

**EFFECT OF TIMES OF SOWING AND NUTRIENT LEVELS ON DRYLAND  
SORGHUM VARIETIES AND EVALUATION OF DSSAT V.3.5 CERES-  
SORGHUM MODEL TO OPTIMIZE FARM MANAGEMENT STRATEGIES**

Thesis submitted in part fulfilment of the requirements for the award of the degree of  
**DOCTOR OF PHILOSOPHY (Agriculture) in AGRONOMY**  
to the Tamil Nadu Agricultural University, Coimbatore.

By

**R. RAJA**  
(I.D. No. 98-806-009)

**DEPARTMENT OF AGRONOMY  
CENTRE FOR SOIL AND CROP MANAGEMENT STUDIES  
AGRICULTURAL COLLEGE AND RESEARCH INSTITUTE  
TAMIL NADU AGRICULTURAL UNIVERSITY  
COIMBATORE-641 003**

2001

## CERTIFICATE

This is to certify that the thesis entitled "EFFECT OF TIMES OF SOWING AND NUTRIENT LEVELS ON DRYLAND SORGHUM VARIETIES AND EVALUATION OF DSSAT V.3.5 CERES-SORGHUM MODEL TO OPTIMIZE FARM MANAGEMENT STRATEGIES" submitted in part fulfilment of the requirements for the award of the degree of DOCTOR OF PHILOSOPHY (Agriculture) in AGRONOMY to the Tamil Nadu Agricultural University, Coimbatore is a record of bonafide research work carried out by Mr. R. RAJA under my supervision and guidance and that no part of this thesis has been submitted for the award of any other degree, diploma, fellowship or other similar titles, prizes and that the work has not been published in part or full in any scientific or popular journal or magazine.

Place : Coimbatore

Date : 31.5.2001

  
31.5.2001  
(Dr. T. N. BALASUBRAMANIAN)

Chairman

Approved by:

Chairman :


  
20.11.01  
(Dr. T. N. BALASUBRAMANIAN)

Members :

  
(Dr. A. BALASUBRAMANIAN)

  
20.11.01  
(Dr. T. M. THIYAGARAJAN)

  
(Dr. C. KAILASAM)

  
Date : 20/11/2001 External Examiner:

## **ACKNOWLEDGEMENT**

---

---

## ACKNOWLEDGEMENT

I wish to express my deep heartfelt sense of gratitude to the Chairman of the Advisory Committee, **Dr. T. N. Balasubramanian**, Professor and Head, Department of Agricultural Meteorology for his benevolent and noble ideas, constructive criticism, valuable guidance, incessant and steadfast inspiration, and keen interest shown throughout the course of investigation which had vivified this script.

With deep respect and esteem regards, I owe my indebtedness to the members of the advisory committee, **Dr. T.M. Thiyagarajan**, Director (Centre for soil and crop management studies), **Dr.A. Balasubramanian**, Professor of Agronomy and **Dr. C. Kailasam**, Professor and Head (Department of Mathematics) for their valuable guidance and suggestions during the course of study.

I express my wholehearted thanks to **Dr. N. Sankaran**, Professor and Head (Department of Agronomy) and **Dr.J. Krishnarajan**, former Professor and Head (Agronomy) for creating a flexible high performance learning environment throughout my postgraduate programme.

I wish to place my high sense of regards and heartfelt thanks to **Prof. Dr. T. Marimuthu**, Dean (P.G. Studies) for his academic counseling.

I wish to express my deep regards to **Dr.K.K.Chandaragiri**, P.G. Coordinator and **Dr. P. Subbian**, former P.G. Coordinator for their academic and administrative help.

I humbly express my wholehearted thanks to all the staff members in the department of **Agronomy and Agricultural Meteorology** for their relishable and timely help.

I express my sincere thanks to **Dr.C. Chinnusamy**, **Dr.S. Sakthivel** and **Thiru. E. Somasundaram**, Farm managers (Eastern Block) and **Dr. G. James Martin**, Farm Superintendent for their kind help and encouragement for the successful conduct of the field experiment.

I wish to avail this opportunity to acknowledge the valuable suggestions and help rendered by **Dr. R. Jaganathan** (Associate professor), **Dr. C. R. Chinnamuthu**, **Dr.R. Selvaraju**, **Dr. V. Geethalakshmi**, **Dr. Paramasivam**, **Er. A. Raviraj** and **Tmt.L. Chithra** Assistant professors.

I express my sincere thanks to **Dr. Samsul Huda**, UWS, Australia, **Dr. Peter Cornish**, UWS, Australia, **Mr. David George**, QCCA, Toowoomba, Australia, **Dr. John Mc. Bride**, BOM, Melbourne and **Dr. Joe T. Ritchie**, Michigan State University, USA for their encouragement and clearful suggestions for the study.

My heartfelt thanks to **ACIAR**, Australia and **Tamil Nadu Agricultural University**, Coimbatore for the financial support to carry out the study.

I wish to deliver my sincere and grateful thanks for everlasting exemplary enthusiasm and unsolicited assistance shown by my friends **Dr. Bhaskar**, **Er. P. Sivaneswaran**, **N. Sakthivel**, **R.Karthikeyan**, **S. Suresh**, **G. Thiyagarajan**, **P. Kadirvel**, **E. P. Venkatachalam**, **R. Nandakumar**, **V. A. Sathyamoorthy** and **S. Shanmugasundaram**. I wish to express my thanks to classmates for their help rendered during the study period and I remember with gratitude the friendly helps rendered by my Junior and Senior P.G. Scholars.

My heart feels elated to thank my parents for their blessings to complete this work successfully. I also wish to empress my gratitude to my sister, brother-in-law, and Master **Naveen kumar** for their encouragement rendered for the study period.

  
[R. RAJA]

*Dedicated to  
My Teachers*

---

---

## **ABSTRACT**

---

---

## ABSTRACT

### EFFECT OF TIMES OF SOWING AND NUTRIENT LEVELS ON DRYLAND SORGHUM VARIETIES AND EVALUATION OF DSSAT V.3.5 CERES- SORGHUM MODEL TO OPTIMIZE FARM MANAGEMENT STRATEGIES

BY

**R.RAJA**

Degree : **Doctor of Philosophy (Agriculture) in Agronomy**

Chairman : **Dr. T. N. BALASUBRAMANIAN**  
Professor and Head  
Department of Agricultural Meteorology  
Tamil Nadu Agricultural University  
Coimbatore – 641 003.

**2001**

Field experiments were conducted in the dryland farm of Department of Agronomy, Tamil Nadu Agricultural University, Coimbatore during Northeast monsoon (NEM) seasons of 1999 and 2000 under dryland condition with a view to study the performance of two sorghum (*Sorghum bicolor* (L.) Moench.) varieties under different sowing dates and levels of nutrients (Nitrogen and Phosphorus) on the growth and yield of grain sorghum. The study also aimed to evaluate DSSAT V.3.5 of Decision Support System (CERES-Sorghum model) for key management practices like choice of varieties, times of sowing and nutrient levels.

