile stage (P_1)	360.0	343.0
2. Optimal photoperiod (P_2O)	14.0	13.0
3. Photoperiod sensitivity coefficient (P_2R)	44.0	26.0
4. TT from beginning of grain filling to physiological maturity	550.0	565.0
5. Scaler for relative leaf size (G_1)	15.0	15.0
6. Scaler for relative head size (G_2)	4.5	4.5

4.4 MODEL EVALUATION:

The observed data was compared with the model simulation results. The components of the model were not directly developed from this study. However, the model evaluation is a long term process in which the confidence in the model is enhanced or reduced through a succession of formal and informal test (Dent and Blackie, 1979).

The input errors are much more likely and are serious source of poor model predictions than are the calibration errors. The common input errors include, LL, DUL and inaccurate estimates of WR and rooting depth due to actual or imagined root restricting layers (Kiniry and Jones, 1986).

Initial simulation results showed that the potential extractable soil water (PESW) after anthesis was zero or even negative for all the four sowing dates and for both genotypes. However, in field condition the crop showed no signs of soil water stress. The observed and predicted soil water content averaged over both the genotypes at different sowing dates is shown in Table 4.5.

Table 4.5 Predicted and observed soil moisture (cm m^{-1})

	Soil moisture (cm m^{-1})					
Sowing dates	Anthesis		Grain filling		Physiological maturity	
	P	O	P	O	P	O
S_1	16.4	28.1	16.4	25.0	16.4	22.2
S_2	17.4	26.8	17.4	22.8	17.4	20.3
S_3	17.4	23.0	17.4	20.8	17.4	18.8
S_4	16.4	21.0	16.4	19.0	16.4	18.0

Note: P = Predicted; O = Observed.

From the above Table, it is revealed that the simulation of water balance is inaccurate. Ultimately, inaccurate simulation of water balance resulted in poor predictions of growth and development as compared to observed data which are explained below.

4.4.1 Phasic Development:

The accuracy of simulating the phasic development of a crop is crucial for accurate simulation of crop growth and yield. Thus evaluation of the phasic development must be the first step.

4.4.1.1 Panicle initiation:

Duration of the PI depends upon day length above P_2O and P_2R. Thus the accuracy of the model to predict date of PI depends upon its ability to predict day length (HRLT) correctly.

The mean difference between predicted and observed dates of PI (Table 4.6) was -1 ±1.28d. The intercept (a) and the slope (b) were significantly different than zero and unity, respectively. The Fig. 4.2 showed that 50% of the points were within the limit of ±1 standard deviation. The degree of agreement (D) was 0.30. The MAE, MBE and RMSE were 1.50, -1.25 and 1.73, respectively. Negative MBE indicates that the predictions were smaller than observations.

4.4.1.2 Anthesis:

Date of anthesis depends upon the number of days for PI. Thus the accuracy with which the model predicts the date of anthesis based upon its accuracy to predict the date of PI.

Table 4.6 CERES-Sorghum model validation results:predicted and observed number of days for PI

Treatment No.	Predicted (d)	Observed (d)	Difference (d)
1	31	32	-1
2	30	33	-3
3	33	33	0
4	33	35	-2
5	33	34	-1
6	32	34	-2
7	34	33	1
8	33	35	-2
Mean	32 ± 1.3	33 ± 1.06	- 1 ± 1.28

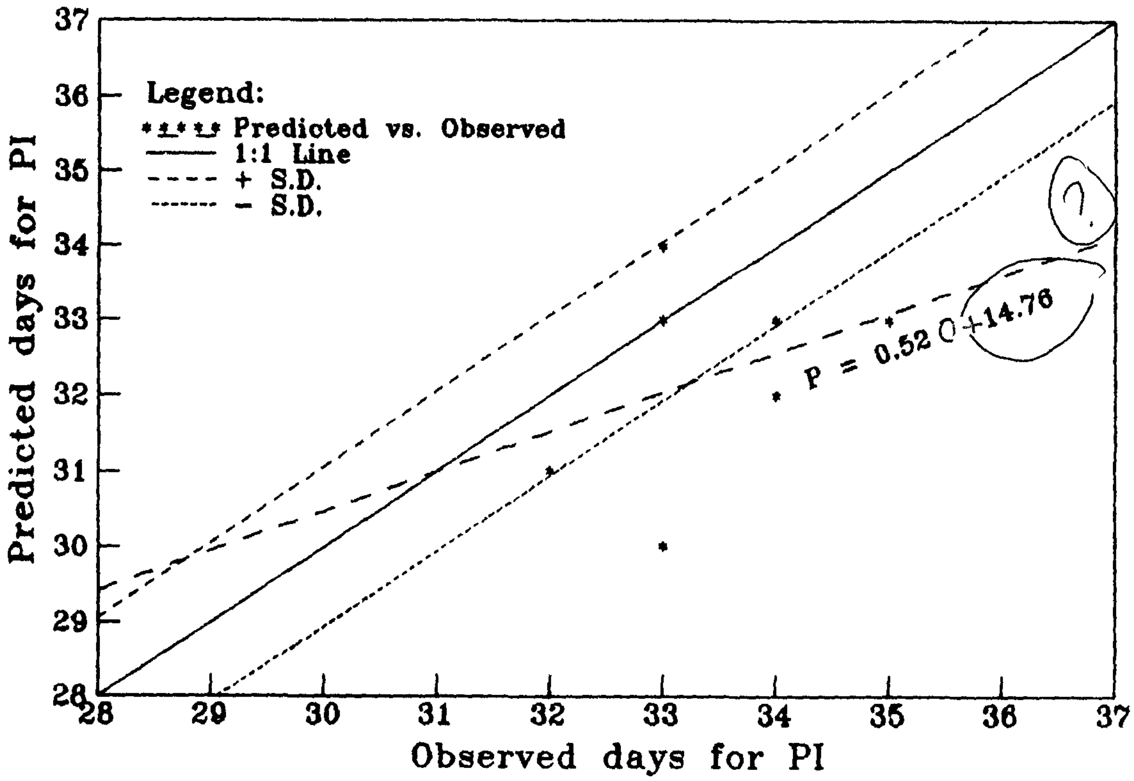

Fig. 4.2 Relationship between predicted and observed number of days for PI

The mean difference between predicted and observed dates of anthesis (Table 4.7) was 14 ± 4.0 d. The intercept (a) and the slope(b)were significantly different from zero and unity, respectively. The Fig. 4.3 shows that all the points are out of the ±1 standard deviation band. The degree of agreement was -1.40. The MAE, MBE, and RMSE wore 14.38, 14.38, 14.85. the positive MBE indicated that date of anthesis was over predicted.

4.4.1.3 Physiological maturity:

Date of physiological maturity is determined by P_5. Physiological maturity also depends upon the soil moisture availability (stress).

The mean difference between predicted and observed number of days for physiological maturity (Table 4.8) was 13 ± 2.72 d. The Fig. 4.4 revealed that all the points were away from 1:1 line and were out of the ±1 standard deviation band. The intercept (a) and the slope (b) of the relationship between predicted and observed dates of physiological maturity were significantly different from zero and unity, respectively. The MAE, MBE and RMSE were 13.38, -13.38 and 13.62, respectively. The negative MBE indicates that date of physiological maturity were under predicted. The degree of agreement was -2.74.

4.4.2 Growth:

4.4.2.1 Leaf area index (LAI):

The mean difference between the predicted and observed LAI (max) (Table 4.9) was 0.02 ± 0.39. The Fig. 4.5 showed that predicted and observed LAI (max) was close to each other. Most of the points were close to 1:1 line and were within the limit of ±1 standard deviation. The intercept (a) and the slope (b) of

Table 4.7 CERES-Sorghum model validation results:predicted and observed number of days for anthesis

Treatment No.	Predicted (d)	Observed (d)	Difference (d)
1	89	69	20
2	87	70	17
3	94	78	16
4	94	78	16
5	95	80	15
6	94	81	13
7	97	86	11
8	96	89	7
Mean	93 ± 3.45	79 ± 6.94	14 ± 4.00

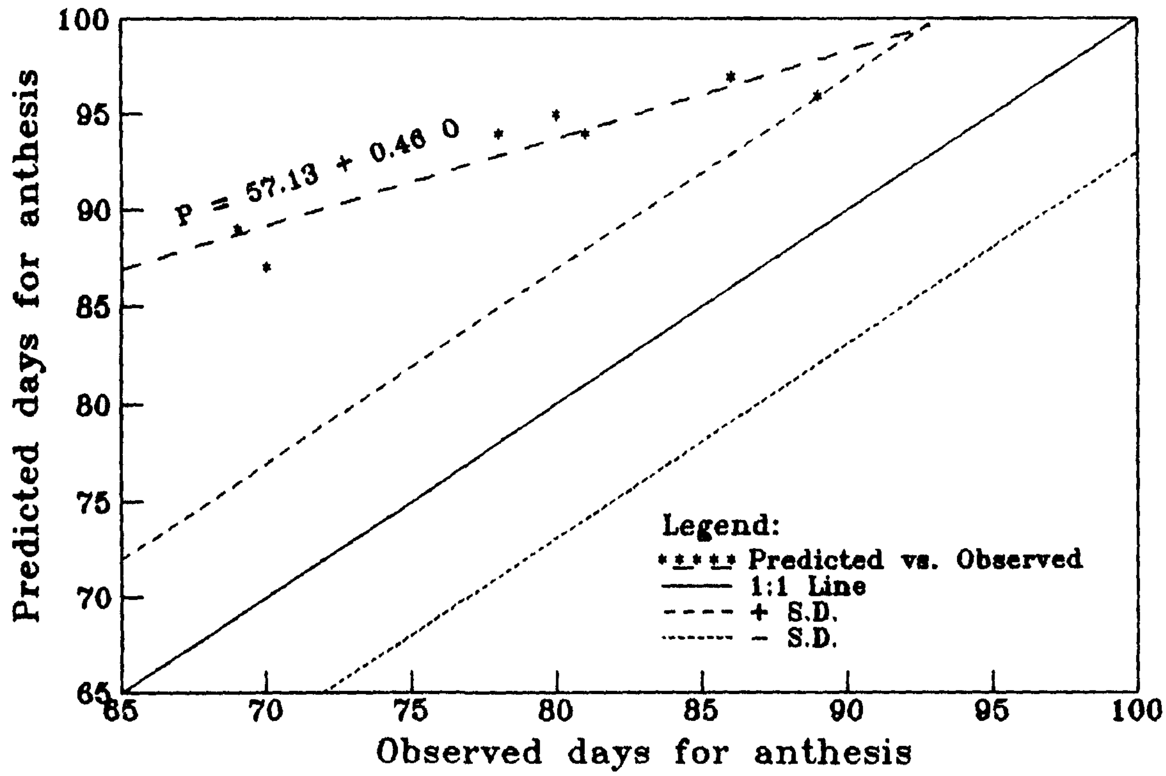

Fig. 4.3 Relationship between predicted and observed number of days for anthesis

Table 4.8 CERES-Sorghum model validation results:predicted and observed number of days for physiological maturity

Treatment No.	Predicted (d)	Observed (d)	Difference (d)
1	107	118	-11
2	106	119	-13
3	113	124	-11
4	113	124	-11
5	113	126	-13
6	112	126	-14
7	114	129	-15
8	113	132	-19
Mean	111 ± 3.07	124 ± 4.68	-13 ± 2.70

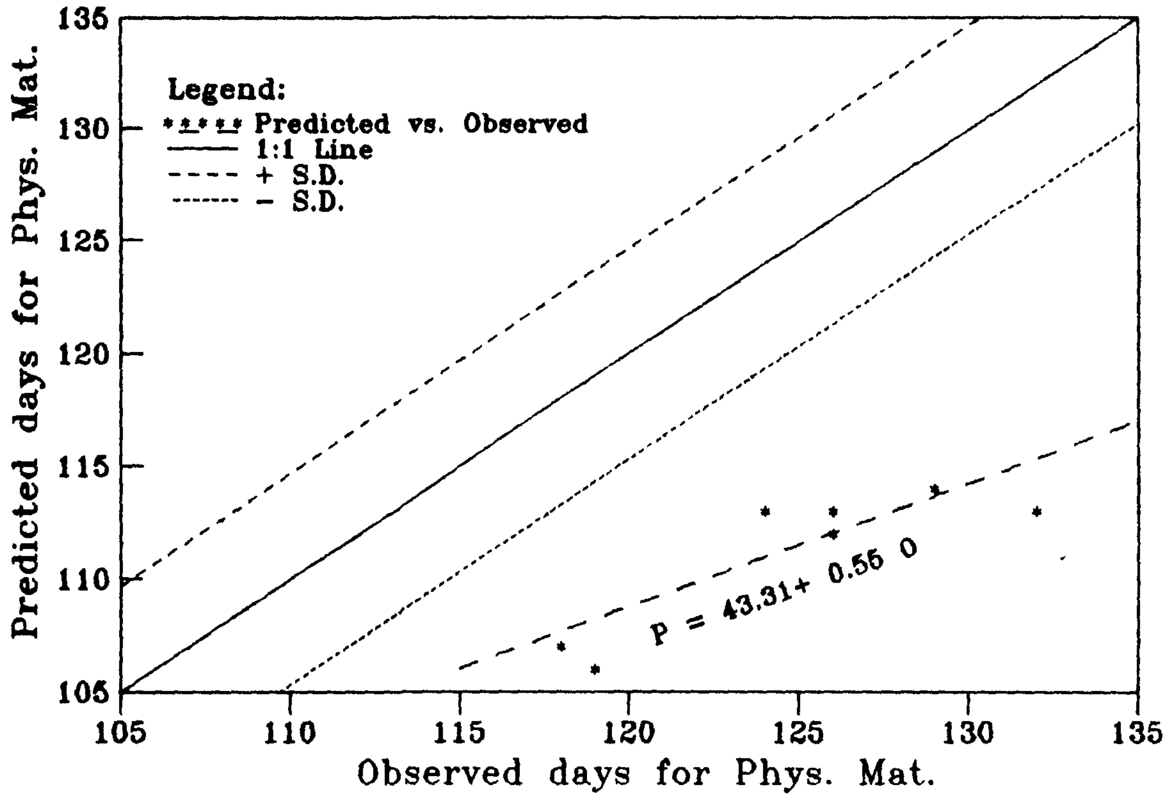

Fig. 4.4 Relationship between predicted and observed number of days for physiological maturity

Table 4.9 CERES-Sorghum model validation results:predicted and observed LAI

Treatment No.	Predicted	Observed	Difference
1	3.55	3.82±0.26	-0.27
2	3.35	3.73±0.38	-0.38
3	3.56	3.36±0.28	0.20
4	3.19	3.82±0.09	-0.63
5	3.27	3.06±0.24	0.21
6	3.23	2.92±0.25	0.31
7	3.24	2.88±0.32	0.36
8	3.20	2.84±0.23	0.36
Mean	3.32 ± 0.15	3.30 ± 0.43	0.02 ± 0.39

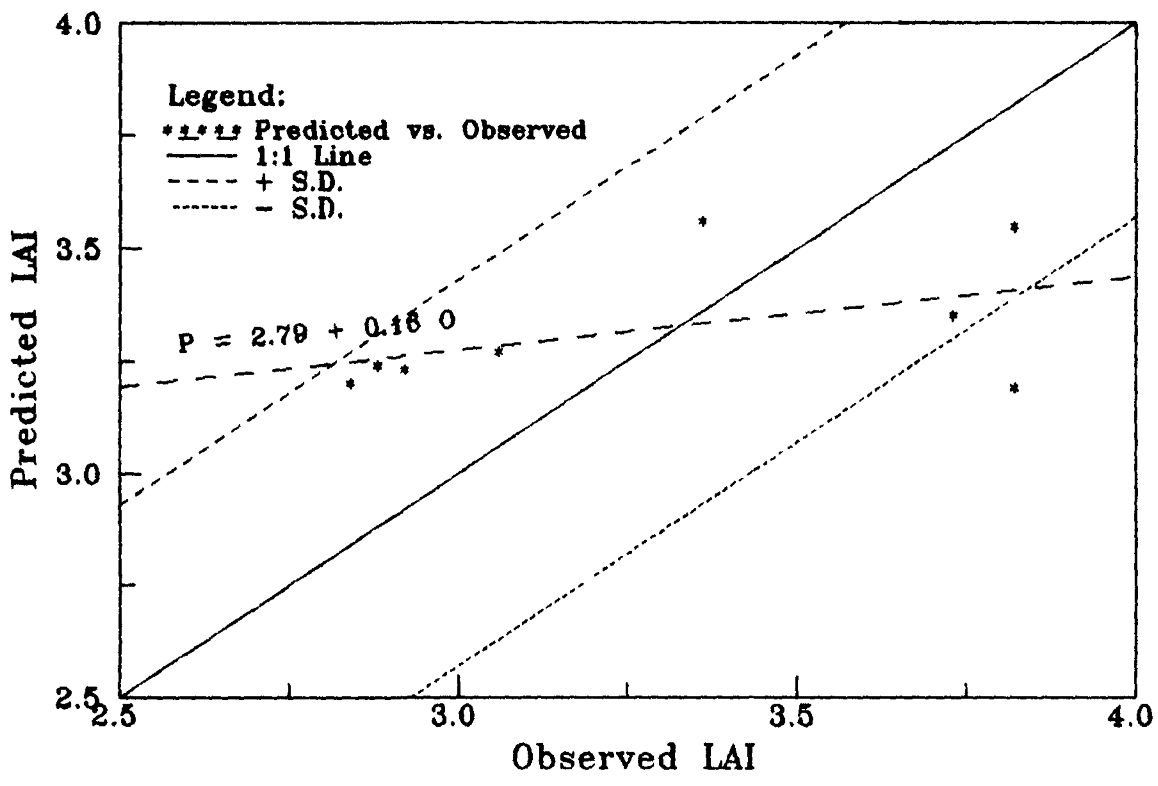

Fig. 4.5 Relationship between predicted and observed LAI

the relationship between predicted and observed LAI (max) were significantly different from zero and unit, respectively. The degree of agreement was 0.52. The MAE, MBE and RMSE were 0.34, 0.02 and 0.36, respectively.

4.4.2.2 Dry matter:

The mean difference between predicted and observed dry matter (Table 4.10) was -4187 ± 485.78 kg ha^{-1}. The Fig. 4.6 showed that all the points were away from 1:1 line and were out of the limit of ±1 standard deviation. The intercept (a) and slope (b) of the relationship between predicted and observed dry matter were significantly different from zero and unity, respectively. The degree of agreement was -12.71. The MAE, MBE and RMSE were 4178.75, -4187.75 and 4270.76, respectively. The predictions of dry matter were much smaller than observations.