Two sowing times (sowing before the receipt of monsoon rainfall and sowing after the receipt of monsoon rainfall), two varieties (CO 26 and CSV 15) and three nutrient levels (No nutrient application (control), 40: 20: 0 kg N: P<sub>2</sub>O<sub>5</sub>: K<sub>2</sub>O ha<sup>-1</sup> and 60: 30: 0 kg N: P<sub>2</sub>O<sub>5</sub>: K<sub>2</sub>O ha<sup>-1</sup>) were evaluated in a split plot design, replicated thrice.

The long term average rainfall of 94 years (1907-2000) for NEM season of Coimbatore is 324.8 mm. The returning period worked out by using 94 years NEM season rainfall indicated that the chances for getting the average NEM rainfall of 324.8 mm was 4/9 (four years out of nine years), while the repeatability of NEM of 1999 and 2000 (427.6 and 284 mm) would be 4/18 and 1/2, respectively. The rainfall received during the 1999 NEM season crop (427.6 mm) was well above the long term

average, where as the rainfall received by the 2000 NEM season crop (284 mm) was below the long term average rainfall.

The experimental results revealed that the evaluated varieties CO 26 and CSV 15 exhibited distinct variation on their growth and yield under different times of sowing and levels of nutrient application studied.

During 1999 NEM season (above average rainfall year), the variety CSV 15 sown before the receipt of monsoon rainfall with 60: 30: 0 kg N: P<sub>2</sub>O<sub>5</sub>: K<sub>2</sub>O ha<sup>-1</sup> had registered enhanced growth attributes in general and produced earheads with higher number of grains and in turn registered higher grain yield. The resource use efficiencies were also higher with CSV 15 sown before the receipt of monsoon rainfall. This combination of sowing CSV 15 before the receipt of monsoon rainfall with 60: 30: 0 kg N: P<sub>2</sub>O<sub>5</sub>: K<sub>2</sub>O ha<sup>-1</sup> resulted in high B: C ratio.

During 2000 NEM season (below average rainfall year), sowing of CSV 15 before the receipt of monsoon rainfall with 40: 20: 0 kg N: P<sub>2</sub>O<sub>5</sub>: K<sub>2</sub>O ha<sup>-1</sup> produced appreciable growth attributes and produced lengthier earheads with more number of grains and finally recorded higher grain yield. The resource use efficiencies and B: C ratio were also higher for this combination.

Water balance studies indicated that total cumulative rainfall received during the cropping period, effective rainfall and available soil moisture were decreased as sowing was delayed. Soil moisture dynamics for available water observed both through water balance model and actual measurements indicated the same trend but registered wide variation in respect of quantity of water gained or lost in both the years (above and below average rainfall years).

During 1999-2000 (first crop), both the varieties had only 76.30 per cent of the total water requirement (218.94 mm out of 286.79 mm) under sowing before the receipt of monsoon rainfall and under sowing after the receipt of monsoon rainfall, the variety CO 26 received only 70.18 per cent of the water requirement (207.7 mm out of 295.96 mm) and the variety CSV 15 received only 75.91 per cent of the water requirement (207.7 mm out of 273.61 mm). During 2000-2001 (second crop), irrespective of the varieties, sowing before the receipt of monsoon rainfall got only 59.86 per cent of the water requirement (206.95 mm out of 345.72 mm), while it was

59.91 per cent for sowing after the receipt of monsoon rainfall (196.46 mm out of 327.89 mm).

The CERES-sorghum model of DSSAT V.3.5 Decision Support System predicted the phenological developments like panicle initiation, anthesis and physiological maturity very well. But the model poorly predicted the growth (biomass) and yield components (number of grains earhead<sup>-1</sup> and single grain weight) especially under moisture stress condition and in turn poorly predicted the grain yield during 2000 NEM season (below average rainfall year) though the model prediction was fairly good for the 1999 NEM season (above average rainfall year).

Summarising, sowing of sorghum variety CSV 15 before the receipt of monsoon rainfall with 60: 30: 0 kg N: P<sub>2</sub>O<sub>5</sub>: K<sub>2</sub>O ha<sup>-1</sup> during above average rainfall year and 40: 20: 0 kg N: P<sub>2</sub>O<sub>5</sub>: K<sub>2</sub>O ha<sup>-1</sup> during below average rainfall year, would be a sustainable *Vertisol* dryland management technology for the western zone of Tamil Nadu. The result is applicable when seasonal climate forecast information is available in advance.

## ABBREVIATIONS USED

BCR	- Benefit-Cost Ratio
CD	- Critical Difference
CERES	- Crop Environment Resource Synthesis
CGR	- Crop Growth Rate
DAS	- Days After Sowing
DMP	- Dry Matter Production
DSS	- Decision Support Systems
g	- gram
HI	- Harvest Index
K	- Potassium
Kg ha <sup>-1</sup>	- Kilogram per hectare
LAI	- Leaf Area Index
N	- Nitrogen
NAR	- Net Assimilation Rate
NEM	- Northeast Monsoon
NS	- Not Significant
P	- Phosphorus
PI	- Panicle Initiation
PM	- Physiological Maturity
RGR	- Relative Growth Rate
SEd	- Standard error of deviation

## LEGEND

First crop	- 1999-2000
First year	- 1999-2000
1999 NEM	- 1999-2000
Second crop	- 2000-2001
Second year	- 2000-2001
2000 NEM	- 2000-2001

## CONTENTS

CHAPTER NO.	TITLE	PAGE NO.
I	INTRODUCTION	1
II	REVIEW OF LITERATURE	4
III	MATERIALS AND METHODS	24
IV	RESULTS	56
V	DISCUSSION	132
VI	SUMMARY AND CONCLUSION	181
	REFERENCES	
	PLATES	
	APPENDICES	