4.4.3 Yield:

4.4.3.1 Grain yield:

The mean difference between predicted and observed grain yield (Table 4.11) was -3196.88 ± 578.37 kg ha^{-1}. The Fig. 4.7 showed that the point were away from 1:1 line and were out of the limit of ±1 standard deviation. The intercept (a) and slope (b) were significantly different from zero and unity, respectively. The degree of agreement was -1.79. The MAE, MBE, RMSE were 3196.88, -3196.88 and 1026.01, respectively.

4.4.3.2 Straw yield:

The mean difference between predicted and observed straw yield (Table 4.12) was -1055.5 ± 600.92 kg ha^{-1}. The Fig. 4.8 showed that the points are away from 1:1 line and only three points were within the limit of ±1 standard deviation.

Table 4.10 CERES-Sorghum model validation results:predicted and observed dry matter

Treatment No.	Predicted (kg ha^{-1})	Observed (kg ha^{-1})	Difference (kg ha^{-1})
1	4254	9702±492.30	-5448
2	4110	9387±572.00	-5277
3	4622	8640±506.22	-4018
4	4126	8559±507.02	-4433
5	3921	8406±563.49	-4489
6	4131	7598±529.26	-3467
7	3811	6739±569.98	-2928
8	3750	7192±570.83	-3442
Mean	4090 ± 276.53	8278 ± 1034.78	-4187 ± 485.78

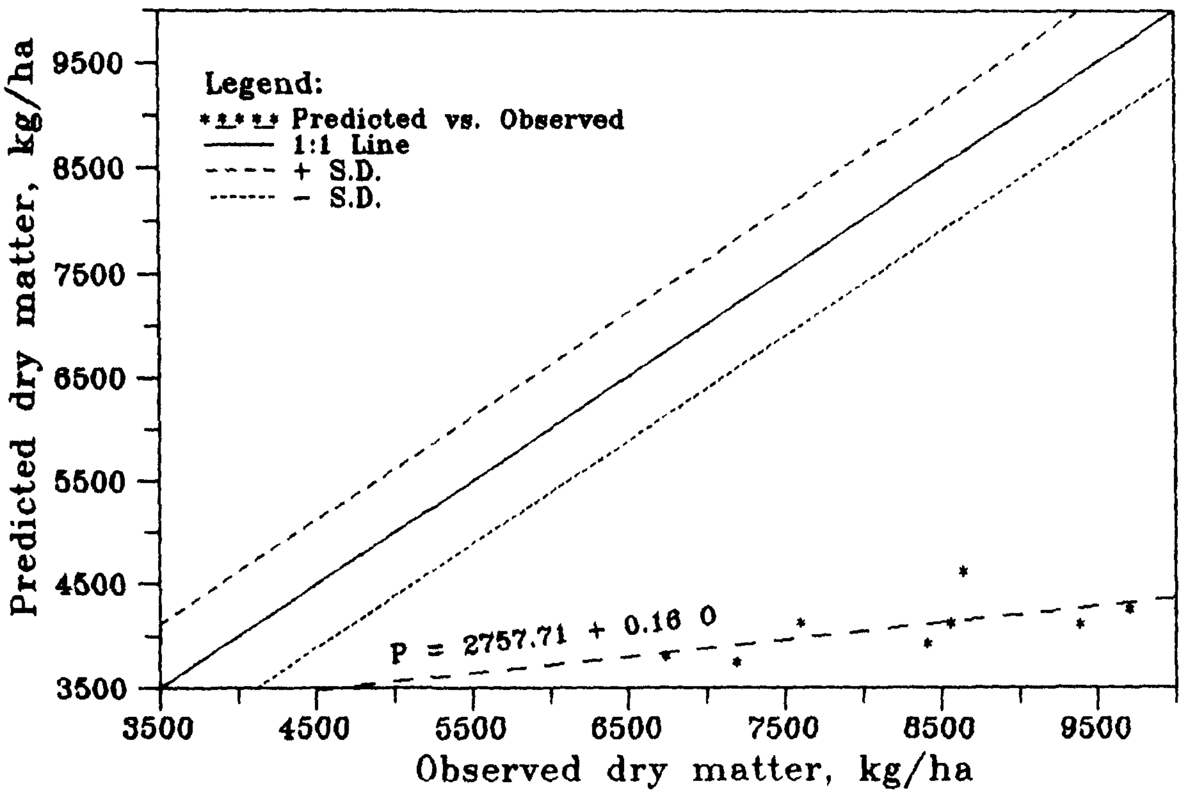

Fig. 4.6 Relationship between predicted and observed dry matter

Table 4.11 CERES-Sorghum model validation results:predicted and observed grain yield

Treatment No.	Predicted (kg ha^{-1})	Observed (kg ha^{-1})	Difference (kg ha^{-1})
1	408	3884±421.48	-3476
2	404	4238±350.43	-3834
3	491	4304±235.94	-3813
4	437	3952±313.58	-3515
5	375	3622±267.16	-3247
6	429	3306±413.30	-2877
7	354	2867±312.08	-2513
8	344	2644±263.69	-2300
Mean	405 ± 48.15	3602 ± 614.74	-3197 ± 578.37

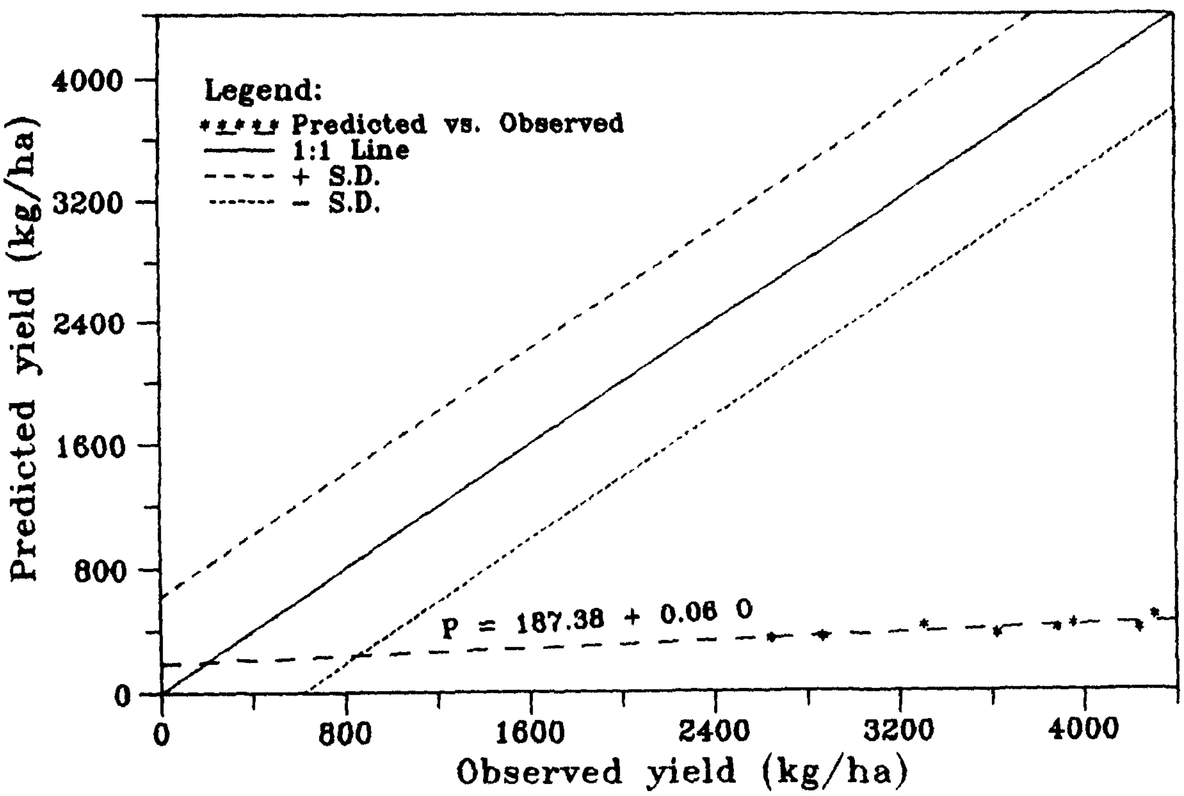

Fig. 4.7 Relationship between predicted and observed grain yield

Table 4.12 CERES-Sorghum model validation results:predicted and observed straw yield

Treatment No.	Predicted (kg ha^{-1})	Observed (kg ha^{-1})	Difference (kg ha^{-1})
1	3845	5818±175.98	-1973
2	3707	5149±184.42	-1442
3	4131	4336±222.61	-205
4	3689	5142±218.86	-1435
5	3546	4788±258.52	-1242
6	3702	4292±191.46	-590
7	3457	3872±199.59	-415
8	3406	4548±244.32	-1142
Mean	3685 ± 231.29	4740 ± 612.59	-1055 ± 600.92

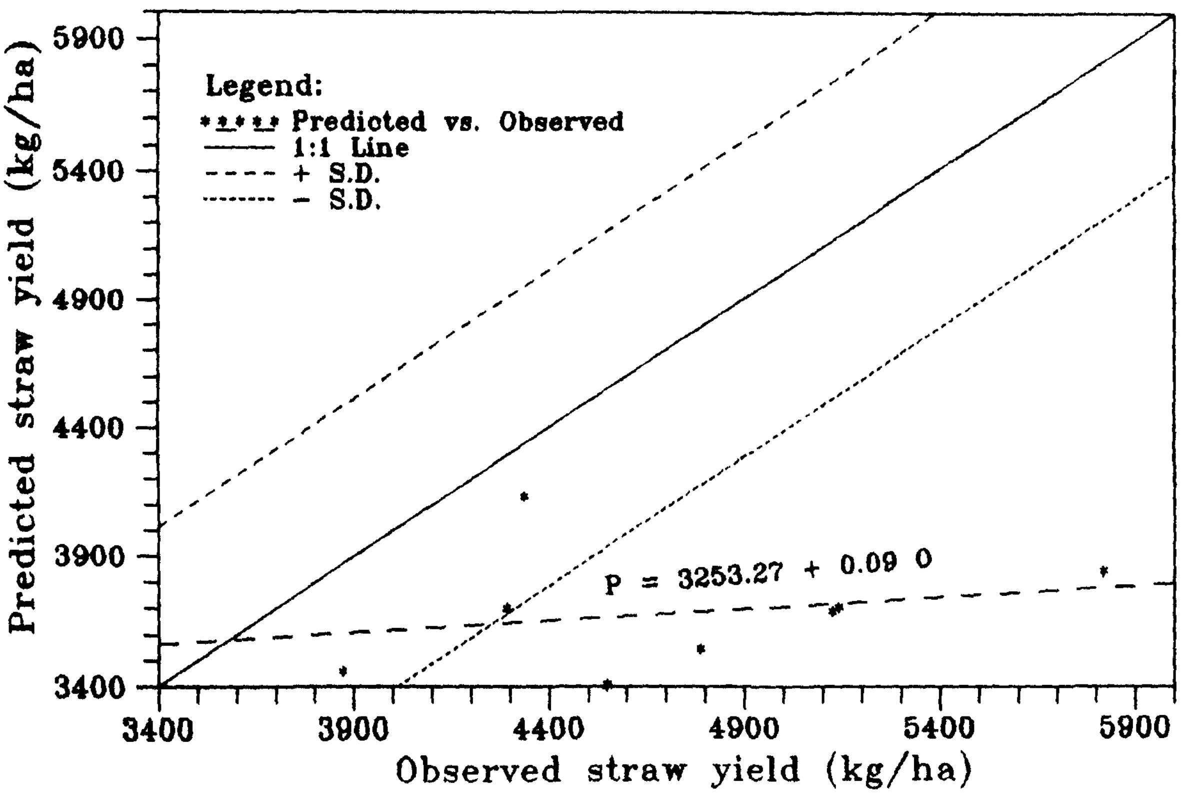

Fig. 4.8 Relationship between predicted and observed straw yield

The degree of agreement was -1.68. The MAE, MBE and RMSE were 1055.5, -1055.5 and 1195.85, respectively. The intercept (a) and slope (b) of the relationship between predicted and observed straw yield were non significantly different from zero and unity, respectively.

4.4.4 Yield Components:

4.4.4.1 Grains per square meter:

The mean difference between predicted and observed GPSM (Table 4.13) was -2836 ± 1037.36. The Fig. 4.9 showed that the points were away from 1:1 line and were out of the limit of ±1 standard deviation. The intercept (a) and slope (b) of the relationship between predicted and observed GPSM were significantly different from zero and unity, respectively. The degree of agreement was -0.78.

The MAE, MBE and RMSE were 2836, -2836 and 2999.42, respectively.

4.4.4.2 Grains per plant:

The mean difference between predicted and observed GPP (Table 4.14) was -236 ± 74.13. The Fig. 4.10 showed thatthe points were away from 1:1 line and were out of the limit of ±1 standard deviation. The intercept (a) and the slope (b) of the relationship between predicted and observed GPP were significantly different from zero and unity, respectively. The degree of agreement was -610.41. The MAE, MBE and RMSE were 236.22, -236.22 and 246.19, respectively.

4.4.4.3 Kernel weight:

The mean difference between predicted and observed kernel weight (Table 4.15) was -27.94 ± 1.92 mg. The Fig. 4.11 showed that the points were far away form 1:1 line and were out of the limit of ±1 standard deviation. The intercept

Table 4.13 CERES-Sorghum model validation results:predicted and observed GPSM

Treatment No.	Predicted (no .)	Observed (no)	Difference (no)
1	9680	14937±563.94	-5247
2	9560	12567±656.90	-3007
3	10073	12964±871.30	-2891
4	8971	11654±923.08	-2683
5	8364	10437±860.49	-2073
6	8798	10929±952.82	-2131
7	7967	10362±513.61	-2395
8	7860	10111±623.95	-2251
Mean	8909 ± 817.15	11745 ± 1661.25	-2836 ± 1037.36

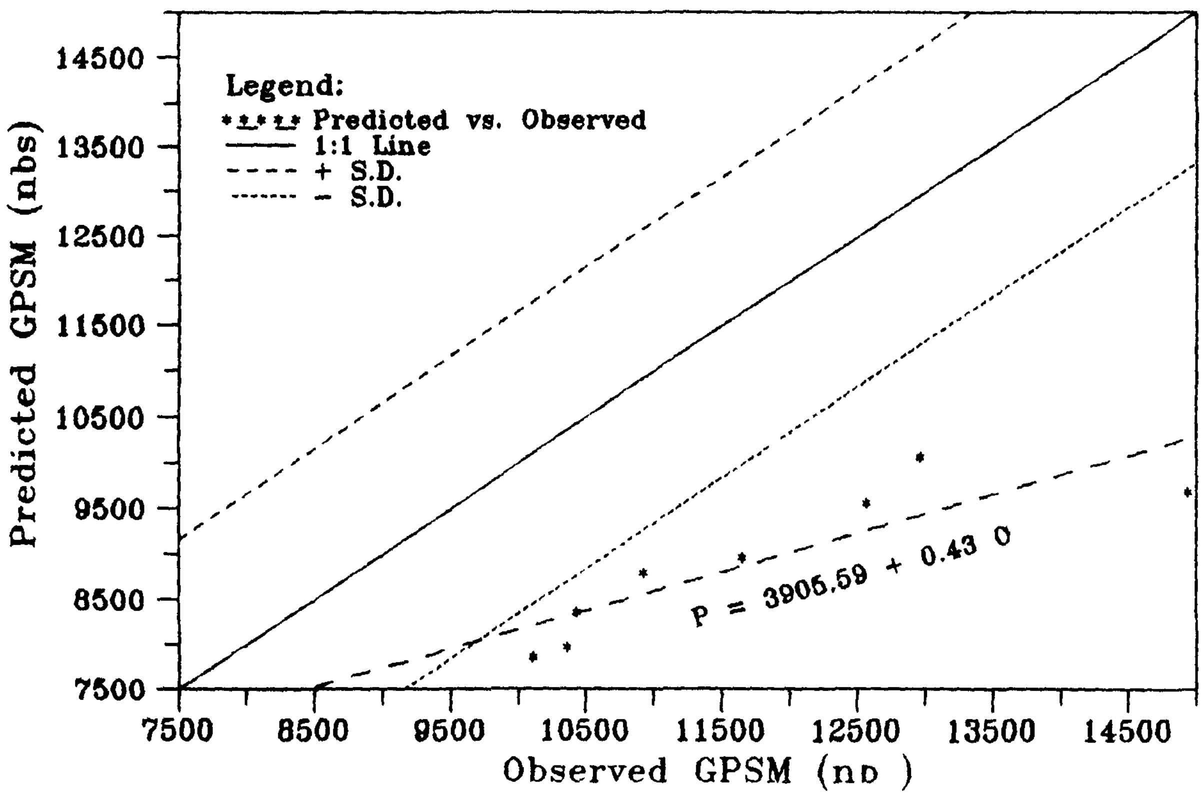

Fig. 4.9 Relationship between predicted and observed GPSM

Table 4.14 CERES-Sorghum model validation results:predicted and observed GPP

Treatment No.	Predicted (nb)	Observed (no)	Difference (no)
1	756	1167±119.89	-411
2	759	998±33.47	-239
3	796	1024±131.54	-228
4	795	1032±19.64	-237
5	734	915±26.42	-181
6	751	933±57.98	-182
7	710	923±99.34	-213
8	688	884±58.65	-196
Mean	749 ± 37.67	965 ± 91.33	-236 ± 74.13

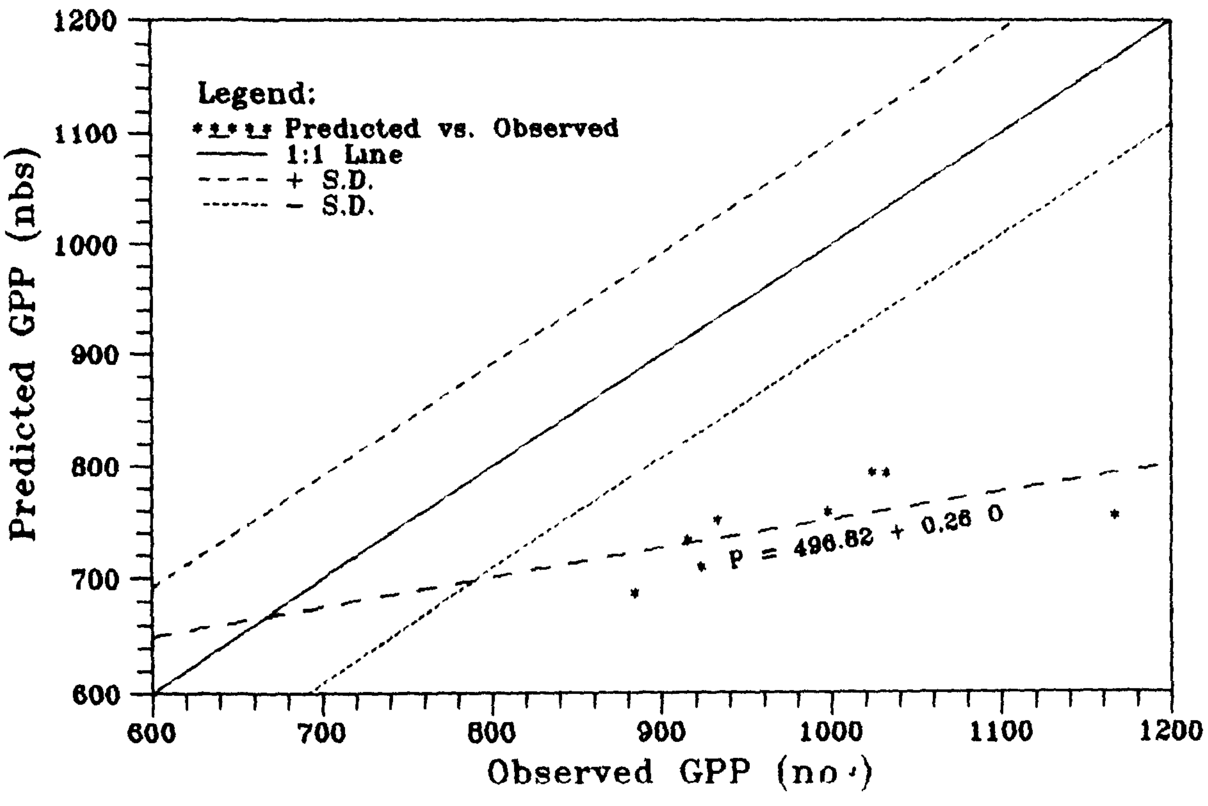

Fig. 4.10 Relationship between predicted and observed GPP

Table 4.15 CERES-Sorghum model validation results:predicted and observed kernel weight

Treatment No.	Predicted (mg)	Observed (mg)	Difference (mg)
1	4	30.67±1.28	-26.67
2	4	32.19±0.86	-28.13
3	5	34.67±2.19	-29.67
4	5	34.13±1.66	-29.13
5	4	34.00±1.45	-30.01
6	5	34.13±0.67	-29.13
7	4	30.12±0.98	-26.13
8	4	28.67±2.21	-24.67
Mean	4.38 ± 0.52	32.32 ± 2.26	-27.94 ± 1.91

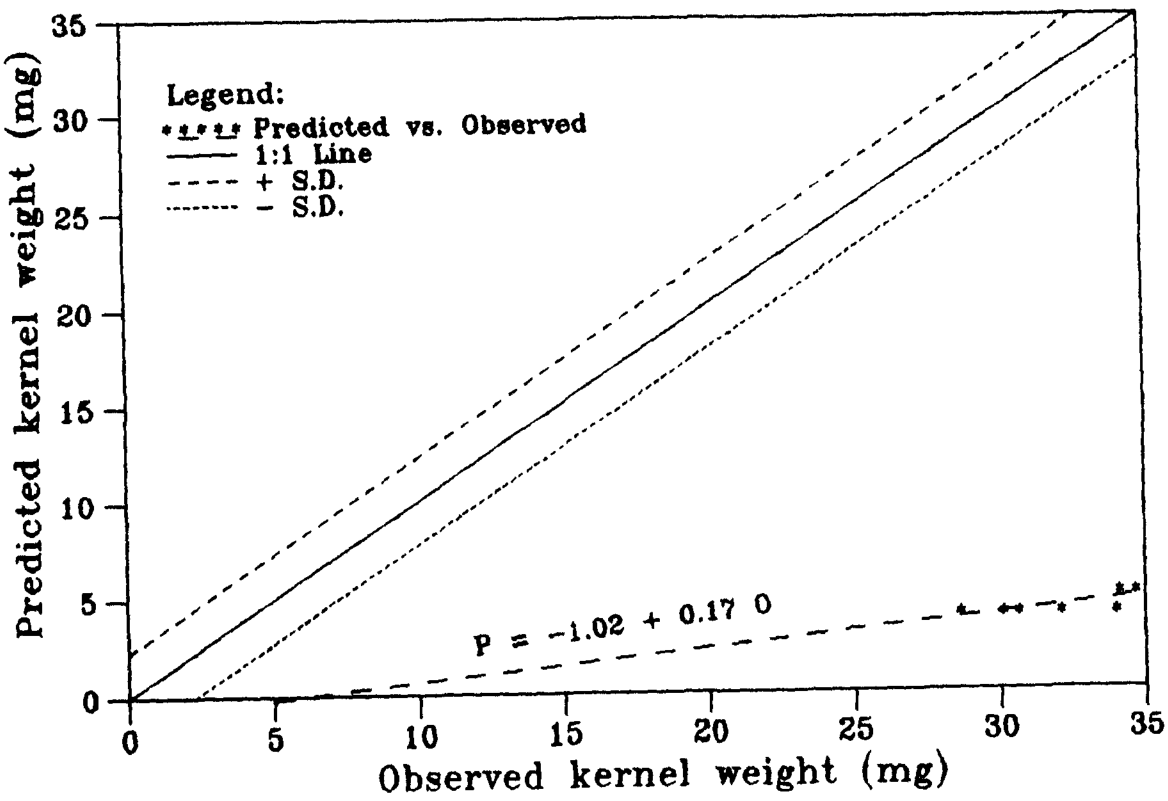

Fig. 4.11 Relationship between predicted and observed kernel weight

(a) and the slope (b) were significantly different from zero and unity, respectively. The degree of agreement was -119.21. The MAE, and RMSE were 27.94, -27.94 and 28.0, respectively.

The above result indicates that model predicted dates of the PI quite close to observed dates. The anthesis date was over predicted by 14 ±4 d. On the other hand physiological maturity was under predicted by -13 ±2.7 d. The under prediction of physiological maturity was due to the stress predicted by the model after anthesis. This was because model did not simulate the water balance correctly. Because of the inaccurate predictions of anthesis and physiological maturity dates, model predictions of growth and yield were not matching with observations. This indicates that the model should be first calibrated to predict the phasic development correctly. Then it should be calibrated for simulation of growth by using independent data sets.

The summary measures and the difference measures are given in Table 4.16a and 4.16b, respectively.

Table 4.16a Summary measures for data set without modifications

Variable	Unit	N	$\bar{O}$	$\bar{P}$	S_o	S_p	P = a + bO		r	D
							a	b		
PI	d	8	33.63	32.38	1.06	1.30	14.76	0.52	0.43	0.30
Anthesis	d	8	78.88	33.25	6.94	3 45	57.13	0.45	0.92	-1 40
Phys.Mat	d	8	124.75	111.38	4.68	3.07	43.31	0.55	0 83	-2 74
Yield	kg ha^{-1}	8	3602.13	405.25	614.74	48 15	187.38	0.06	0 77	-1.79
Kernel weight	mg	8	32.32	4 38	2.26	0 52	-1.02	0.17	0 72	-119.21
GPSM	no.	8	11745 13	8909.13	1661.25	817.15	3905.59	0.43	0.87	-0 78
GPP	no	8	984.79	748.57	91.33	37 57	496.82	0.26	0 62	-610 41
LAI	-	8	3.30	3.32	0.43	0.15	2.79	0.16	0 47	0 52
Dry matter	kg ha^{-1}	8	827.38	4090.63	1034.78	276.53	2757 71	0 16	0.60	-12.71
Straw	kg ha^{-1}	8	4739.88	3685 38	612.59	231.29	3253.27	0.09	0.24	-1 68

Table 4.16b Difference measures for data set without modifications

Variable	Unit	N	MAE	MBE	RMSE
PI	d	8	1.50	-1.25	1.73
Anthesis	d	8	14.38	14.38	14.85
Phys. mat.	d	8	13.38	-13.38	13.62
Yield	kg ha^{-1}	8	3196.88	-3196.88	1026.01
Kernel wt.	mg	8	27.94	-27.94	28.00
GPSM	no.	8	2836.00	-2836.00	2999.42
GPP	no.	8	236.22	-236.22	246.19
LAI	-	8	0.34	0.02	0.36
Dry matter	kg ha^{-1}	8	4187.75	-4187.75	4270.76
Straw	kg ha^{-1}	8	1055.50	-1055.50	1195.85

4.5 MODEL REVISION:

Initial testing of the model showed that it needed modifications for its application in this area. Accordingly, the modifications are made in the subroutines that calculates the phasic development and growth of the sorghum. A brief account of these modifications is given below.

4.5.1 Phasic Development Subroutines:

It is observed that sorghum hybrids have short phyllochron interval (PHINT), however, the varieties M-35-1 and SPV-504 have higher PHINT. On an average 54 TT PHINT value was observed as against 49 TT for hybrids (Karande, 1991).

The algorithm to calculate the TT from PI to end of leaf growth (P_3) was;

$$P_3 = 5.6 * PHINT + 0.19 SUMDTT$$

This was modified as:

$$P_3 = 3.0 * PHINT + 0.19\ SUMDTT$$

The algorithm to calculate TT from end of leaf growth to beginning of grain filling was:

$$P_4 = 5.51 * PHINT$$

This was calculated as:

$$P_4 = 4.0 * PHINT$$

The variable 'pflowr' used in the algorithm to calculate date of PI was calculated as:

$$pflowr = 3.0 * PHINT + 3.0$$

This is now calculated as:

$$pflowr = 3.3 * PHINT$$

4.5.2 Growth Subroutine:

The earhead size of the sorghum varies from genotype to genotype. In original version the earhead size was not taken into consideration. Therefore, a scaler for relative head size (G_2) is incorporated in the model. This resulted in the modification of some algorithms as follows:

The algorithm to calculate panicle weight (PANWT) was:

$$PANWT = 0.3 * STMWT$$

It is modified as:

$$PANWT = AG_2 * STMWT$$

Where,

$$AG_2 = G_2 * 0.05$$

The algorithm to calculate the grain weight was:

$$GRNWT = PANWT * 0.81$$

It is modified as:

$$GRNWT = PANWT * 0.80$$

The panicle growth constant (PGC) was calculated by using the algorithm as below:

$$PGC = 0.25 * PANWT$$

This is altered as:

$$PGC = AG_2 * PANWT$$

The algorithm to calculate the grain number per plant (GPP) was:

$$GPP = 1354.0 * (Blom\ 2 - Blom\ 1)/IDUR1$$

This is modified as:

$$GPP = 1364 * (Blom\ 2 - Blom\ 1)/IDUR1$$

The modified model resulted in the smaller prediction of leaf area. Therefore, the variable 'XTN' used for the calculation of leaf area was calculated as:

$$XTN = -10.34 * EXP\ (-PLAY * CUMPH)$$

This is modified as:

$$XTN = -6.54 * EXP\ (-PLAY * CUMPH)$$

Where,

PLAY = Temporary variable

The leaf senescence factor GCS was 0.31. It is increased to 0.43 because sorghum varieties (M-35-1 and SPV 504) senesce leaf area at faster rate than hybrids which retain the green color of leaves upto physiological maturity.

4.6 SENSITIVITY ANALYSIS:

A sensitivity analysis of modified CERES-Sorghum was carried out for different dates and amount of irrigations. The results showed that if two irrigations given, the model accurately simulated the growth and phenology of sorghum crop. The time of irrigations, was syncronised approximately to the boot and grain filling stage.

The first irrigation (85 mm) was tried on 60, 56, 56 and 69 DAS and second irrigation (80 mm) was tried on 92, 94, 96 and 99 for S_1, S_2, S_3 and S_4 sowing dates, respectively.

The results of the sensitivity analysis are presented below.

4.6.1 Phasic Development:

There was no change in the predicted dates PI after accounting for irrigation in the modified model.

4.6.1.1 Anthesis:

The mean difference between predicted and observed days for anthesis (Table 4.17) was -1 ± 4.14 d. The Fig.4.12 showed that the points were close to he 1:1 line and were within the limit of ± 1 standard deviation. The intercept

Table 4.17 Modified CERES-Sorghum model validation results:predicted and observed number of days for anthesis

Treatment No.	Predicted (d)	Observed (d)	Difference (d)
1	73	69	4
2	72	70	2
3	79	78	1
4	79	78	1
5	80	80	0
6	78	81	-3
7	82	86	-4
8	80	89	-9
Mean	77.88 ± 3.52	79.00 ± 6.94	-1 ± 4.14

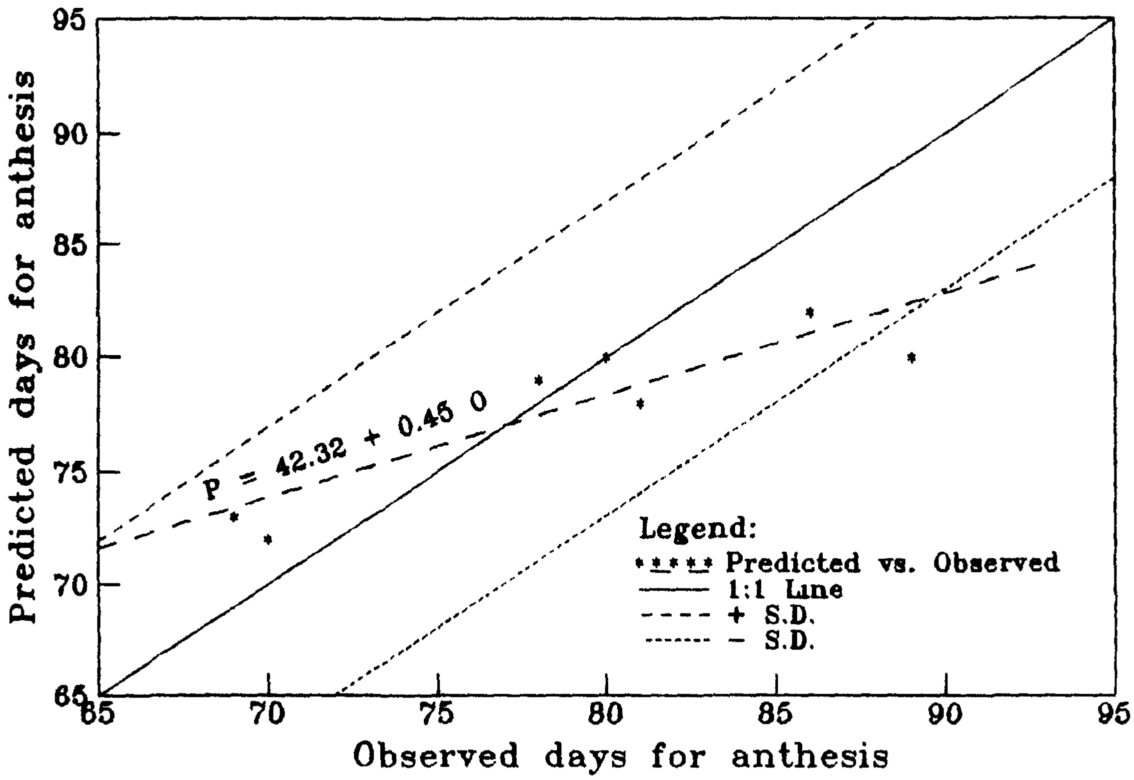

Fig. 4.12 Relationship between predicted and observed number of days for anthesis after modifications and accounting for irrigation

(a) and the slope (b) of the relationship between predicted and observed duration of anthesis were significantly different form zero and unity, respectively. The degree of agreement was 0.17. The MAE, MBE and RSME were 3, -1 and 4.0, respectively.

4.6.1.2 Physiological maturity:

The mean difference between predicted and observed dates of physiological maturity (Table 4.18) was -5 ± 2.75 d. The Fig. 4.13 showed that the points were close to 1:1 line and were within the limit of ± 1 standard deviation. The intercept (a) and the slope (b) of the relationship between predicted and observed duration of physiological maturity were significantly different from zero and unity, respectively. The degree of agreement was 0.36. The MBE, MAE and RMSE were 4.88, -4.88 and 5.51, respectively.

4.6.2 Growth:

4.6.2.1 Leaf area index:

The mean difference between predicted and observed LAI (Table 4.19) was -0.05 ± 0.35. The Fig. 4.14 showed that the points were close to 1:1 line and most of the points were within the limit of ± 1 standard deviation. The intercept (a) and slope (b) of the relationship between predicted and observed LAI were significantly different from zero and unity, respectively. The degree of agreement was 0.59. The MAE, MBE and RSME were 0.28, 00.05 and 0.33, respectively.