## LIST OF TABLES

Table No.	Title	Page No.
1	Weather parameters prevailed during the crop growth period (Northeast monsoon 1999)	25
2	Weather parameters prevailed during the crop growth period (Northeast monsoon 2000)	26
3	Soil characteristics of the experimental field	30
4	Characteristics of sorghum cultivars	31
5	Particulars on dates of sowing and dates of harvest for different treatments	36
6	Particulars of biometric observations taken in the experimental plots during 1999-2000 and 2000-2001	38
7	Kc values for sorghum	39
8	Effect of varieties, times of sowing and nutrient levels on plant height (cm) of sorghum at vegetative stage	57
9	Effect of varieties, times of sowing and nutrient levels on plant height (cm) of sorghum at flowering and maturity stages	58
10	Effect of varieties, times of sowing and nutrient levels on dry matter production ( $\text{kg ha}^{-1}$ ) of sorghum at vegetative stage	60
11	Effect of varieties, times of sowing and nutrient levels on dry matter production ( $\text{kg ha}^{-1}$ ) of sorghum at flowering and maturity stages	61
12	Interaction effect of varieties and times of sowing on dry matter production ( $\text{kg ha}^{-1}$ ) of sorghum during 2000-2001 (second crop)	63
13	Effect of varieties, times of sowing and nutrient levels on leaf area index of sorghum at vegetative stage	64
14	Effect of varieties, times of sowing and nutrient levels on leaf area index of sorghum at flowering and maturity stages	65
15	Effect of varieties, times of sowing and nutrient levels on crop growth rate ( $\text{g m}^{-2} \text{ day}^{-1}$ ) of sorghum during 1999-2000 (first crop)	67
16	Effect of varieties, times of sowing and nutrient levels on crop growth rate ( $\text{g m}^{-2} \text{ day}^{-1}$ ) of sorghum during 2000-2001 (second crop)	68
17	Effect of varieties, times of sowing and nutrient levels on relative growth rate ( $\text{g g}^{-1} \text{ day}^{-1}$ ) of sorghum during 1999-2000 (first crop)	70
18	Effect of varieties, times of sowing and nutrient levels on relative growth rate ( $\text{g g}^{-1} \text{ day}^{-1}$ ) of sorghum during 2000-2001 (second crop)	71

Cont'd.,

Cont'n.,

Table No.	Title	Page No.
19	Effect of varieties, times of sowing and nutrient levels on net assimilation rate ( $\text{g m}^{-2} \text{day}^{-1}$ ) of sorghum during 1999-2000 (first crop)	73
20	Effect of varieties, times of sowing and nutrient levels on net assimilation rate ( $\text{g m}^{-2} \text{day}^{-1}$ ) of sorghum during 2000-2001 (second crop)	74
21	Effect of varieties, times of sowing and nutrient levels on root volume (cc) of sorghum at vegetative stage	75
22	Effect of varieties, times of sowing and nutrient levels on root volume (cc) of sorghum at flowering and maturity stages	76
23	Effect of varieties, times of sowing and nutrient levels on Root: Shoot ratio of sorghum during 1999-2000 (first crop)	78
24	Effect of varieties, times of sowing and nutrient levels on Root: Shoot ratio of sorghum during 2000-2001 (second crop)	79
25	Effect of varieties, times of sowing and nutrient levels on earhead length (cm), grain number per earhead and test weight (g) of sorghum	81
26	Effect of varieties, times of sowing and nutrient levels on grain yield ( $\text{kg ha}^{-1}$ ) of sorghum	83
27	Effect of varieties, times of sowing and nutrient levels on straw yield ( $\text{kg ha}^{-1}$ ) of sorghum	85
27a	Interaction effect of varieties and times of sowing on straw yield ( $\text{kg ha}^{-1}$ ) of sorghum during 1999-2000 (first crop)	85
28	Effect of varieties, times of sowing and nutrient levels on harvest index (per cent) of sorghum	87
29	Effect of varieties, times of sowing and nutrient levels on resource use efficiency of sorghum	88
30	Effect of varieties and times of sowing on water balance components (cumulative values) of sorghum during 1999-2000 (first crop)	91
31	Effect of varieties and times of sowing on mean water requirement of sorghum during 1999-2000 (first crop)	92
32	Effect of varieties and times of sowing on water balance components (cumulative values) of sorghum during 2000-2001 (second crop)	93
33	Effect of varieties and times of sowing on mean water requirement of sorghum during 2000-2001 (second crop)	94
34	Effect of varieties and times of sowing on available soil moisture dynamics at different stages of sorghum-simulated values (water balance model- Gupta <i>et al.</i> , 1972) in mm per m depth during 1999-2000 (first crop)	97

Cont'd.,

Cont'n.,

Table No.	Title	Page No.
34a	Effect of varieties and times of sowing on available soil moisture dynamics at different stages of sorghum-estimated values (Gravimetric method) in mm per m depth during 1999-2000 (first crop)	97
35	Effect of varieties and times of sowing on available soil moisture dynamics at different stages of sorghum-simulated values (water balance model- Gupta <i>et al.</i> , 1972) in mm per m depth during 2000-2001 (second crop)	98
35a	Effect of varieties and times of sowing on available soil moisture dynamics at different stages of sorghum-estimated values (Gravimetric method) in mm per m depth during 2000-2001 (second crop)	98
36	Effect of varieties, times of sowing and nutrient levels on N uptake (kg ha <sup>-1</sup> ) of sorghum at vegetative stage	101
37	Effect of varieties, times of sowing and nutrient levels on N uptake (kg ha <sup>-1</sup> ) of sorghum at flowering and maturity stages	102
38	Effect of varieties, times of sowing and nutrient levels on P uptake (kg ha <sup>-1</sup> ) of sorghum at vegetative stage	103
39	Effect of varieties, times of sowing and nutrient levels on P uptake (kg ha <sup>-1</sup> ) of sorghum at flowering and maturity stages	104
40	Effect of varieties, times of sowing and nutrient levels on K uptake (kg ha <sup>-1</sup> ) of sorghum at vegetative stage	106
41	Effect of varieties, times of sowing and nutrient levels on K uptake (kg ha <sup>-1</sup> ) of sorghum at flowering and maturity stages	107
42	Effect of varieties, times of sowing and nutrient levels on post harvest available soil NPK (kg ha <sup>-1</sup> ) status	109
43	Economics of sorghum cultivation under dryland condition during 1999-2000	110
44	Economics of sorghum cultivation under dryland condition during 2000-2001	111
45	Minimum Data Set (MDS) for genetic coefficient calculation of sorghum varieties (CSV 15 and CO 26)	112
46	Genetic coefficients for CSV 15 and CO 26	113
47	Observed and CERES-Sorghum model predicted Panicle Initiation (PI) date for sorghum cultivars under different times of sowing and nutrient levels	116
48	Observed and CERES-Sorghum model predicted anthesis date for sorghum cultivars under different times of sowing and nutrient levels	118