4.6.2.2 Dry matter:

The mean difference between predicted and observed dry matter (Table 4.20) was 193.79 ± 735.33 kg ha^{-1}. The Fig. 4.15 showed that the limit of ± 1

Table 4.18 Modified CERES-Sorghum model validation results:predicted and observed number of days for physiological maturity

Treatment No.	Predicted (d)	Observed (d)	Difference (d)
1	116	118	-2
2	115	119	-4
3	119	124	-5
4	121	124	-3
5	122	126	-4
6	122	126	-4
7	123	129	-6
8	121	132	-11
Mean	120 ± 2.94	124 ± 4.68	-5 ± 2.95

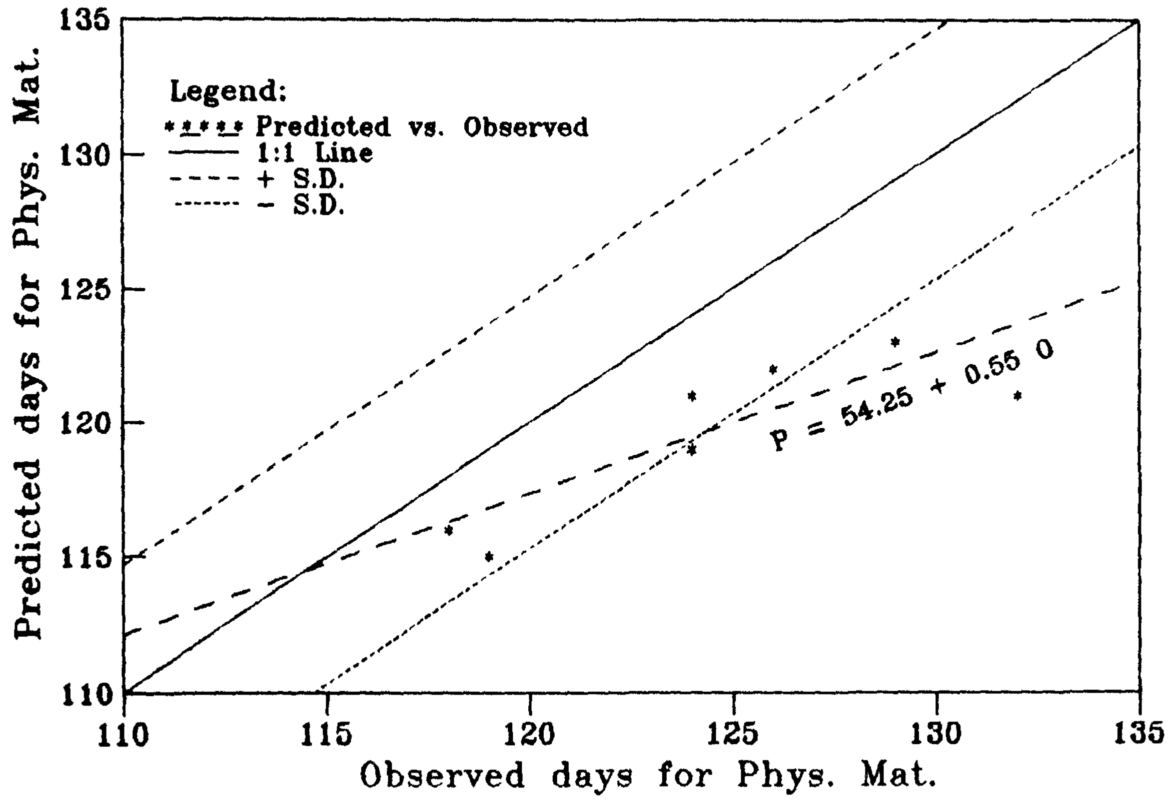

Fig. 4.13 Relationship between predicted and observed number of days for Phys. Mat. after modifications and accounting for irrigation

Table 4.19 Modified CERES-Sorghum model validation results:predicted and observed LAI

Treatment No.	Predicted	Observed	Difference
1	3.58	3.82±0.26	-0.24
2	3.35	3.73±0.38	-0.38
3	3.50	3.36±0.28	0.14
4	3.12	3.82±0.09	-0.70
5	3.16	3.06±0.24	0.10
6	3.04	2.92±0.25	0.12
7	3.17	2.88±0.32	0.29
8	3.12	2.84±0.23	0.28
Mean	3.26 ± 0.20	3.30 ± 0.43	-0.05 ± 0.35

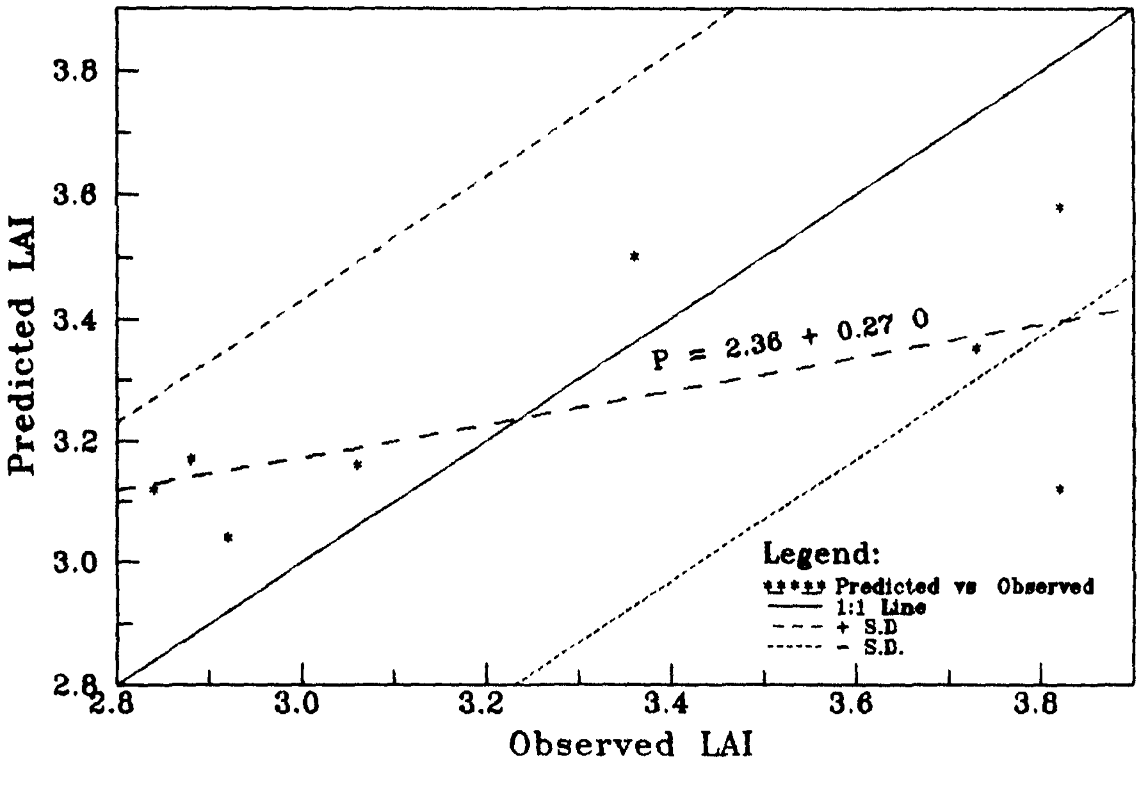

Fig. 4.14 Relationship between predicted and observed LAI after modifications and accounting for irrigation

Table 4.20 Modified CERES-Sorghum model validation results:predicted and observed dry matter

Treatment No.	Predicted ($kg\ ha^{-1}$)	Observed ($kg\ ha^{-1}$)	Difference ($kg\ ha^{-1}$)
1	8704	9702±492.30	-998
2	8594	9387±572.00	-793
3	9389	8640±506.22	749
4	9127	8559±507.02	568
5	8350	8406±563.49	-60
6	8525	7598±529.26	927
7	7466	6739±569.98	727
8	7623	7192±570.83	431
Mean	8472 ± 664.31	8278 ± 1034.78	-194 ± 735.33

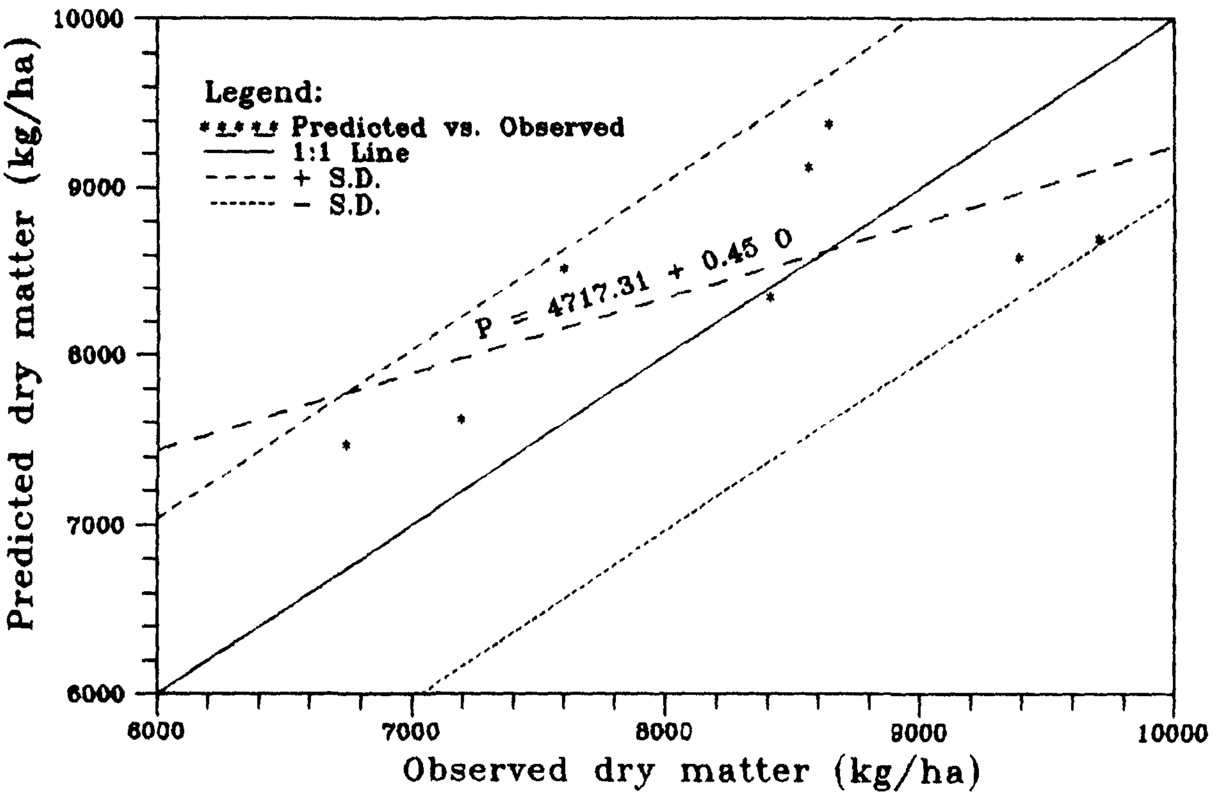

Fig. 4.15 Relationship between predicted and observed dry matter after modifications and accounting for irrigation

standard deviation. The intercept (a) and the slope (b) of the relationship between predicted and observed dry matter were significantly different from zero and unity, respectively. The degree of agreement was -1.32. Here the (D) is negative though the predictions and observations were close to each other. The reason for this is that the deviations from the means of predicted and observed dry matter over all the sowing dates and genotypes were higher than those from the mean of the difference between predicted and observed dry matter.

The MAE, MBE and RMSE were 656.63, 193.79 and 714.64, respectively.

4.6.3 Yield:

4.6.3.1 Grain yield:

The mean difference between predicted and observed grain yield (Table 4.21) was -37.88 ± 315.68 kg ha^{-1}. The Fig. 4.16 showed that all the points were close to 1:1 line and were within the limit of ± 1 standard deviation. The intercept (a) and the slope (b) of the relationship between predicted and observed grain yield were significantly different from zero and unity, respectively. The degree of agreement was 0.90. The MAE, MBE and RMSE were 242.88, -37.88 and 297.71, respectively.

4.6.3.2 Straw yield:

The mean difference between predicted and observed straw yield (Table 4.22) was 167.88 ± 636.14 kg ha^{-1}. Most of the points were close 1:1 line and were within the limit of ± 1 standard deviation (Fig.4.17). The intercept (a) and the slope (b) of the relationship between predicted and observed straw yield were non-significantly different from zero and unity, respectively. The degree

Table 4.21 Modified CERES-Sorghum model validation results:predicted and observed grain yield

Treatment No.	Predicted (kg ha^{-1})	Observed (kg ha^{-1})	Difference (kg ha^{-1})
1	3700	3884±421.48	-184
2	3820	4238±350.43	-418
3	3839	4304±235.94	-465
4	4003	3952±313.58	51
5	3566	3622±267.16	-56
6	3693	3306±413.30	387
7	2891	2867±312.08	24
8	3002	2644±263.69	358
Mean	3564 ± 403.16	3602 ± 614.74	-38 ± 315.68

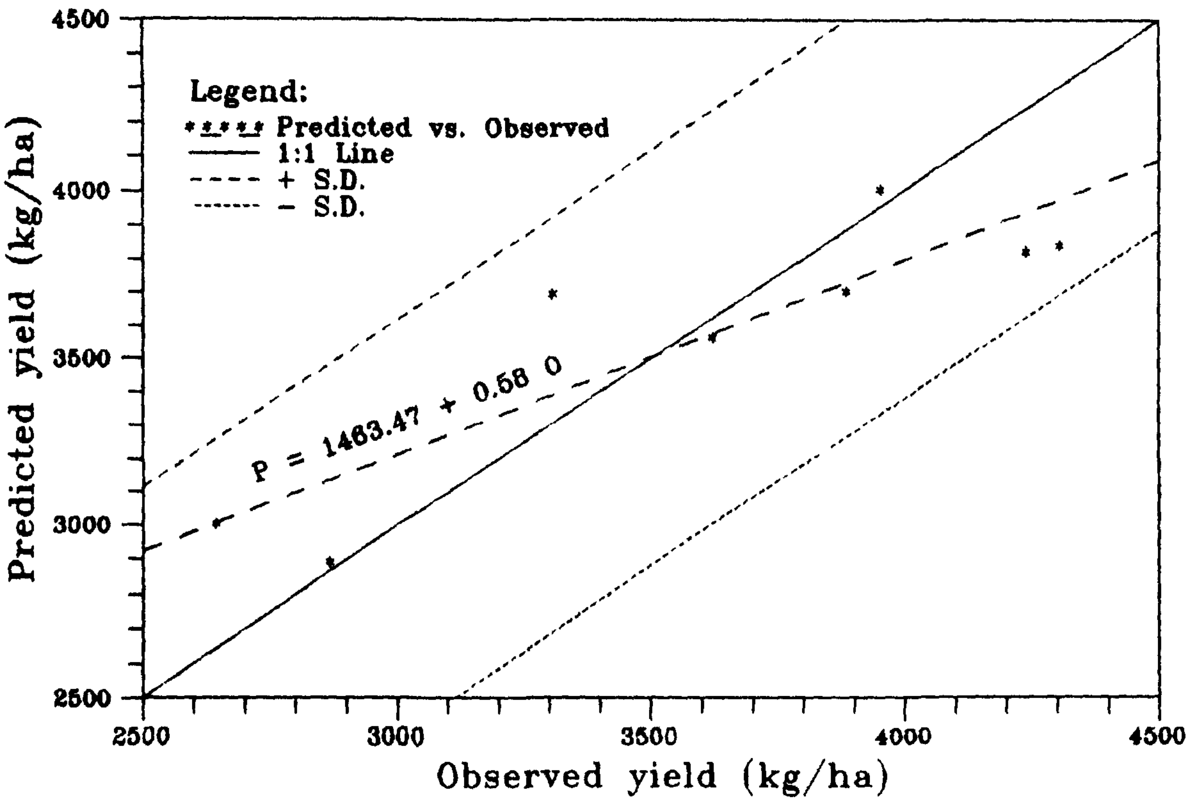

Fig. 4.16 Relationship between predicted and observed grain yield after modifications and accounting for irrigation

Table 4.22 Modified CERES-Sorghum model validation results:predicted and observed straw yield

Treatment No.	Predicted ($kg\ ha^{-1}$)	Observed ($kg\ ha^{-1}$)	Difference ($kg\ ha^{-1}$)
1	5005	5818±175.98	-813
2	4774	5149±184.42	-367
3	5550	4336±222.61	1214
4	5124	5142±218.86	0
5	4783	4788±258.52	-5
6	4831	4292±191.46	539
7	4574	3872±199.59	702
8	4621	4548±244.32	73
Mean	4908 ± 316.60	4740 ± 612.59	168 ± 636.14

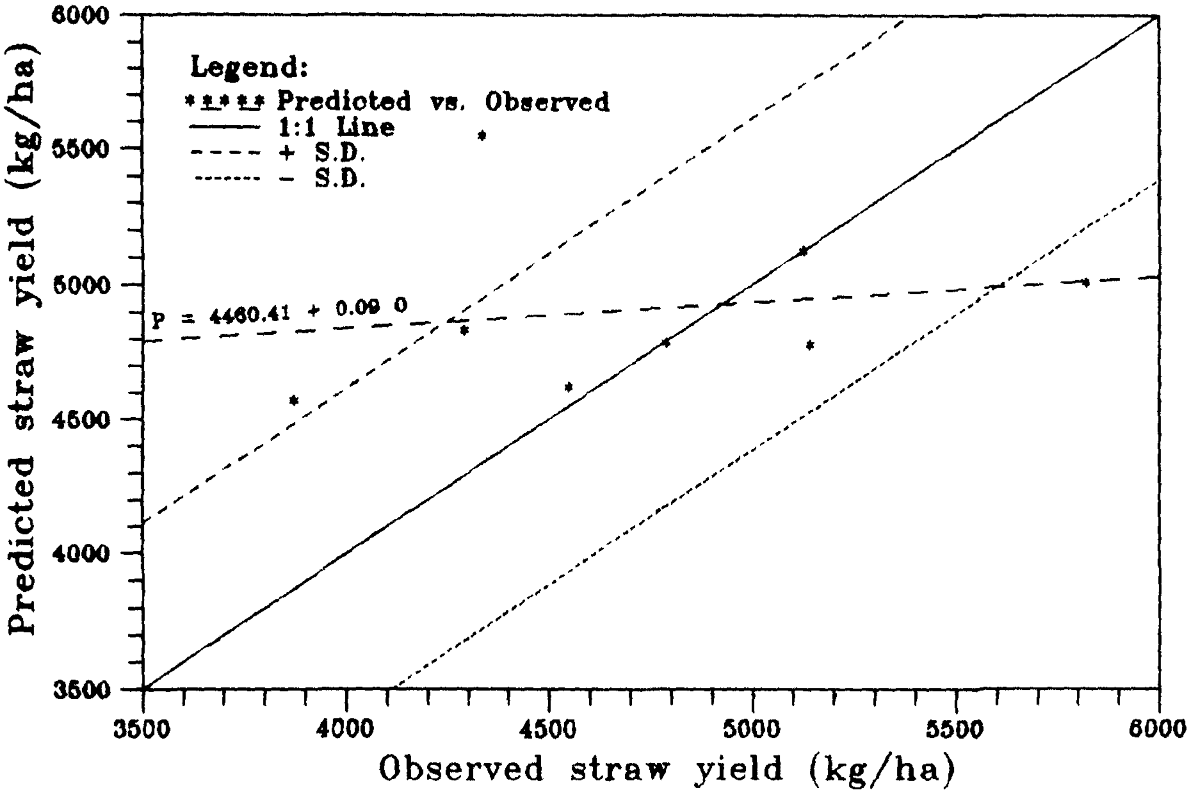

Fig. 4.17 Relationship between predicted and observed straw yield after modifications and accounting for irrigation

of agreement was 0.18. The MAE, MBE and RMSE were 464.13, 167.88 and 618.28, respectively.

4.6.4 Yield Components:

4.6.4.1 Grains per square meter(GPSM):

The mean difference between predicted and observed GPSM (Table 4.23) was -90 ± 714.38. All the points were close to 1:1 line and were within the limit of ± 1 standard deviation (Fig. 4.18). The intercept (a) and slope (b) of the relationship between predicted and observed GPSM were significantly different from zero and unity, respectively. The degree of agreement was 0.97. The MAE, MBE and RMSE were 407.25, -90.0 and 704.88, respectively.

4.6.4.2 Grains per plant:

The mean difference between predicted and observed GPP (Table 4.24) was -5.87 ± 59.37. Most of the points were close to 1:1 line and were within the limit of ± 1 standard deviation (Fig. 4.19). The relationship between predicted and observed GPP had an intercept (a) and a slope (b) significantly different from zero and unity, respectively. The degree of agreement was 0.62. The MAE, MBE and RMSE were 32.20, -5.87 and 55.85, respectively.

4.6.4.3 Kernel weight:

The mean difference between predicted and observed kernel weight (Table 4.25) was -1.69 ± 1.63 mg. Most of the points were close to 1:1 line and were within the limit of ± 1 standard deviation (Fig. 4.20). The relationship between predicted and observed kernel weight had an intercept (a) and a slope (b) significantly different from zero and unity, respectively. The degree of

Table 4.23 Modified CERES-Sorghum model validation results:predicted and observed GPSM

Treatment No.	Predicted (nbs)	Observed (nbs)	Difference (nbs)
1	13068	14937±563.94	-1869
2	12761	12567±656.90	194
3	12924	12964±871.30	-40
4	11574	11654±923.08	-80
5	10876	10437±860.49	439
6	11058	10929±952.82	129
7	10394	10362±513.61	32
8	10586	10111±623.95	475
Mean	11655 ± 1104.07	11745 ± 1661.25	-90 ± 747.38

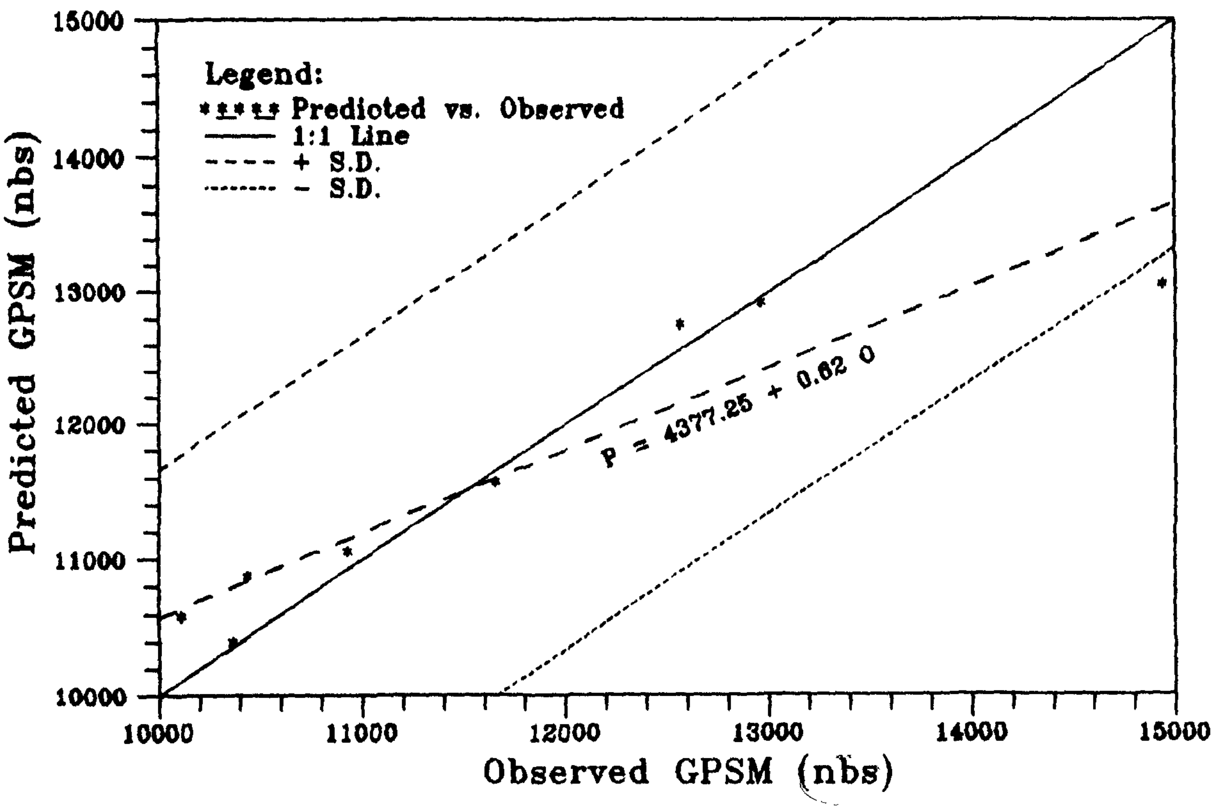

Fig. 4.18 Relationship between predicted and observed GPSM after modifications and accounting for irrigation

Table 4.24 Modified CERES-Sorghum model validation results:predicted and observed GPP

Treatment No.	Predicted (nD)	Observed (nD)	Difference (nD)
1	1021	1167±119.89	-146
2	1014	998±33.47	16
3	1021	1024±131.54	-3
4	1025	1032±19.64	-7
5	954	915±26.42	39
6	944	933±57.98	11
7	926	923±99.34	3
8	926	884±58.65	42
Mean	979 ± 44.08	965 ± 91.33	-6 ± 59.37

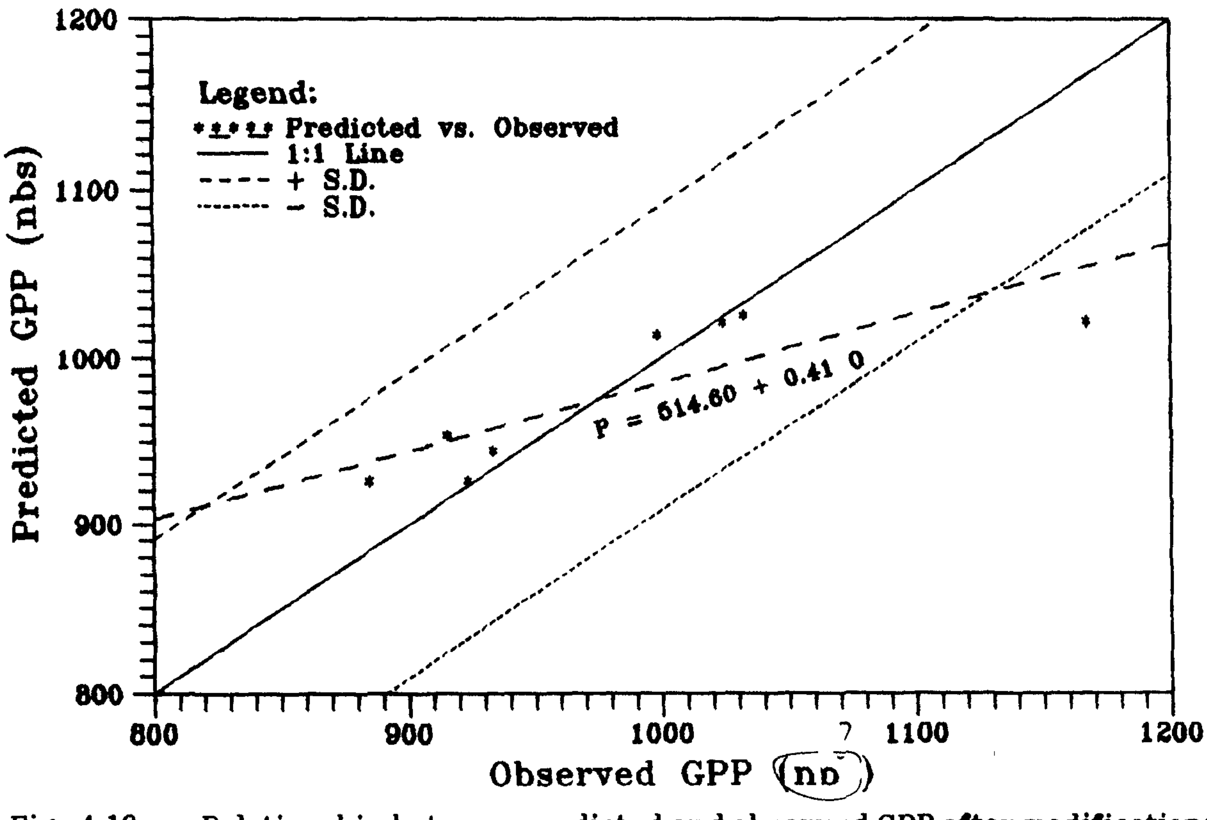

Fig. 4.19 Relationship between predicted and observed GPP after modifications and accounting for irrigation

Table 4.25 Modified CERES-Sorghum model validation results:predicted and observed kernel weight

Treatment No.	Predicted (mg)	Observed (mg)	Difference (mg)
1	28	30.67±1.28	-2.67
2	30	32.19±0.86	-2.13
3	30	34.67±2.19	-4.67
4	35	34.13±1.66	-0.87
5	33	34.00±1.45	-1.01
6	33	34.13±0.67	-1.13
7	28	30.12±0.98	-2.13
8	28	28.67±2.21	-0.67
Mean	30.63 ± 2.72	32.32 ± 2.26	-1.69 ± 1.63

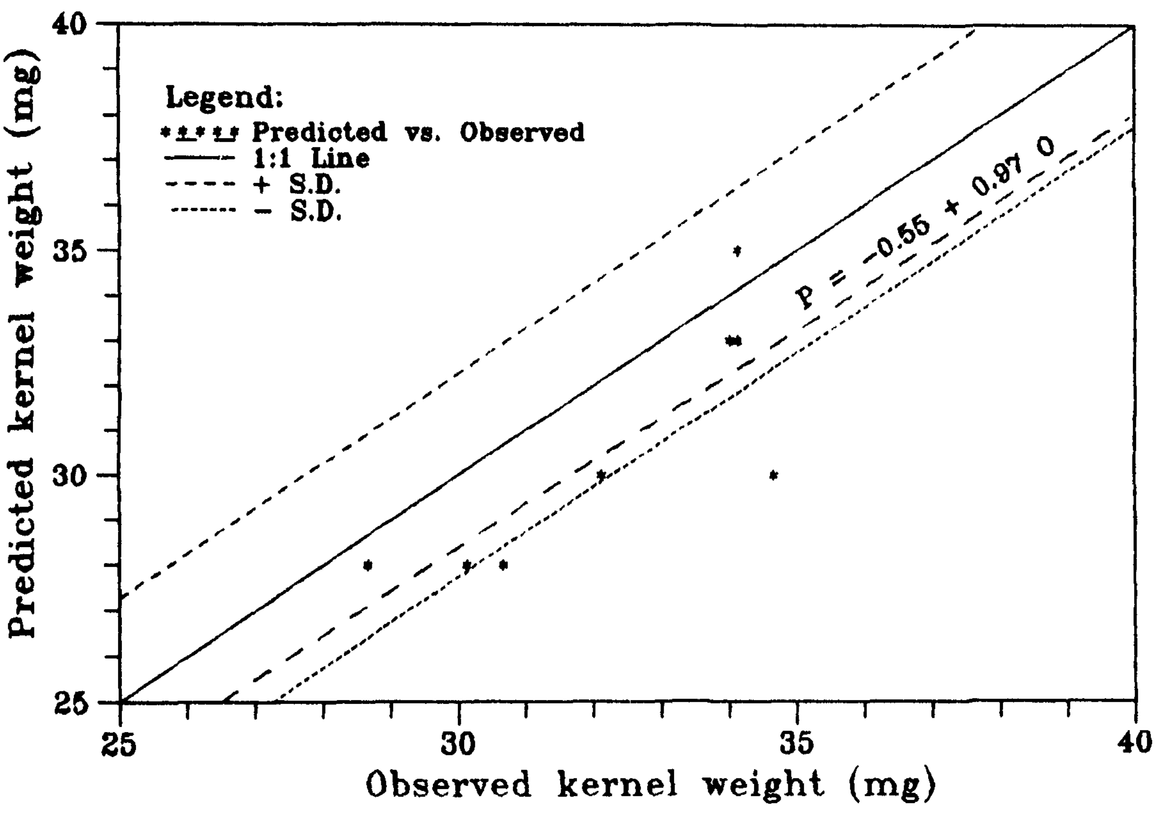

Fig. 4.20 Relationship between predicted and observed kernel weight after modifications and accounting for irrigation

agreement was 0.80. The MAE, MBE and RSME were 1.91, -1.69 and 1.28, respectively.

The summary measures and difference measures for data set after modifications and accounting for irrigations are given in Table 4.26a and 4.26b, respectively.

Table 4.26a Summary measures for data set after modifications and accounting for irrigation

Variable	Unit	N	$\bar{O}$	$\bar{P}$	S_o	S_p	P = a + bO: a	P = a + bO: b	r	D	S.E
PI	d	8	33.33	32.38	1.06	1.30	14.76	0.52	0.43	0.30	1.27
Anthesis	d	8	78.88	77.88	6.94	3.52	42.32	0.45	0.89	0.17	1.75
Phys. maturity	d	8	124.75	119.88	4.68	2.95	54.25	0.53	0.84	0.36	1.75
Yield	kg ha^{-1}	8	3602.13	3664.35	614.74	403.17	1463.47	0.58	0.89	0.90	119.18
kernel weight	mg	8	32.32	30.63	2.26	2.72	-0.55	0.97	0.80	0.74	1.76
GPSM	no.	8	11745.13	11655.13	1661.25	1104.07	4377.25	0.62	0.93	0.92	431.15
GPP	no.	8	984.79	978.92	91.33	45.08	514.60	0.41	0.83	0.79	27.03
LAI	-	8	3.30	3.26	0.43	0.20	2.36	0.27	0.59	0.65	0.17
Dry matter	kg ha^{-1}	8	8278.38	8472.25	1034.78	664.31	4717.31	0.45	0.71	-1.32	507.79
Straw	kg ha^{-1}	8	4739.88	4907.75	612.59	316.60	4460.41	0.09	0.18	0.40	

Table 4.26b Difference measures for data set after modifications and accounting for irrigation

Variable	Unit	N	MAE	MBE	RMSE
PI	d	8	1.50	-1.25	-1.73
Anthesis	d	8	3.00	-1.00	4.00
Phys. mat.	d	8	4.88	-4.88	5.51
Yield	kg ha^{-1}	8	242.88	-37.88	297.71
Kernel wt.	mg	8	1.91	-1.69	2.28
GPSM	no.	8	407.25	-90.00	-704.88
GPP	no.	8	33.20	-5.87	55.85
LAI	-	8	0.28	-0.05	0.33
Dry matter	kg ha^{-1}	8	656.63	193.79	714.64
Straw	kg ha^{-1}	8	464.13	167.88	618.28

4.7 DAILY GROWTH PATTERN - MODEL OUTPUT COMPAREd TO OBSERVED DATA:

Tracing the daily pattern of different aspects of plant growth B10M, LAI, dry weight of stem, leaf and panicle and comparing them with observed is another way to trace errors in the simulation process. Thus, the accuracy of the model can be ensured.