Cont'd.,

Cont'n.,

Table No.	Title	Page No.
49	Observed and CERES-Sorghum model predicted Physiological Maturity (PM) date for sorghum cultivars under different times of sowing and nutrient levels	119
50	Observed and CERES-Sorghum model predicted biomass yield ( $\text{kg ha}^{-1}$ ) of sorghum cultivars under different times of sowing and nutrient levels	120
51	Observed and CERES-Sorghum model predicted grains per earhead of sorghum cultivars under different times of sowing and nutrient levels	122
52	Observed and CERES-Sorghum model predicted single grain weight (g) of sorghum cultivars under different times of sowing and nutrient levels	123
53	Observed and CERES-Sorghum model predicted grain yield ( $\text{kg ha}^{-1}$ ) of sorghum cultivars under different times of sowing and nutrient levels	124
54	Simulated grain yield of CSV 15 during 1999-2000 by sensitivity analysis	126
55	Simulated grain yield of CO 26 during 1999-2000 by sensitivity analysis	127
56	Simulated grain yield of CSV 15 during 2000-2001 by sensitivity analysis	128
57	Simulated grain yield of CO 26 during 2000-2001 by sensitivity analysis	129
58	Weather parameters prevailed at different stages of crop growth during 1999-2000 (first crop) and 2000- 2001 (second crop)	133

## LIST OF FIGURES

Figure No.	Title	Page No.
1	Weather parameters prevailed during crop growth period (1999-2000)	27
2	Weather parameters prevailed during crop growth period (2000-2001)	28
3	Field lay out of experiment (1999-2000)	32
4	Field lay out of experiment (2000-2001)	33
5	Structure of DSSAT program	48
6	Schematic drawing of DSSAT components	49
7	Plot diagram of harvest area for collecting MDS for DSSAT V.3.5 CERES-Sorghum model	54
8	Economics of sorghum cultivation	114
9	Dry matter production (kg ha <sup>-1</sup> ) of sorghum varieties CO 26 and CSV 15 during 1999 NEM and 2000 NEM	143
10	Effect of treatments on grain yield (kg ha <sup>-1</sup> ) of sorghum	145
11	Effect of times of sowing on dry matter production (kg ha <sup>-1</sup> ) of sorghum during 1999 NEM and 2000 NEM	149
12	Effect of nutrient levels on dry matter production (kg ha <sup>-1</sup> ) of sorghum during 1999 NEM and 2000 NEM	160
13	Observed and model predicted Panicle Initiation (PI) date of sorghum (first crop)	165
14	Observed and model predicted Panicle Initiation (PI) date of sorghum (second crop)	165
15	Observed and model predicted anthesis date of sorghum (first crop)	167
16	Observed and model predicted anthesis date of sorghum (second crop)	167
17	Observed and model predicted Physiological Maturity (PM) date of sorghum (first crop)	168
18	Observed and model predicted Physiological Maturity (PM) date of sorghum (second crop)	168
19	Observed and model predicted biomass yield (kg ha <sup>-1</sup> ) of sorghum (first crop)	169

Cont'd.,

Cont'n.,

Figure No.	Title	Page No.
20	Observed and model predicted biomass yield (kg ha <sup>-1</sup> ) of sorghum (second crop)	169
21	Observed and model predicted grains earhead <sup>-1</sup> of sorghum (first crop)	171
22	Observed and model predicted grains earhead <sup>-1</sup> of sorghum (second crop)	171
23	Observed and model predicted single grain weight (g) of sorghum (first crop)	172
24	Observed and model predicted single grain weight (g) of sorghum (second crop)	172
25	Observed and model predicted grain yield (kg ha <sup>-1</sup> ) of sorghum (first crop)	174
26	Observed and model predicted grain yield (kg ha <sup>-1</sup> ) of sorghum (second crop)	174
27	Simulated grain yield (kg ha <sup>-1</sup> ) of CSV 15 during 1999-2000 (first crop) by sensitivity analysis	176
28	Simulated grain yield (kg ha <sup>-1</sup> ) of CO 26 during 1999-2000 (first crop) by sensitivity analysis	177
29	Simulated grain yield (kg ha <sup>-1</sup> ) of CSV 15 during 2000-2001 (second crop) by sensitivity analysis	179
30	Simulated grain yield (kg ha <sup>-1</sup> ) of CO 26 during 2000-2001(second crop) by sensitivity analysis	180

## LIST OF PLATES

Plate No.	Title	Page No.
1	Soil Profile	52
2	View of the D <sub>1</sub> sown CSV 15 sorghum under F <sub>1</sub> level at vegetative stage	155
3	View of the D <sub>1</sub> sown CSV 15 sorghum under F <sub>3</sub> level at vegetative stage	155
4	Influence of nutrient levels on the root system of D <sub>1</sub> sown CO 26 sorghum	157
5	Influence of nutrient levels on the root system of D <sub>2</sub> sown CO 26 sorghum	157
6	Influence of nutrient levels on the root system of D <sub>1</sub> sown CSV 15 sorghum	158
7	Influence of nutrient levels on the root system of D <sub>2</sub> sown CSV 15 sorghum	158
8	View of the D <sub>1</sub> sown CSV 15 sorghum under F <sub>3</sub> level at flowering stage (first crop)	162
9	View of the D <sub>1</sub> sown CSV 15 sorghum under F <sub>2</sub> level at flowering stage (second crop)	162

## LIST OF APPENDICES

Appendix No.	Title	Page No.
1	Weekly water balance of sorghum crop for Coimbatore	-
2	Soil morphological characteristics and physio-chemical properties of the experimental field	-
3	Description of various growth stages of sorghum	-
4	Effect of varieties and times of sowing on the daily water balance components of sorghum crop during 1999 NEM and 2000 NEM	-
5	Soil moisture content (mm) estimated at 0-15 cm and 15-30 cm by gravimetric method during 1999-2000 and 2000-2001	-
6	Returning period for Northeast monsoon season of Coimbatore	-

## **INTRODUCTION**

---

---

## CHAPTER I

### INTRODUCTION

India prepares herself to launch an Ever Green Revolution (EGR) through a paradigm shift in agricultural research and developmental strategies especially in dryland agriculture. Dryland farming is the heart of Indian agriculture occupying about 68 per cent of total cultivable area and contributing about 44 per cent to total food grains production. Extending area from drylands under further irrigation becomes limited because of many obvious reasons and hence the existing drylands would last as drylands forever. In Tamil Nadu, 55 per cent of total cultivable area (4 m ha) is critically under drylands. Considering the future food demand, research and development activities of dryland agriculture should be further strengthened as indicated elsewhere.

Among many annual crops, sorghum is one of the important crop being raised in dryland agriculture. Sorghum (*Sorghum bicolor* (L.) Moench) is characterized by its ability to interrupt its growth under moisture stress for extended periods and resume its growth as soon as favourable condition again occurs. Hence in India, it is cultivated in about 12.59 million ha with an annual production of 8.36 million tonnes, while Tamil Nadu produces about 0.70 million tonnes of sorghum grains from 0.58 million ha. Since the possibility of increasing land area under sorghum crop is quite limited with the introduction of alternate land use concept, timely sowing of improved varieties which have higher resources use efficiencies under adequate nutrients is the kingpin to increase the sorghum productivity for sustained production from drylands.

Time and labour, in addition to water are the main production constraints for a dryland farmer, since the agricultural operation of dryland agriculture starts with monsoon rains and every farmer has to do it simultaneously. Labour and water are to be shared equally between dryland farmers, and hence dry sowing of crops in anticipation of monsoon rainfall (pre monsoon sowing) would be the alternate technology.

Sowing of crops in anticipation of rainfall helps to utilize the initial showers of monsoon rainfall to the maximum extent possible for the germination and the

establishment of the concerned crop. Hence, one strategy to overcome the problem cited elsewhere is attempting through advanced sowing in anticipation of monsoon rains. Though such studies were conducted earlier, there was no concrete recommendation on the correct time of sowing (date). Under these circumstances, a simple water balance model developed by Frere and Popov (1979) becomes a handy tool for identifying the time of sowing.

Though productivity of dryland sorghum is mainly limited by soil moisture availability, the experiences gained so far from the dryland research has shown that under given rainfall situation, crop yields could be still enhanced with the application of nutrients. This in turn increases the water use efficiency. Therefore, to increase crop yields in the drylands, it is not only necessary to increase moisture availability but also to ensure the availability of required nutrients. At present, in Tamil Nadu for dryland sorghum, application of 40: 20: 0 kg N: P<sub>2</sub>O<sub>5</sub>: K<sub>2</sub>O ha<sup>-1</sup> is being recommended irrespective of varieties and rainfall amount. But sorghum crop responds differently under varying times of sowing and different cultivars have varying magnitude of response to nutrient application. The information on the response of high yielding sorghum varieties to nutrient levels under different times of sowing with varying rainfall situation is lacking at present and this makes the decision making process of dryland farmers more complex and complicated one.

Under these circumstances, Decision Support Systems (DSS) is a valuable tool for making a viable decision on the adoption of selected technologies at any point of time. Decision support systems is a specialised computer program that assist in farm decision making processes when many options are available for a single problem.

The International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT) initiated in 1982 for developing a systems analysis approach for addressing a wide range of agricultural, environmental and economic problems in developing countries has developed a special software system known as Decision Support System for Agrotechnology Transfer (DSSAT).

DSSAT has been designed to easily create "experiments" on computers to simulate outcomes of complex interactions between various agricultural practices, soil and weather conditions. This program is to suggest appropriate solutions to the site

specific problems. DSSAT relies heavily on crop simulation models to predict the performance of crops for making wide range of decisions. In DSSAT, CERES (Crop Environment Resource Synthesis) family crop model is used to predict the performance of six grain crops *viz.*, rice, wheat, barley, maize, sorghum and pearl millet.

The CERES-Sorghum model is based on plant morphogenesis, biomass accumulation and partitioning, soil water balance and soil plant nitrogen dynamics. The CERES-Sorghum model was developed and validated by Ritchie and Algarswamy (1989) by using data from multilocation sorghum modeling experiments in which sorghum hybrid CSH 1 was grown at several locations of India. Their results indicated that model was capable of simulating phasic development reasonably well, but yield predictions were poor. However, CERES-Sorghum model has not been evaluated under diverse agroclimatic conditions of Tamil Nadu.

In view of the above facts, the present study was taken up with the following objectives:

- ❖ To ascertain the effect of times of sowing of two sorghum varieties under different rainfall events on dryland sorghum growth and yield,
- ❖ To evaluate the effect of different nutrient doses on dryland sorghum yield and other related parameters under varying rainfall events and
- ❖ Evaluation of CERES-Sorghum dynamic simulation model of DSSAT V.3.5 for farm decision making.

## **REVIEW OF LITERATURE**

---

---

## CHAPTER II

### REVIEW OF LITERATURE

Sorghum is one of the most important cereal crops grown in arid and semi-arid tropics of India. Since, mostly grown under dryland condition, the productivity of sorghum is relatively low and highly unstable. The major constraints for higher productivity in the dryland regions are the lack of adequate soil moisture during the critical crop growth period coupled with poor fertility status of the soil. Hence it is desirable to select a suitable variety for this situation so as to accommodate with in the particular Length of Growing Period (LGP) identified. In other words, sowing the seed at appropriate time in order to utilize the rainfall and available nutrients most efficiently is the most important key management practice for dryland sorghum. Sorghum responds differently under varying times of sowing and different cultivars have varying magnitudes of response to fertilizer application. Under these circumstances, Decision Support Systems (DSS) is a valuable tool for making a viable decision on the adoption of selected technologies at any point of time. Decision support system is a specialised computer program that assist in farm decision making processes when many options are available for a single problem. At present, many countries employ DSS for developing strategies. The work done on the effect of times of sowing, varieties and fertilizer levels on the growth and yield of sorghum and the role of DSS in decision making under varying situations are reviewed in this chapter.

#### **2.1 Part I Main Experiment**

##### **2.1.1 Identifying sowing dates through water balance study**

Among various crop production factors, rainfall plays an important role in determining sowing time especially for dryland crops. Frere and Popov (1979) developed a simple water balance model to estimate the water availability to the crop by using rainfall, reference crop evapotranspiration and water holding capacity of the soil as inputs. In this method, it was assumed that the sowing could be done at the beginning of the monsoon season during any week when the rainfall satisfied the estimated water requirement of the crop under consideration.

Omer (1984) used water balance model and identified 20<sup>th</sup> June to 10<sup>th</sup> July as the optimum planting time for sorghum. Maximum transpiration, minimum evaporation and Water Stress Index (WSI) were the principal water balance components for selecting the sowing times. Schouwenaars *et al.* (1988) adopted water balance models namely SWETAM and SWATER to analyse sowing strategies for maize and suggested that sowing could be taken in October and April, respectively for expected potential production of 2300 kg ha<sup>-1</sup> at Southern Mozambique.

Stern (1988) used Frere and Popov (1979) water balance model and showed that sowing could be taken on second decade of June (10-20<sup>th</sup> June) for soil with both 100 and 60 mm Water Holding Capacity (WHC) as the mean Water Requirement Satisfaction Index (WRSI) was maximum compared to other sowing decades for groundnut at Hyderabad.

Axel Thomas (1992) adopted WRSI of Frere and Popov (1979) to identify the potential sowing period for rainfed maize at Yunnan province, PR, China. The results indicated that the South western part of the province was qualified as fully suitable with a seasonal water supply of 80 to 100 per cent, while East Yunnan generally showed less favourable condition with 50 to 80 per cent of seasonal water supply.

Sahu *et al.* (1993) adopted the Frere and Popov's (1979) model to identify the commencement of growing period for groundnut. The productivity was above average during the years of normal sowing (between June 1<sup>st</sup> and July 1<sup>st</sup>). The risk of below average production increased with delay in commencement of growing period beyond 2<sup>nd</sup> July when WRSI was below 89 per cent.