4.7.1 Leaf Area Index (LAI)

Fig. 4.21 and 4.22 explain the comparison between model predicted LAI with observed LAI in the present experiment, where two sorghum genotypes were sown at four different sowing dates. The maximum LAI predicted was close to

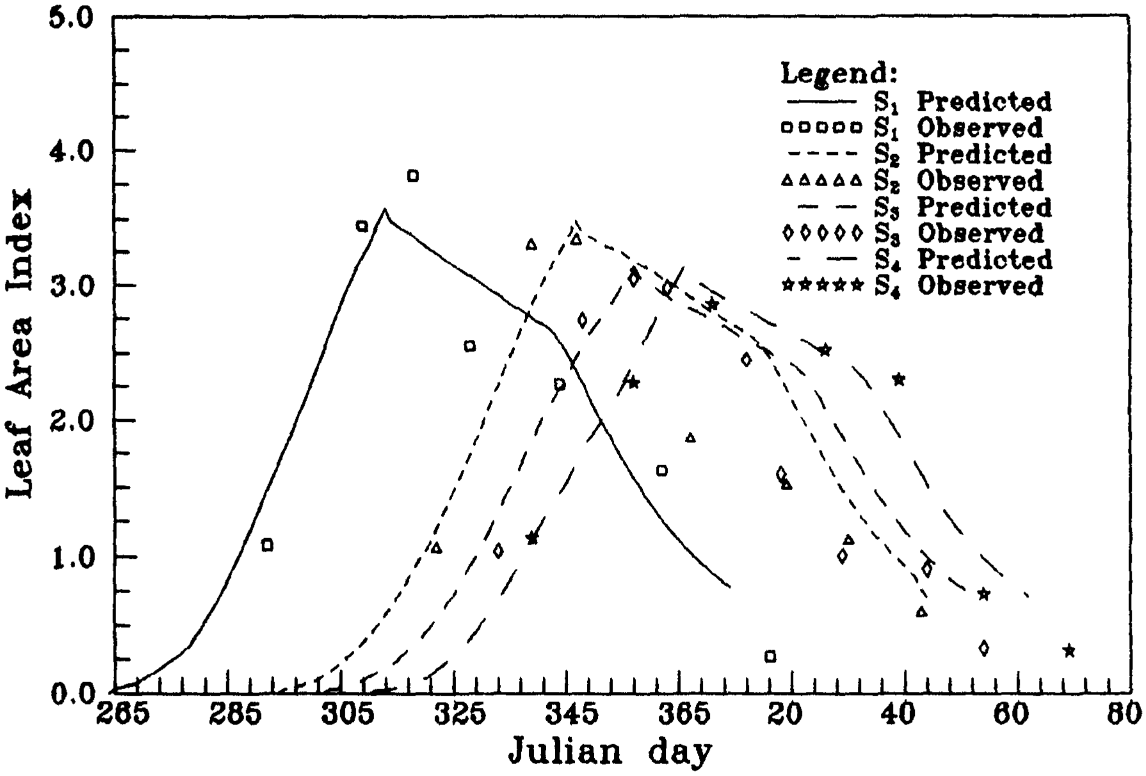

Fig. 4.21 Daily pattern of LAI prediction of M-35-1 as compared to observed

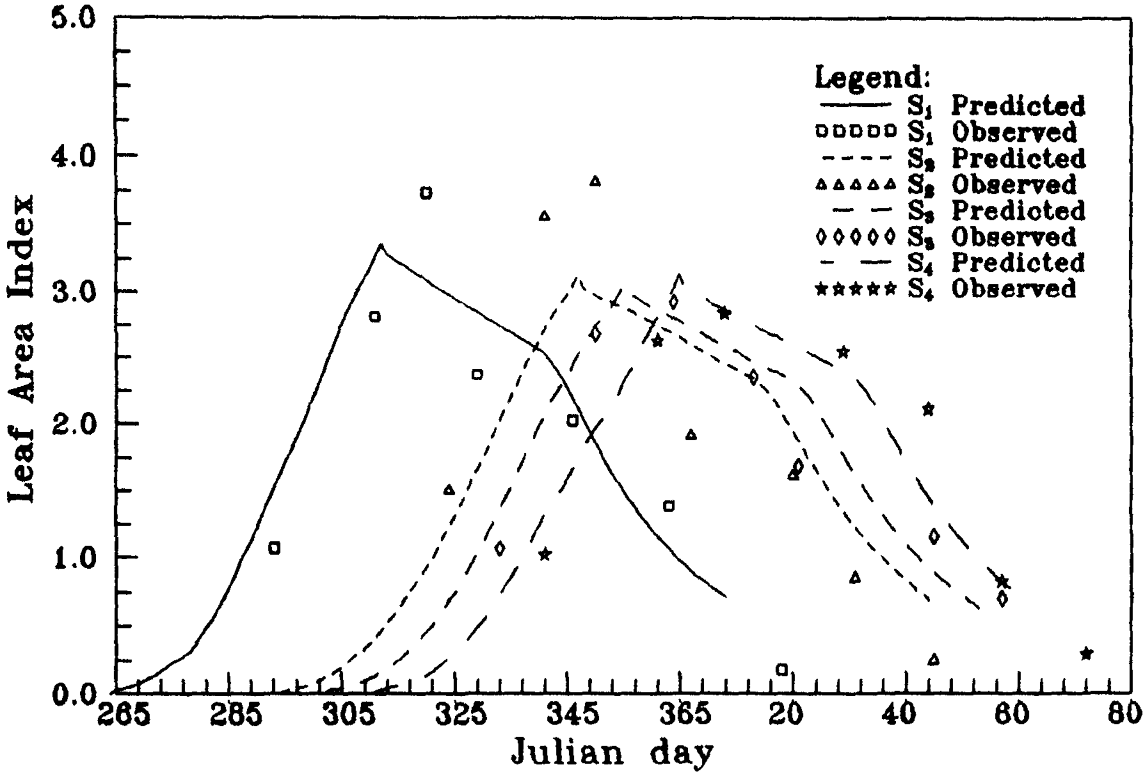

Fig. 4.22 Daily pattern of LAI prediction of SPV-504 as compared to observed

the observed but with a time lag. Simulated maximum LAI was predicted at earlier time than observations. However, time and amount of LAI produced followed the trend of the observations.

4.7.2 Drymatter:

The daily pattern of dry matter production has been compared to observed data (Fig. 4.23 and 4.24). Both the genotypes performed well and produced matching dry matter yield. The time and amount of biomass production was in tune with observed data.

4.7.3 Partitioning of Dry Matter:

Data on stem weight from this experiment were compared to model predictions (Fig. 4.25 and 4.26). Stem weight was under estimated by the model. Daily pattern of prediction of the stem weight followed the trend of the observations. However, the model showed abrupt decrease in stem weight approximately at anthesis stage. Then it remained constant.

Predicted and observed leaf weight followed the same trend upto boot stage and thereafter predicted value of leaf weight remained constant. On the contrary the observed leaf weight slowed decreasing trend (Fig. 4.27 and 4.28). The observed values of leaf weight were higher than the predicted.

The comparison between predicted and observed panicle (Fig. 4.29 nd 4.30) Showed that the predicted and observed amount and timing of panicle weight was close together. However, predictions were slightly higher than the observations.

Partitioning of dry matter into stem, leaf and panicle, which are sinks in different stages of the plant cycle have not been modified satisfactorily.

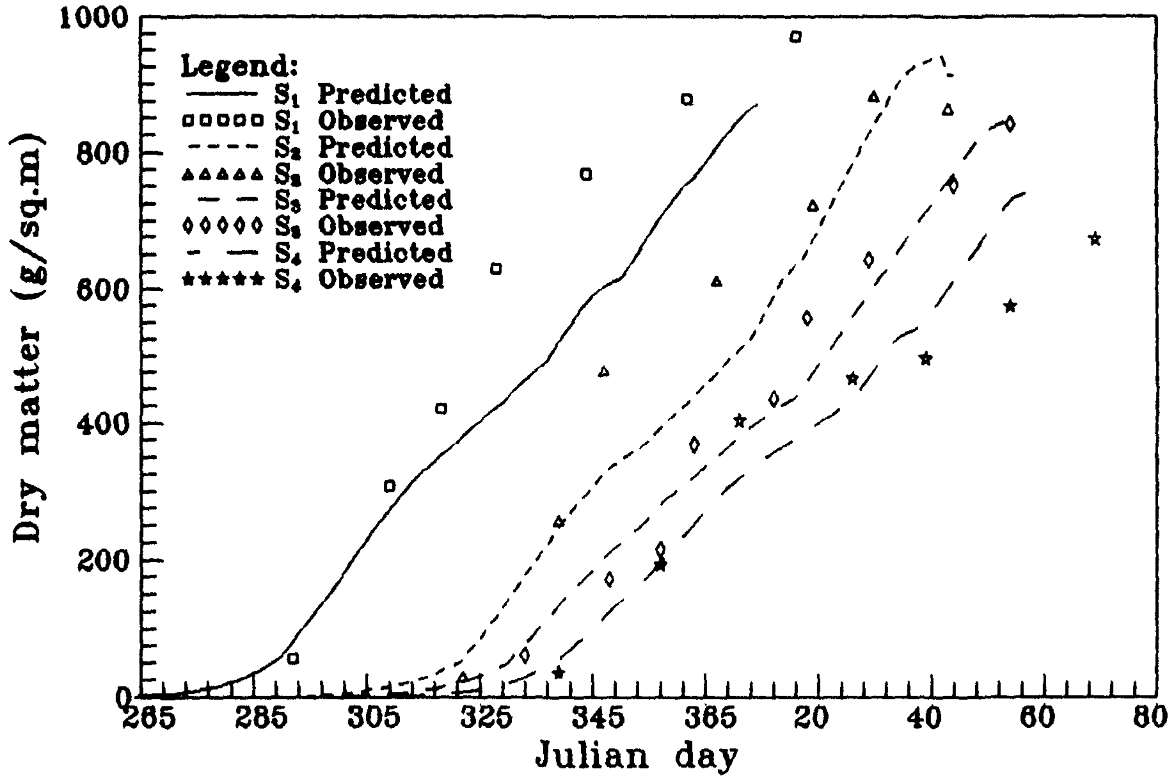

Fig. 4.23 Daily pattern of dry matter prediction of M-35-1 as compared to observed

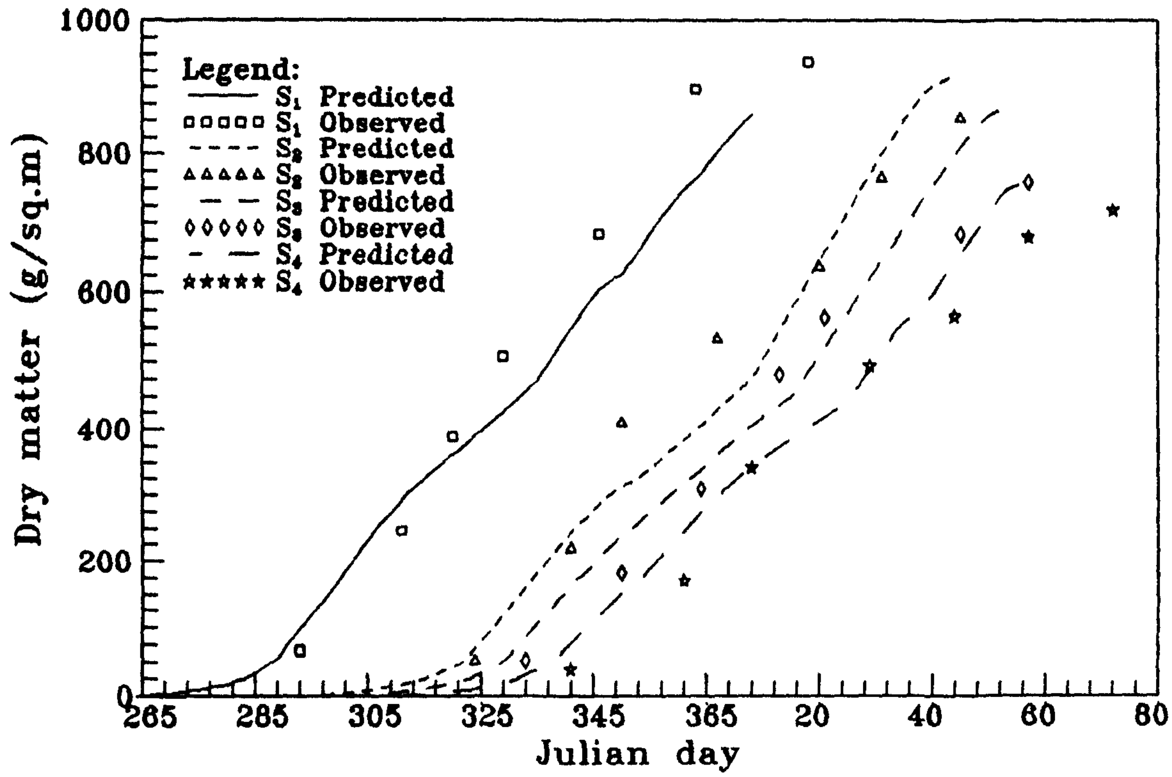

Fig. 4.24 Daily pattern of dry matter prediction of SPV-504 as compared to observed

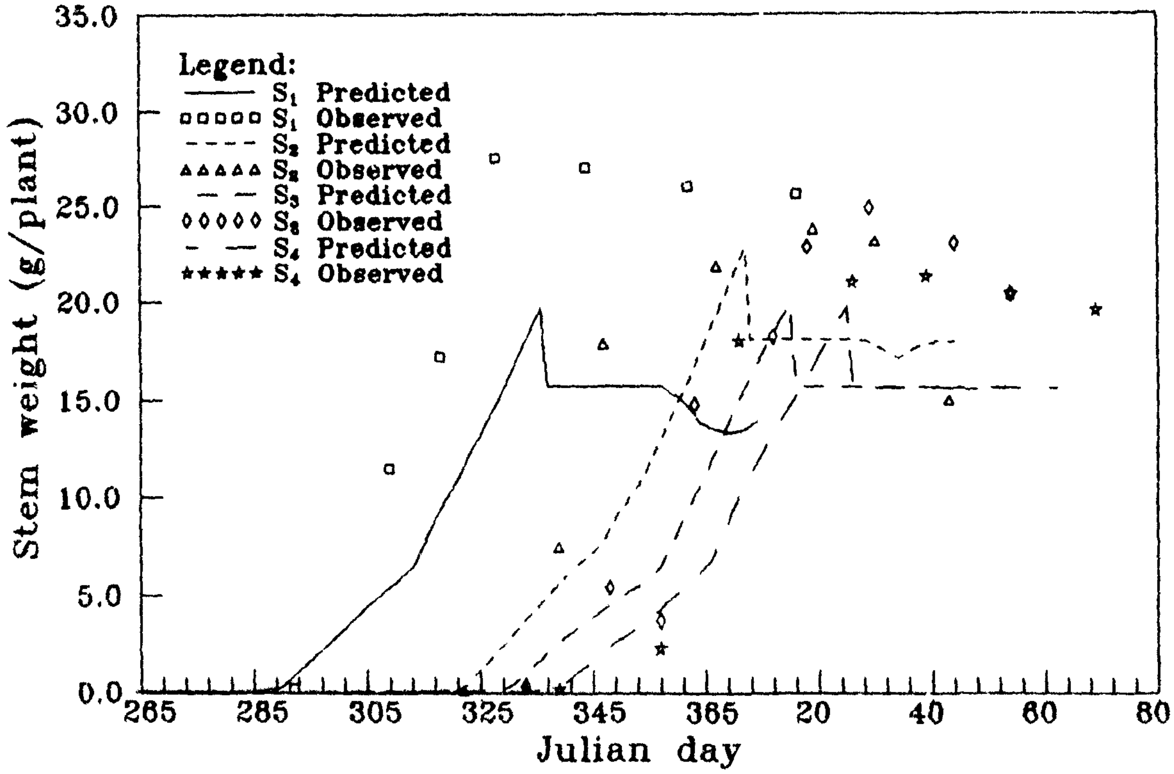

Fig. 4.25 Daily pattern of stem weight prediction of M-35-1 as compared to observed

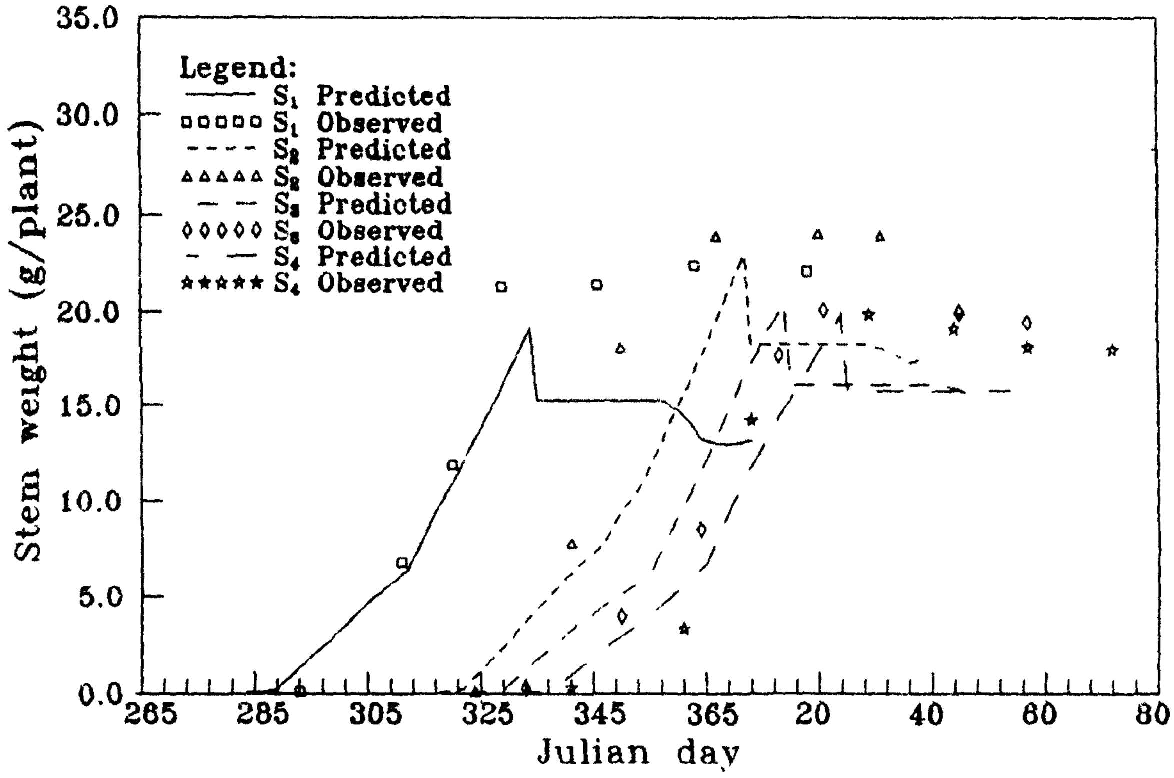

Fig. 4.26 Daily pattern of stem weight prediction of SPV-504 as compared to observed

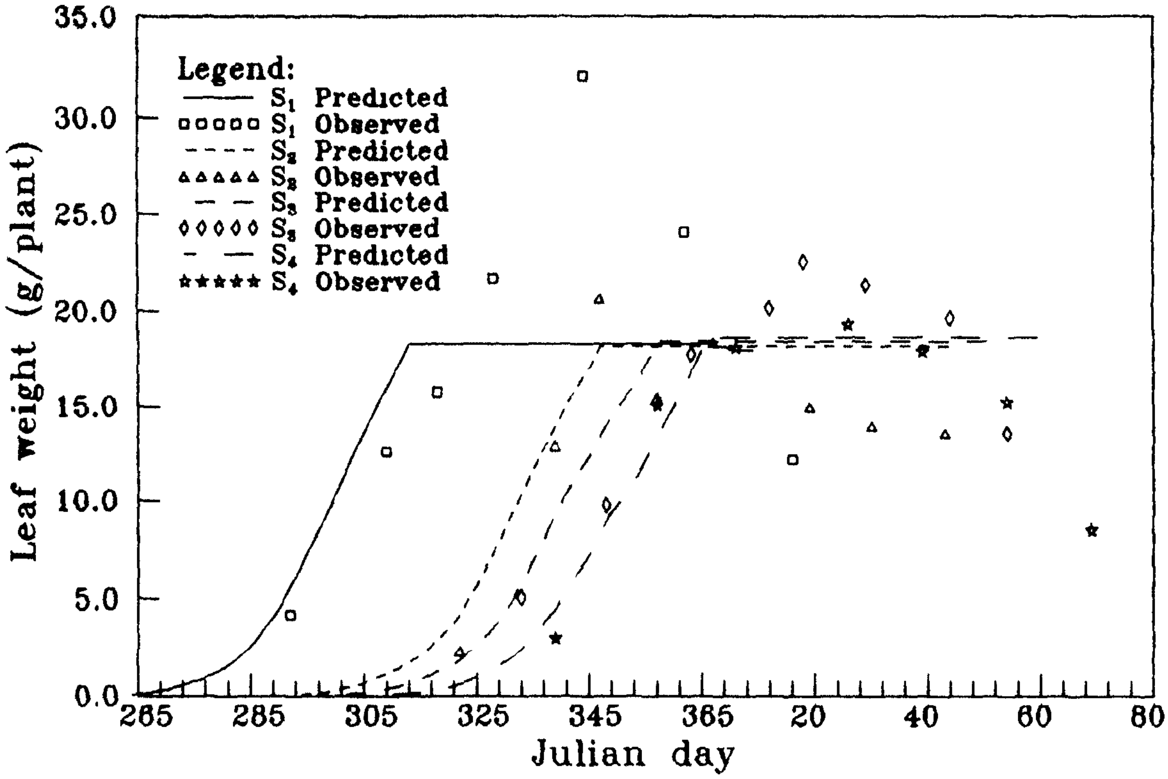

Fig. 4.27 Daily pattern of leaf weight prediction of M-35-1 as compared to observed

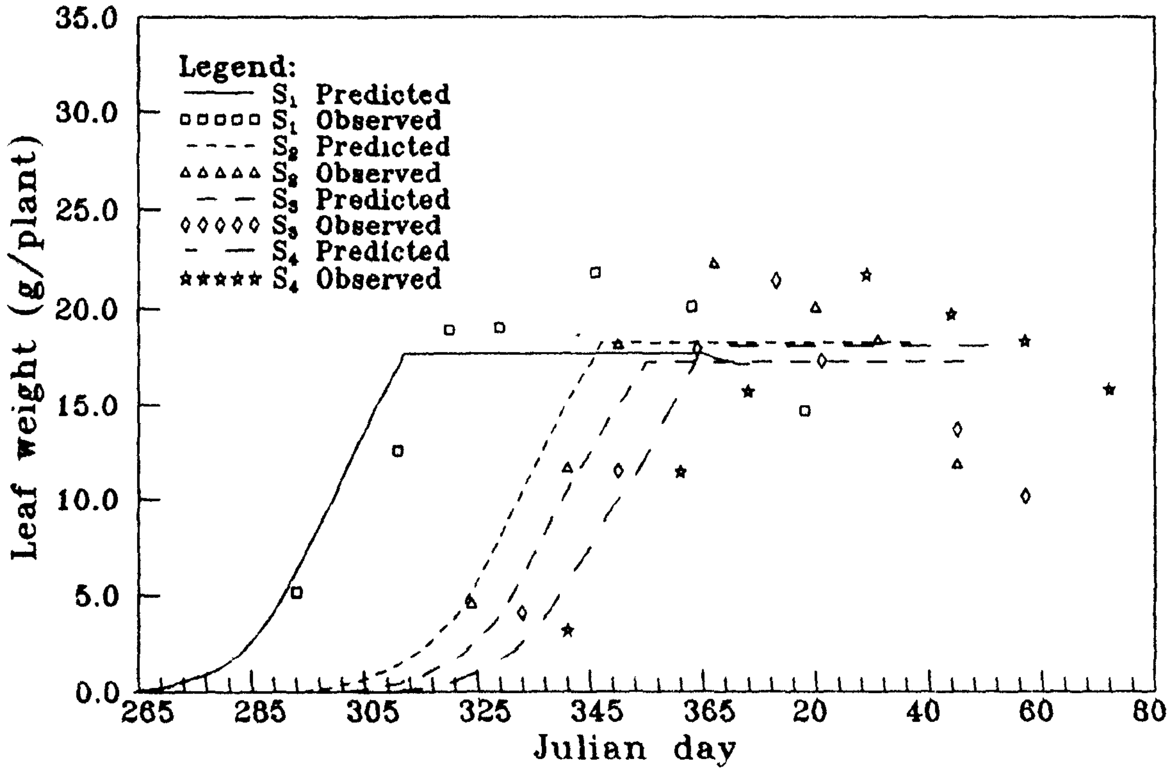

Fig. 4.28 Daily pattern of leaf weight prediction of SPV-504 as compared to observed

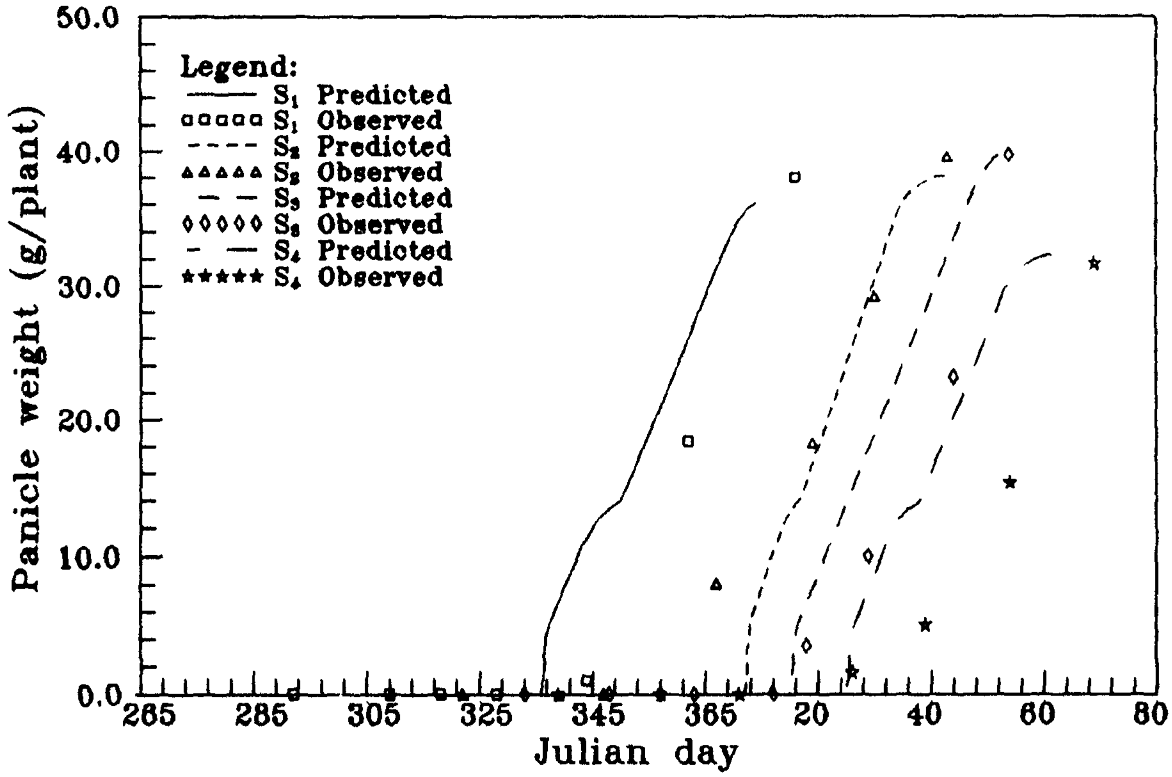

Fig. 4.29 Daily pattern of panicle weight prediction of M-35-1 as compared to observed

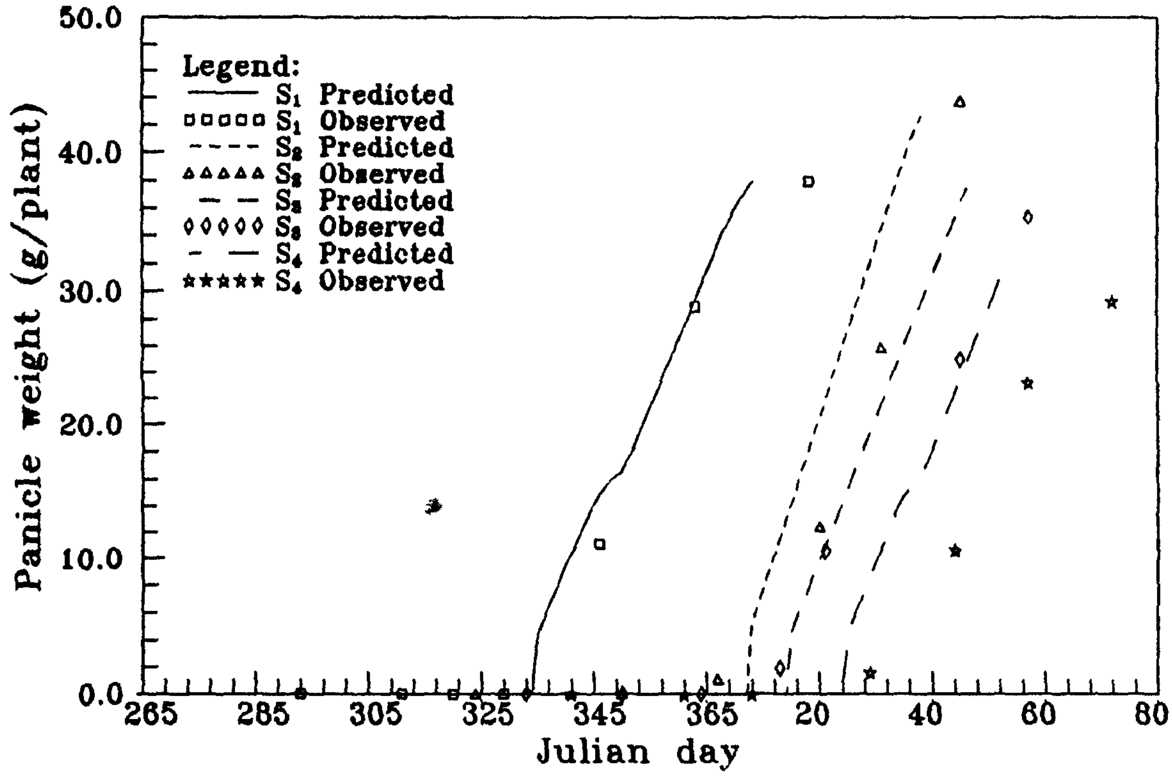

Fig. 4.30 Daily pattern of panicle weight prediction of SPV-504 as compared to observed

5. SUMMARY AND CONCLUSIONS

5. SUMMARY AND CONCLUSIONS

5.1 SUMMARY:

The validation of the CERES-Sorghum V1.99 was carried out by using data from the experiment carried out at Centre of Advanced Studies in Agricultural Meteorology, College of Agriculture, Pune during the post monsoon season of 1989-90. The experiment was laid in split plot design with four replications. There were four main treatments of sowing dates and two sub-treatments of genotypes.

Data on crop growth, development and yield was taken from the present experiment. The climatic data on daily maximum and minimum temperature, solar radiation and precipitation, required for the model was collected from Agromet observatory, located at College of Agriculture Farm, Pune. The genetic coefficients of the two sorghum genotypes (M-35-1 and SPV 504) were determined in a separate experiment carried out at the Centre of Advanced studies in Agricultural Meteorology, Pune by Karande during the same season.

The determination of lower limit of plant extractable soil water (LL) drained upper limit of soil water availability (DUL) saturation water content and initial soil water was done by gravimetric method. The measurements on soil albedo, drainage rate constant. (SWCON), stage 1 evaporation coefficient (U) and runoff curve number were not available and these parameters are approximated on the basis of soil classification data. The determination of root weighing factor (WR) was not done and hence WR values were adopted from the model.

The input files required to run the model were created by using IBSNAT's DSSAT V2.1 programme.

Initial testing of the model showed that the model predicted dates of PI and LAI correctly. The degree of agreement (d) was negative for all cases excluding dates of PI and LAI. The MAE, MBE and RMSE were very high. The predictions were usually smaller than observations except for PI, anthesis dates and LAI.

The performance of the model to predict anthesis date improved after modifications in phenology subroutine by incorporating genetic coefficients of these varieties. However the predictions of physiological maturity, growth and yield components were under predicted and the magnitudes of the predictions were almost similar to the initial results of the validation.

The cause of these contrasting results was the stress shown by the model from end of leaf growth to the physiological maturity. However, the crop had not shown any stress during the growth period. Thus, the simulation of water balance was inaccurate and this resulted in inaccurate predictions of growth parameters.

The sensitivity analysis of the model showed that after accounting for irrigations given approximately at boot and grain filling stages the model accuracy improved predicting crop growth and development improved. The MAE, MBE and RMSE decreased to a great extent. The degree of agreement increased over initial results. The mean difference between predictions and observations and the standard deviation of the difference decreased as compared to initial values. Thus the sensitivity analysis showed that model can be accepted after incorporating irrigations.

5.2 CONCLUSIONS :

The CERES sorghum model is designed to be used as a management-oriented simulation model for a diversity of applications in all environments suitable for sorghum growing regions to make the model useful to an audience as wide aspossible, the inputs must be minimal and they must be reasonably easy to estimate from standard agricultural practices. Under these premises, the model simulates crop growth and development, response to sowing dates, plant densities, irrigation and N fertilizer reasonably and reliably.

A sensitivity analysis of the model and statistical analysis indicated acceptance of model simulations. However, some problems are yet to be resolved with the simulation of water balance subroutine and nitrogen subroutines.

Further data sets are required to test the soil water balance and N subroutines of the model.

Additional testing and refinement of the indicated parts of the model will be beneficial.

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LITERATURE CITED

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Alagarswamy, G., U. Singh, and D.C. Godwin. 1989. Modelling nitrogen uptake and response in sorghum and pearlmillet. ICARISAT bulletin No. 12:11-13.

Alagarswamy, G., J.T. Ritchie, D.C. Godwin, U. Singh. 1989. Users' guide to CERES-Sorghum V2.00. Personal communication.

Arkin, G.F., R.L. Vanderlip, and J.T. Ritchie. 1976. A dynamic grain sorghum growth model. Transactions of ASAE. 19:622-626, 630.

Arkin, G.F., and W.A. Dugas. 1984. Evaluating sorghum production strategies using a crop model. Agrometeorology of Sorghum and Millet in the Semi-Arid-Tropics. Proceedings of the international Symposium, 15-20 November, 1982. ICRISAT Centre, Patancheru, A.P., India.

Arkin, G.F., C.W. Richardson, S.J. Mass. 1978. Forecasting grain sorghum yields using probability functions. Transactions of ASAE. 21(5):874-877,880.

Baier, W. 1973. Crop-weather analysis model, 1. Summary Int. J. Biometerol., 17(4):313-320.

Bair, W., Davidson, H., Desjardins, R.L., Quellet, C.E. and Williams, G.D.V, 1976. Recent biometerol., 20(2)·10-8-127.

Baier, W. 1979. Note on the terminology of crop-weather models. Agric. Meteorol. 20:137-145.

Black, C.A. 1965. Methods of soil analysis, Part - I & II, American Soc. of Agronomy, Inc. Publisher Madison, Wisconsin, USA (1966).

Craford, D.J., and R.W. Nott. 1981. Yield formulas for summer crop of the Highved region. Tech. Comm. Dept. Agril. and Fisheries No. 169. pp.22

Curry, R.B. 1971. Dynamic simulation of plant growth-Part I. Development of a model. Transactions of ASAE. 14:946-949.

Curry, R.B., and L.H. Chen. 1971. Dynamic simulation of plant growth-Part II. Incorporation of daily weather and partitioning of net photosynthate. Transactions of ASAE. 14:1170-1174.

Decoursey, D.G. 1980. Runoff erosion, and crop yield simulation for land use management. Transactions of ASAE. 23:(2):379-386.

Dent, J.B., and M.J. Blackie. 1979. Systems Simulation in Agriculture Essex, England: Applied Science Publishers Pvt. Ltd.

De Witt, C.T. 1965. Photosynthesis of leaf canopies. Agric. Res. Rep., 663, Pudoc, Wageningen, 57 pp.

Dugas, W.A., and G.F. Arkin. 1980. Evaluating sorghum production strategies using climatic data and crop models. American Society of Agronomy (72nd annual meet.),11

Feddes, R.A. 1982. Simulation of field water use and crop yield. p. 194-207. In Penning de Varies and Van Laar (ed). Simulation of plant growth and crop production PUDOC, Wageningen, Netherlands.

Frere, M., and G.F. Popov. 1979. Agrometeorological crop monitoring and forecasting. FAO plant production and protection paper 17. Rome, Italy, FAO.

Godwin, D.C. 1989. Weather generation programme. ICRISAT bulletin No. 12:18-19.

Grant, R.F. 1989. Simulation of maize phenology. Agron. J. 81:451-457.

Hammer, G.L., and Vanderlip. 1989. Genotype-by-environment interaction in grain sorghum. III. Modelling the impact in field environments. Crop Science. 29:385-391,1336.

Hawkins, R., J. Henas, R. Alegria, and E. Celada. 1986. Empirical models of maize-sorghum intercrop production and agrotechnology transfer in Central America, Agric. For. Meteorol. 36:269-280.

Heslehurst, M.R. 1982. Modelling seasonal sorghum yields in subtropical Australia. Agricultural Systems. Dept. of Agro. Queentland Agr. coll. 9(4):281-300.

Hodges, Tom, E.T. Kanemasu, and I.D. Teare. 1979. Modelling dry matter accumulation and yield of grain sorghum. can. J. Plant Sci. 59:803-818.

Huda, A.K.S. 1987. Simulating yields of sorghum and pearl millet in the semi-arid -tropics. Field Crops, Res. 15:309-325.

Jackson, M.L. 1967. Soil chemical analysis. Prentice Hall, New Delhi.

Karande, B.I. 1991. Determination of genetic coefficients of various sorghum genotypes for validation of CERES-Sorghum model. M.Sc. thesis, Mahatma Phule Agricultural University, College of Agriculture, Pune, Maharashtra, India.

Kartz, R.W. 1979. Sensitivity analysis of statistical crop-weather models. Agric. Meteorol. 20:291-300.

Kiniry, J.R., and C.A. Jones. 1986. Model Evaluation. CERES-Maize a simulation model of maize growth and development. p.113-144.

Legg, B.J. 1981. Aerial environment and crop growth. pp. 123-149 in Mathematics and Plant Physiology (eds. D.A. Rose and D.A. Charies-Edwards). Academic Press, New York, USA.

Lemon, E.R. 1977. In "Final Report of the USDA Modelling Coordinating Committee". pp.1-17.

Liu, W.T.H., D.M. Botner, C.M. Sakamoto. 1989. Application of CERES-Maize model to yield prediction of Brazilian maize hybrid. Agric. For. Meteorol. 45:299-312.

MacKerron, D.K.L. 1986. A simple model of potato growth and yield. Part II. Validation and external sensitivity. Agric. For. Meteorol. 34:285-300.