### **2.1.2 Influence of sowing dates/ weeks**

Most of the dryland crops were with lesser yields due to the non availability of information on the optimum sowing dates. Also the lag period observed between initiation of monsoon rain and actual sowing. Resource constraints prevailed also reduced the yield to greater extent. The sowing date was an important agronomic practice, which could be manipulated to increase the yield of dryland crops without any additional input cost. Dry seeding in anticipation of rain was one such advanced risk free agronomic practice, which helped to establish the crop at the earliest

opportunity of first seasonal rain and ensured better utilization of rainfall with out any plant population loss.

Sowing the crops in anticipation of the onset of monsoon rains had both advantages and disadvantages. Sowing crops in dry soil before the onset of monsoon had been reported to have the following benefits: i) There was ease, speed and precision of planting in dry soils; ii) The seasonal starting rain was used for the crop germination; and iii) dry planting usually resulted in better plant stands (ICRISAT, 1978). Some of the disadvantages of advance sowing were: i) in some years the first shower of the monsoon might be so light that they suffice only to start germination and not to complete germination and ii) frequently caused total loss of the seeds due to field ants and birds when the onset of monsoon was delayed unduly where information on weather forecast (rain forecast) was unavailable (ICRISAT, 1978).

#### **2.1.2.1 Effect of sowing dates/ weeks on growth components of sorghum**

Periyathambi (1980) observed beneficial effects on the growth components of sorghum due to early sowing. Pre-monsoon sowing (10 to 20 days prior to the onset of monsoon) significantly increased the plant height, Dry Matter Production (DMP) and Leaf Area Index (LAI) over sowing done at normal monsoon onset date at Coimbatore.

Kandiannan (1988) reported that sowing of sorghum after the onset of monsoon had decreased the plant height over sowing before the onset of monsoon at Coimbatore. Halepyati and Hosmani (1991) reported higher DMP and LAI under normal sowing as compared to late sowing in sorghum.

Mohammad and Hasan (1993) observed reduction in plant height due to delay in sowing from onset of monsoon (9<sup>th</sup> June).

#### **2.1.2.2 Effect of sowing dates/ weeks on sorghum yield components**

At Akola, Dahatonde and Moghe (1991) obtained higher 1000 grain weight of sorghum by sowing in 17<sup>th</sup> (23<sup>rd</sup> April-29<sup>th</sup> April) Meteorological Standard Week (MSW) over 21<sup>st</sup> MSW (21<sup>st</sup> May-27<sup>th</sup> May). Number of seeds earhead<sup>-1</sup>, earhead weight plant<sup>-1</sup> and 1000 grain weight were decreased in sorghum at Aruppukottai

(Tamil Nadu) due to delay in sowing from 15<sup>th</sup> September to 13<sup>th</sup> October (Solaiappan and Subramanian, 1995).

Mohammad and Hasan (1995) reported that panicle length was increased under early sowing (9<sup>th</sup> June) as compared to late sowing after the receipt of adequate rains (1<sup>st</sup> July).

### 2.1.2.3 Effect of sowing dates/ weeks on the yield of sorghum

Venkataraman (1981) found that sowing sorghum in early September at Solapur gave 100 per cent increased yield as compared to sowing in October. Sowing of sorghum at the onset of monsoon rains gave higher grain and fodder yields than sowing at later dates (Srivastava and Sardar Singh, 1981).

Pre-monsoon sowing in mid September gave 282 per cent increased grain yield *vis-a-vis* late sowing in rainfed sorghum at Hyderabad (Narkhede *et al.*, 1985). Itnal *et al.* (1986) observed that at Bijapur, sowing of sorghum in the first fortnight of September enhanced the grain yield by 47 per cent and fodder yield by 96 per cent over sowing in the first fortnight of October. Rao and Vijayalakshmi (1986) observed reduction in sorghum yield due to delayed sowings.

Rajapandian *et al.* (1991) obtained higher grain yields in sorghum by sowing three, two and one weeks before the onset of anticipated monsoon than sowing at the receipt of monsoon at Kovilpatti. Dahatonde and Moghe (1991) reported 34 per cent reduction in sorghum grain yield because of delay in sowing from 27<sup>th</sup> September (39<sup>th</sup> MSW) to 27<sup>th</sup> October (43<sup>rd</sup> MSW).

Kushwaha and Kushwaha (1991) found that dry seeding of sorghum one week before the monsoon onset resulted in higher grain yield as compared to normal sowing after the receipt of sufficient rain at Indore.

Sowing before monsoon rains gave higher grain yield and fodder yield in sorghum as compared to sowing after monsoon rain (Dashora *et al.*, 1992). Durairaj *et al.* (1993) obtained lowest grain yield of 627 kg ha<sup>-1</sup> in sorghum when sowing was done one week after the onset of monsoon and highest grain yield of 2033 kg ha<sup>-1</sup> was recorded when sowing was done two weeks before the onset of monsoon in *Vertisols* of Kovilpatti.

Sowing at the onset of monsoon (9<sup>th</sup> June) in Southern Telangana zone of Andhra Pradesh resulted in higher grain yield and fodder yield of sorghum (2132 and 3678 kg ha<sup>-1</sup>, respectively) as compared to sowing taken after the receipt of soaking rains (1<sup>st</sup> July) which gave only 1481 kg ha<sup>-1</sup> of grain yield and 2579 kg ha<sup>-1</sup> of fodder yield (Mohammad and Hasan, 1993). Balasubramanian *et al.* (1993) conducted field experiments during the Northeast monsoon seasons of 1986-1991 on clay loam soil at Coimbatore (Tamil Nadu) and concluded that dry sowing of sorghum before the monsoon rain (38-39 MSW; Sep 17<sup>th</sup>-30<sup>th</sup>) resulted in higher grain yield of 1.49 t ha<sup>-1</sup> than sowing done after the receipt of sufficient rainfall *viz.*, 40-41 MSW (Oct 1<sup>st</sup>-14<sup>th</sup>) which gave 1.12 t ha<sup>-1</sup> only.

Lomte *et al.* (1994) found that dry sowing on 24<sup>th</sup> MSW (June 11<sup>th</sup>-17<sup>th</sup>) gave 24.8 and 11.3 per cent higher grain and fodder yields (3051 and 8284 kg ha<sup>-1</sup>, respectively) than sowing done at 25<sup>th</sup> MSW (June 18<sup>th</sup>-24<sup>th</sup>). Solaiappan and Subramanian (1995) reported 67 per cent reduction in sorghum grain yield due to delay in sowing from 15<sup>th</sup> September to 13<sup>th</sup> October.

#### **2.1.2.4 Effect of sowing dates/ weeks on the efficiency and monetary returns in sorghum**

Arunachalam and Subramanian (1984) reported higher monetary return in sorghum due to early sowing in September than October under Coimbatore situation.

Balasubramanian *et al.* (1993) obtained higher rainfall use efficiency and net returns when sorghum sowing was done through dry sowing before the monsoon onset (38-39 MSW; Sep 17<sup>th</sup>-30<sup>th</sup>) over sowing done after sufficient rainfall received (40-41 MSW; Oct 1<sup>st</sup>-14<sup>th</sup>) under Coimbatore condition.

At Aruppukottai, an increase of 171, 137 and 28 per cent in gross return was obtained by sowing sorghum in 15<sup>th</sup> September, 23<sup>rd</sup> September and 6<sup>th</sup> October over sowing taken on 13<sup>th</sup> October. The rainfall use efficiency was significantly higher in 15<sup>th</sup> September sowing, which gradually decreased with delay in subsequent sowings (Solaiappan and Subramanian, 1995). Mohammad and Hasan (1995) obtained 80 per cent increased profit by virtue of early sowing (9<sup>th</sup> June) over normal sowing (1<sup>st</sup> July).

### 2.1.3 Varietal performance under varying rainfall events

Grain yield in sorghum had substantially increased with the use of high yielding, management responsive varieties, but these cultivars had miserably failed under adverse conditions prevailing in the Semi-Arid Tropics (SAT). This was because, sorghum crop in SAT environments faced different biotic and abiotic stresses at different stages of its development. So, there was a necessity to select genotypes resistant to stress factors that affect the crop at this environment.

Nalayini *et al.* (1998) stated that for Coimbatore dryland tract, the safer growing period fell from 38<sup>th</sup> MSW (Sep 17<sup>th</sup>-23<sup>rd</sup>) to 48<sup>th</sup> MSW (Nov 26<sup>th</sup>-Dec 2<sup>nd</sup>). Since, soil moisture was the most important limiting factor for crop production at this tract, early maturing varieties could be planted at the beginning of monsoon rains, and thereby prolonged period of stress at the reproductive stage of the crop could be avoided.

Umrani and Patil (1985) reported that choice of cultivar had no significant effect on grain yield, but the cultivar M 35-1 gave markedly higher forage yields than CSH 8R at Solapur (Maharashtra).

Solankey *et al.* (1988) reported that CSH 6 was the most efficient genotype in utilizing the major nutrients as compared to other genotypes (Vdisha 60-1 and CSV 6) in Indore under rainfed condition. Lakshmaiah *et al.* (1989) evaluated 17 sorghum genotypes for their suitability for cultivation under rainfed condition of Andhra Pradesh and found that the hybrids MSH 55 and MSH 50 showed higher phenotypic stability and also gave higher yields as compared to other genotypes evaluated.

Dahatonde and Moghe (1991) reported that among the different varieties evaluated (SPV 86, SPV 504, CSH 8R, Maldandi and Ringni), SPV 86 gave the highest grain yield and Ringni gave the highest fodder yield in Sindewahi of Maharashtra. Sorghum genotypes CSH 9, SPV 351 and SPV 741 were evaluated for their suitability for dry sowing at Indore and the results indicated that CSH 9 registered the highest grain yield under 80 kg N ha<sup>-1</sup> when dry planting was done as compared to other genotypes (Kushwaha and Kushwaha, 1991).

Wanjari *et al.* (1992) found that at Akola (Maharashtra), the cultivar SPV 468 gave the highest grain yield and cultivar SPV 775 gave the highest fodder yield when

compared to other cultivars. Balasubramanian *et al.* (1993) reported that among different cultivars evaluated (CSH 9, SPV 351, TNS 30, SPV 462 (CO 26) and COH 4) in clay loam soil at Coimbatore (Tamil Nadu), the cultivars COH 4 and SPV 351 gave the maximum yields, whereas the cultivar SPV 462 gave the least yield. The rainfall use efficiency and the net returns were higher with SPV 351 and the lowest was with SPV 462.

Mohammad and Hasan (1994) evaluated sorghum genotypes in *Alfisols* at Palem (Andhra Pradesh) and recommended CSH 14 and SPV 946 for cultivation when N was not applied and CSH 6 and CSH 9 for cultivation when N was applied. Dashora and Porwal (1994) found that among six cultivars tested (SPV 775, SPV 881, SPH 296, CSV 11, CSH 9 and PVK 400) at Udaipur (Rajasthan), CSH 9 and SPH 296 out yielded other cultivars in terms of grain and straw yields.

For the encrusted *Alfisols* at Palem (Andhra Pradesh), the cultivars SPV 462 and CSH 9 could be sown at the break of monsoon rain with 80 kg N ha<sup>-1</sup> to get maximum grain yield and profit (Mohammad and Hasan, 1995). At Rahuri (Maharashtra), eight sorghum cultivars were evaluated for their suitability for cultivation in *Rabi* season. The result indicated that cultivar Sel 3 TL gave the highest grain yield as compared to local cultivar M 35-1 and Swati because of its higher grains number panicle<sup>-1</sup>, 1000 grain weight and extended leaf area duration (Pinjari and Shinde, 1995).

Singh *et al.* (1996) found that among five sorghum cultivars tried (PJH 58, PJH 55, CSH 11, CSV 13 and SPV 1025), the hybrid PJH 58 gave the highest grain yield in clay loam soil at Pant Nagar of Uttar Pradesh. Mulik *et al.* (1996) reported that under early sowing condition, the improved cultivar, Swati resulted in significantly higher grain yield than M 35-1. But under late sown condition, M 35-1 gave significantly higher fodder yield than Swati.

Parameshwarappa and Dhanelappagol (1998) reported that at Bailhongal of Karnataka, sorghum cultivar SPV 1293 recorded the highest grain and fodder yields as compared to other cultivars (SPV 1022, CSV 15 and DSV 2).

#### 2.1.4 Effect of nutrients on rainfed sorghum under different seasonal rainfall

Among the plant nutrients, N and P were found to increase the yield of sorghum to a greater extent. The response of sorghum to N and P varied widely from place to place, depending upon the fertility level of soil and other environmental factors.

##### 2.1.4.1 Effect of nitrogen on rainfed sorghum

###### 2.1.4.1.1 Effect of nitrogen on growth components

Mohammad and Hasan (1995) reported that under *Alfisol* condition at Palem (Andhra Pradesh), fertilization at lower level of N impaired the crop growth and the plants attained lower height than crop fertilized with higher level of N.

Surakod and Itnal (1997) observed that sorghum plant height was increased with increasing N levels from 25 to 75 kg ha<sup>-1</sup>. Similarly, field experiments conducted in *Vertisols* of Kovilpatti also revealed that application of N @ 40 kg ha<sup>-1</sup> resulted in taller plants, whereas, the control had shorter plants (Chitdeswari *et al.*, 1998).