MacKerron, D.K.L., and P.D. Waister. 1985. A simple model of potato growth and yield. Part I. Model development and sensitivity analysis. Agric. For. Meteorol. 34:241-252.

MaCree, K.J., and C.J. Fernandez. 1989. Simulation model for studying physiological water stress responses of whole plant. Crop science. 29:353-360.

Mani, A., and S. Rangarajan. 1982. Solar Radiation over India. Applied Science Pub.

Mass, S.J., and G.F. Arkin. 1980. Sensitivity analysis of a Grain Sorghum Growth Simulation Model. Sorghum News Letter. 23:142.

Mass, S.J. 1988. Using satellite data to improve model estimates of crop yield. Agro. J. 80:655-662.

Monteith, J.L., A.K.S. Huda, and D. Midya. 1989. Resource Capture Model for sorghum and pearl millet. ICRISAT bulletin No. 12:21:24.

Newman, J.E. 1974. Applying meteorology to agriculture. Editorial Agric. Meteorol., 13(1):1-3.

Piper, C.S. 1966. Soil and plant analysis. Hans. Publishers, Bombay.

Ragab, R., F Beese, and w. Ehlers. 1990a. A soil water balance and dry matter production model:I. Soil water balance of oat. Agron. J. 82:152-156.

Ragab, R., F Beese, and w. Ehlers. 1990b. A soil water balance and dry matter production model:II. Dry matter production of oat. Agron. J. 82:157-161.

Reddy, J.T. 1981. Validation of the cotton simulation model in agriculture and biology. Conclusions of Workshop. Agriculture System. 2:99-107.

Reddy, V.R., Baker, D.N. and Jenkins, J.N. 1985. Agric. Syst., 17:133-154.

Ritchie, J.T. 1972. Model for predicting evaporation from a row crop with incomplete cover. Water Resource Research, 8(5):1204-1213.

Ritchie, J.T., S. Otter, Nicke, and D. Godwin. 1988. Personal Communication. CERES-Wheat Draft No. 1.

Ritchie, J.T., and G. Alagarswamy. 1988. Documentation of CERES-Sorghum model: Growth and Development. Simulation Modelling Workshop. ICRISAT, Patoncheru, Andhra Pradesh, India. October 1988. 12-21.

Ritchie, J. T., and G. Alagarswamy. 1989. Simulation of growth and development in CERES models. ICRISAT bulletin No. 12:23-39.

Ritchie, J.T., and D.C. Godwin. 1989. Obtaining soil input for the CERES model. ICRISAT bulletin No. 12:16-18.

Ritchie, J.T., and G. Alagarswamy. 1989. Simulation of sorghum and pearl millet phenology. ICRISAT Bulletin. 12:24-26.

Rosenthal, W.P., R.L. Vanderlip, B.S. Jackson, and G.F. Arkin. 1989. SORKAM: A grain sorghum growth model. Research Centre and Model Documentation. MP-1669 Texas Agric. Exp. Stn. College Station, Tx.

Smith, R.C.G., and J.T. Ritchie. 1978. Importance of relationship between yield, climate, and phenological development in wheat and risks involved in production for a specific environment. Agronomy Abstract:14.

Thornely, J.H.M. 1975. Modelling as a tools in plant physiology. pp. 339-359 in Environmental effects on crop physiology (eds. J.J. Landsberg and C.V. Cutting) Academic Press New York, USA.

Thornley, J.H.M. 1976. Mathematical modes in plant physiology. Academic Press New York, USA.

Vanderlip, R.L., and H.E. Reeves. 1972. Growth stages of sorghum (*Sorghum bicolor* L. Moench). Agro. J. 64:13-16.

Versteeg, M.N., and H. Vankeulen. 1986. Potential crop production prediction by some simple calculation methods, as compared with computer simulations. Agricultural Systems. 19:249-272.

Walker, J.N., and W.E. Splinter. 1971. Introduction: Mathematical modelling of plants. Transactions of ASAE. 14:945.

Whistler,F.D., B. Acock, D.N. Baker, R.E. Fye, H.F. Hodges, J.R. Lamberton, H.E. Lemmon, J.M. Mackinion, and V.R. Reddy. 1986. Crop simulation models in agronomic systems. Advances in Agronomy. 40:141-208.

Willmott. 1982. Validation of the model. Chapter No. 8 in CERES-Wheat Book Draft No. 1.

Wu, W.T.H., D.M. Bother, and C.M. Sakamoto. 1989. Application of CERES-Maize model to the North China Plain. Agric. For. Meteorology. ICRISAT Bulletin. 12:24-26.

Yarraton, G.A. 1971. Mathematical representation and models in plant ecology: response to a note by R. Mead. Journal of Ecology. 59:221-224.

Zur, B., and J.W. Jones. 1981. A model for water relations, photosynthesis and expansive growth of crop. Wat. Reso. Res. 17(2):311-320.

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APPENDIX

APPENDIX

RUN 1 OUTPUT SUMMARY
INST_ID :CS SITE_ID: PU EXPT_NO: 01 YEAR : 1989 TRT_NO· 1
EXP. :VLIDATION OF CERES MODEL
TRT. :S1V1(M-35-1/16-09-89
WEATHER : CASAM Pune 1989-90
SOIL .MEDIUM BLACK CALCARIOUS SOIL (VERTISOL)
VARIETY M-35-1
IRRIG. :ACCORDING TO THE FIELD SCHEDULE.
LATITUDE = 18.5 , SOWING DEPTH = 5. CM , PLANT POPULATION = 13. PLANTS PER SQ METER
GENETIC SPECIFIC CONSTANTS
P1 =360. P2O =14.0 P2R= 44. P5 = 550.0 G1 =15.0 G2= 4.5

SOIL PROFILE DATA [PEDON: PUNE]
SOIL ALBEDO= .17 U= 6.0 SWCON= .15 RUNOFF CURVE NO.= 85.0

DEPTH-CM	LO LIM	UP LIM	SAT SW	EXT SW	IN SW	WR	NO3	NH4
0.- 5.	.148	.371	.429	.223	.067	.897	10.2	5.6
5.- 10.	.149	.385	.420	.236	.108	1.000	10.9	5.5
10.- 25.	.151	.391	.433	.240	.155	.789	9.6	4.5
25.- 40.	.155	.398	.434	.243	.185	.598	5.4	2.2
40.- 55.	.162	.392	.432	.230	.230	.387	5.0	1.7
55.- 70.	.185	.399	.434	.214	.287	.212	5.4	2.7
70.- 85.	.220	.399	.434	.179	.320	.212	5.6	2.5
85.- 100.	.220	.409	.434	.189	.320	.212	5.6	2.5
T 0.- 100.	17.9	39.6	43.3	21.7	23.3		70.*	32.*

* NOTE: Units are in kg / hectare.

FERTILIZER INPUTS

DAY OF YEAR	KG/HA	DEPTH	SOURCE
259	50.00	5.00	UREA

THE PROGRAM STARTED ON JULIAN DATE 256

DATE	CDTT	PHENOLOGICAL STAGE	BIOM	LAI	NUPTK	N%	CET	RAIN	PESW
16 Sep	0.	SOWING	g/m^2		kg/ha		----mm	-----	cm
17 Sep	17.	GERMINATION					5.	96.	15.
21 Sep	65.	EMERGENCE					13.	13.	15.
11 Oct	364.	END JUVENILE	29.	.74	12.8	4.46	84.	157.	20.
17 Oct	472.	PANICLE INITIATION	60.	1.28	24.0	4.00	104.	157.	18
9 Nov	854.	END LF GRTH	316.	3.58	80.0	2.53	209.	157.	7.
28 Nov	1170.	ANTHESIS	456.	2.96	84.8	1.86	306.	242.	6.
3 Dec	1248.	END PAN GRTH	494.	2.83	84.2	1.70	326.	242.	4.
9 Jan	1799.	END GRAIN FILL	870.	.78	35.8	.88	443.	322.	0.
10 Jan	1814.	PHYSIOLOGICAL MATURITY	870.	.78	35.8	.88	443.	322.	0.

YIELD (KG/HA)= 3700. (BU/ACRE)= 58.9 FINAL GPSM= 13068. KERNEL WT.(mg)= 28.3

ISTAGE	CSD1	CSD2	CNSD1	CNSD2	S T A G E O F G R O W T H
1	.00	.00	.06	.06	EMERGENCE - END JUVENILE
2	.00	.00	.00	.00	END JUVENIL - PANICLE INIT
3	.00	.00	.06	.06	PANICLE INIT - END LF GROWTH
4	.00	.00	.12	.12	END LF GRTH - END PAN GROWTH
5	.07	.12	.66	.66	END PAN GRTH - PHYS MATURITY

* NOTE: In the above table, 0.0 represents minimum
stress and 1.0 represents maximum stress for water
(CSD) and nitrogen (CNSD), respectively.

JUL. DAY 259 319 351
AMOUNT mm 95. 85. 80.
IRRIGATION THIS SEASON : 260. mm

	PREDICTED	OBSERVED
ANTHESIS DATE	332	328
MATURITY DATE	10	12
GRAIN YIELD (KG/HA)	3700.	3884.
KERNEL WEIGHT (G)	.028	.031
GRAINS PER SQ METRE	13068.	14937.
GRAINS PER PANICLE	1020.95	1166.00
MAX. LAI	3.58	3.82
BIOMASS (KG/HA)	8704.	9702.
STRAW (KG/HA)	5005.	5818.
GRAIN N%	1.35	-9.00
TOT N UPTAKE (KG N/HA)	85.7	-9.0
STRAW N UPTAKE	35.8	-9.0
GRAIN N UPTAKE	49.9	-9.0

RUN 1 S1V1(M-35-1/16-09-89
INST_ID :CS SITE_ID· PU EXPT_NO: 01 YEAR : 1989 TRT_NO: 1
EXP. :VLIDATION OF CERES MODEL
TRT. :S1V1(M-35-1/16-09-89
WEATHER : CASAM Pune 1989-90
SOIL :MEDIUM BLACK CALCARIOUS SOIL (VERTISOL)
VARIETY :M-35-1
IRRIG. :ACCORDING TO THE FIELD SCHEDULE.

DAY OYR	SDTT	BIO g/m2	LN	LAI	ROOT ¦-----	STEM Weight	PANICLE in g	LEAF -----¦	RTD (cm)	PTF	L1 ¦-	L3 RLV	L5 --¦
270	120.	4.	1	.10	.19	.01	.00	.31	34.	.63	.6	.2	.0
277	240.	12.	3	.30	1.10	.01	.00	.92	61.	.46	.8	.6	.2
284	367.	29.	4	.74	4.27	.01	.00	2.24	88.	.35	.9	2.1	.9
291	17.	71.	5	1.38	9.25	.53	.00	5.04	100.	.38	.9	4.7	2.2
298	130.	147.	7	2.08	14.91	2.41	.00	9.06	100.	.43	.9	5.0	3.8
305	251.	230.	8	2.85	20.87	4.40	.00	13.59	100.	.46	.8	5.0	5.0
312	363.	305.	9	3.49	27.27	6.14	.00	17.68	100.	.47	.8	5.0	5.0
319	105.	360.	9	3.34	33.53	9.85	.00	18.27	100.	.46	1.2	5.0	5.0
326	222.	411.	9	3.13	39.95	13.82	.00	18.27	100.	.45	5.0	5.0	5.0
333	334.	464.	9	2.94	45.83	17.94	.00	18.27	100.	.44	4.9	5.0	5.0
340	59.	533.	9	2.74	49.35	15.74	7.65	18.27	100.	.46	4.7	5.0	5.0
347	156.	603.	9	2.37	50.15	15.74	13.10	18.27	100.	.48	4.5	5.0	5.0
354	246.	664.	9	1.79	49.42	15.74	17.88	18.27	100.	.51	4.6	5.0	5.0
361	352.	747.	9	1.32	47.81	15.00	25.07	18.27	100.	.55	4.6	5.0	4.9
3	468.	818.	9	.99	46.16	13.47	32.23	18.18	100.	.58	4.6	5.0	4.9

RUN 1 S1V1(M-35-1/16-09-89
INST_ID ·CS SITE_ID· PU EXPT_NO: 01 YEAR : 1989 TRT_NO: 1
EXP. :VLIDATION OF CERES MODEL
TRT. .S1V1(M-35-1/16-09-89
WEATHER . CASAM Pune 1989-90
SOIL .MEDIUM BLACK CALCARIOUS SOIL (VERTISOL)
VARIETY :M-35-1
IRRIG. :ACCORDING TO THE FIELD SCHEDULE.

* Units are in MJ/square meter.

	---------- AVERAGE					--------- PERIOD		SW CONTENT	W/DEPTH		TOTAL	
DAY OYR	EP (mm)	ET (mm)	EO (mm)	SR*	MAX C	MIN C	PREC (mm)	SW1	SW2	SW3	SW4	SW5	PESW (cm)
262	.0	1.7	4.7	19.	30.4	21.3	99.00	.21	.10	.43	.33	.32	14.1
269	.1	3.6	4.2	17.	31.0	20.4	109.00	.34	.42	.42	.43	.40	21.2
276	.3	3.6	3.7	15.	29.4	20.8	43.00	.28	.42	.41	.41	.41	22.8
283	1.8	3.2	5.4	22.	33.2	18.4	2.00	.11	.34	.38	.37	.38	20.4
290	3.3	3.4	5.6	22.	34.2	17.8	.00	.10	.26	.31	.35	.36	17.7
297	4.2	4.2	5.3	22.	33.6	15.0	.00	.10	-.12	.34	.34	.34	14.6
304	4.5	4.5	5.0	21.	33.9	16.5	.00	.10	-.11	.29	.29	.30	11.5
311	5.0	5.0	5.1	20.	35.8	14.3	.00	.10	-.10	.25	.25	.26	8.0
318	4.9	4.9	4.9	18.	37.1	16.7	.00	.10	-.10	.21	.21	.23	4.5
325	4.3	5.6	5.6	19.	38.6	17.3	85.00	.21	.02	.32	.31	.30	9.1
332	3.9	4.7	4.7	19.	35.7	13.2	.00	.10	.08	.25	.25	.25	5.8
339	4.1	4.1	4.3	18.	34.4	13.0	.00	.10	.10	.19	.20	.21	3.0
346	3.9	3.9	4.3	18.	33.6	11.1	.00	.10	.11	.16	.16	.17	.3
353	2.2	2.9	4.0	18.	31.4	9.9	80 00	.30	.21	.31	.34	.18	6.3
360	2.5	3.9	3.9	16.	32.5	14.0	.00	.10	.24	.24	.24	.21	3.6
2	2.4	2.5	3.5	14.	32.9	15.7	.00	.10	.20	.20	.20	.20	1.8
9	2.5	2.5	4.3	17.	33.3	13.9	.00	.10	.16	.16	.16	.17	.1

```
RUN   1          S1V1(M-35-1/16-09-89
INST_ID :CS  SITE_ID: PU  EXPT_NO: 01  YEAR : 1989  TRT_NO.  1
EXP.      VLIDATION OF CERES MODEL
TRT.     :S1V1(M-35-1/16-09-89
WEATHER : CASAM Pune 1989-90
SOIL     :MEDIUM BLACK CALCARIOUS SOIL (VERTISOL)
VARIETY :M-35-1
IRRIG.   .ACCORDING TO THE FIELD SCHEDULE.
```

DAY	TOPS	NFAC	VEG N	GRAIN	NO3	NO3	NO3	NO3	NO3	NH4	NH4	NH4
	N %		UPTK	UPTK	1	2	3	4	5	1	2	3
OYR			- kg N/ha -		¦---------------		ug N/g soil			---------------		¦
262	6.30	1.00	.0	.0	30.2	11.4	18.2	11.4	6.8	8.2	12.7	5.1
269	5.15	.95	1.5	.0	4.6	13.6	18.2	18.5	11.6	3.7	9.0	3.4
276	4.18	.90	4.0	.0	1.6	9.1	15.8	18.4	13.9	1.9	4.6	2.2
283	4.69	.96	11.7	.0	2.0	8.2	12.8	15.6	12.8	1.6	2.4	1.6
290	4.33	1.00	24.0	.0	2.1	13.1	8.3	10.8	10.3	1.5	2.1	1.3
297	3.75	.94	47.2	.0	2.1	8.7	4.7	5.6	6.6	1.5	1.3	1.2
304	3.25	.94	67.0	.0	2.1	8.7	2.3	2.8	3.3	1.5	1.3	1.2
311	2.84	.94	78.8	.0	2.1	8.7	1.4	1.3	1.4	1.5	1.3	1.1
318	2.44	.87	80.8	.0	2.1	8.7	1.3	1.3	1.3	1.5	1.3	1.1
325	2.21	.86	84.1	.0	1.0	2.5	1.3	1.2	1.2	1.3	1.3	1.1
332	1.96	.89	84.8	.0	1.1	2.6	1.1	1.3	1.3	1.0	1.3	1.1
339	1.76	.96	73.1	10.9	1.1	2.6	1.3	1.3	1.3	1.0	1.3	1.0
346	1.28	.71	46.9	37.2	1.1	2.7	1.4	1.4	1.4	1.0	1.3	.9
353	.98	.24	40.8	44.3	.5	1.2	1.0	1.3	1.4	1.0	1.3	.9
360	.91	.16	38.9	46.5	.7	1.1	1.1	1.3	1.3	.9	1.2	.9
2	.91	.19	37.0	48.6	.7	1.4	1.3	1.3	1.3	.9	1.1	.9
9	.90	.21	35.8	49.9	.7	1.4	1.4	1.4	1.4	.9	1.0	.8

```
   A-M B-M NLOSS NIT  STRS NUPTK NIRR TOT  WAT STRS CET  RAIN BIONASS YIELD YIELD PLANTS NFT  NRATE  TITLE
                                  RUN IN SI YEAR EX TR IRR VARIETY    FILE1      SOIL           ROW
   --DAYS- kgN/h   3    5  kg/h        IRR    1   5  -- mm ---  ----- T/ha -------
                                                                                                 SPACE

SG:  74   0   14.  .06  .66  85.7   3  260.  .00  .07  443.    0.  8.70  3.70  3.70  12.80   1    50.
S1V1(M-35-1/16-09-89                          1 CS PU 1989 01  1  2 M-35-1   ICPU0112.W89 PUNE          6.600
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VITA

VITA

PANDURANG B. SHELKE

A candidate for the degree

of

MASTER OF SCIENCE

in

AGRICULTURE

1991

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