Rego *et al.* (1998) found that rainfed sorghum raised in the post rainy season at ICRISAT produced maximum biomass under 60 kg N ha<sup>-1</sup>. Patil and Sheelavantar (2000) observed that dry matter production in sorghum was increased with increase in N levels from 0 to 50 kg ha<sup>-1</sup>.

Ishwar Singh *et al.* (1993) concluded that LAI of sorghum was increased with increase in N application rate from 0 to 80 kg ha<sup>-1</sup> in sandy loam soil at Sumerpur, Rajasthan.

###### 2.1.4.1.2 Effect of nitrogen on yield attributes

Bhosekar and Raikhelkar (1990) reported that application of 80 kg N ha<sup>-1</sup> gave significantly higher ear weight, number of grains earhead<sup>-1</sup> and test weight as compared to its lower N levels on black cotton soils of Parbhani under rainfed condition. Porwal and Pushpendra Singh (1992) found that successive increase in N levels (0, 50 and 100 kg ha<sup>-1</sup>) had progressively increased the earhead weight plant<sup>-1</sup> and the test weight significantly.

Rama Mohan Rao *et al.* (1995) reported that application of N during both good and bad rainfall years had increased the yield components like panicle length, panicle weight and 1000 grain weight. But the results were of non significant in nature. Chitdeswari *et al.* (1998) concluded that increasing levels of N had also increased the yield attributing characters, *viz.*, earhead length and 1000 grain weight in *Vertisol* at Kovilpatti under rainfed condition.

#### 2.1.4.1.3 Effect of nitrogen on the yield of rainfed sorghum

Nitrogen application for *Rabi* sorghum under dryland situation at Solapur (Maharashtra) significantly improved the sorghum grain yield (Umrani and Patil, 1983). Nagre and Khedekar (1984) inferred that application of 60 kg N ha<sup>-1</sup> to rainfed sorghum at Akola had significantly increased the grain yield and further increase in yield with 120 kg N ha<sup>-1</sup> was non significant.

Daftardar *et al.* (1987) conducted field trials in *Rabi* season in deep black soil at Solapur (drought prone region) and concluded that application of 50 kg N ha<sup>-1</sup> significantly increased the grain yield of sorghum over control. Application of 40 and 80 kg N ha<sup>-1</sup> resulted in 63 and 130 per cent increase in yield over control at Surat, Gujarat (Patel *et al.*, 1989).

Jadhav *et al.* (1991) found that application of 50 kg N ha<sup>-1</sup> produced higher grain and fodder yields than under 0 and 25 kg N ha<sup>-1</sup> at Solapur (Maharashtra). Many other workers also confirmed the positive response of sorghum to N application. But the rates limiting the responses varied from 40 to 120 kg N ha<sup>-1</sup> in different regions (Ahmed *et al.*, 1984; Balyan and Singh, 1985; Bhosekar and Kulkarni, 1990 and Kushwaha and Kushwaha, 1991).

Nazirkar and Sonar (1991) opined that application of N fertilizer to sorghum was beneficial where soil available N was upto 230 kg ha<sup>-1</sup>. Porwal and Pushpendra Singh (1992) found that for rainfed sorghum in Udaipur, 100 kg N ha<sup>-1</sup> was the optimum level which gave 38 and 18 per cent increased grain yield over control and 50 kg N ha<sup>-1</sup>, respectively.

Dashora *et al.* (1992) found that grain and fodder yields of sorghum were increased with the increase in the rate of N application from 0 to 80 kg ha<sup>-1</sup> at Udaipur (Rajasthan). Similar positive response of sorghum to applied N under rainfed

condition was also reported by Mahakulkar *et al.* (1992), Wanjari *et al.* (1992) and Hirpara *et al.* (1992).

Ishwar Singh *et al.* (1993) concluded that application of 80 kg N ha<sup>-1</sup> resulted in higher grain yield of sorghum over control and 40 kg N ha<sup>-1</sup>. Balasubramanian *et al.* (1993) found that in clay loam soil of Coimbatore, grain yield of sorghum was increased with the increase in nitrogen application rate from 20 to 40 kg ha<sup>-1</sup>.

Response of rainfed sorghum to N application went upto 80 kg ha<sup>-1</sup> at Hyderabad (Andhra Pradesh) as reported by Sarma and Ramana (1993). Tripathi and Bhan (1993) reported that application of 60 kg N ha<sup>-1</sup> to rainfed sorghum had increased the grain yield significantly, though the rate of increase slowed down after a certain level.

Lomte *et al.* (1994) reported 12 per cent reduction in sorghum grain yield due to decrease in the recommended N rate from 80 to 40 kg ha<sup>-1</sup>. At Akola (Maharashtra), application of 80 kg N ha<sup>-1</sup> produced highest grain (4.03 t ha<sup>-1</sup>) and fodder (8.99 t ha<sup>-1</sup>) yields (Wanjari *et al.*, 1995).

Suraj Bhan *et al.* (1995) reported that sorghum yield found increased with increasing levels of N and reached the maximum at 80 kg N ha<sup>-1</sup>. Mulik *et al.* (1996) reported that application of 50 kg N ha<sup>-1</sup> at sowing resulted in a significant increase in sorghum grain yield as compared to control (0 kg N ha<sup>-1</sup>).

Surakod and Itnal (1997) recommended N application upto 75 kg ha<sup>-1</sup> to increase the sorghum grain yield at Bijapur (Karnataka). Chitdeswari *et al.* (1998) reported that increased N application resulted in increased grain yield of sorghum at Kovilpatti (Tamil Nadu). Similar beneficial effect of N application in rainfed sorghum had been reported by several workers (Suraj Bhan *et al.*, 1998; Kolekar *et al.*, 1998 and Rego *et al.*, 1998).

Sutaria *et al.* (1999) reported that application of 30, 60 and 90 kg N ha<sup>-1</sup> resulted in 55, 157 and 177 per cent increase in sorghum grain yield over control (0 kg ha<sup>-1</sup>). The fodder yield also shown 32, 53 and 56 per cent increase over control. Hirpara *et al.* (1999) found that application of N @ 40, 80 and 120 kg ha<sup>-1</sup> produced more yields of sorghum grain and straw to the tune of 115, 167 and 220 as well as 133, 201 and 272 per cent, respectively over their respective control (0 kg ha<sup>-1</sup>).

#### 2.1.4.1.4 Effect of nitrogen on nutrient content and uptake by sorghum

Muthuvel *et al.* (1988) found that increased rate of N application from 20 to 50 kg ha<sup>-1</sup> to rainfed sorghum at Kovilpatti did increase the NPK uptake to the tune of 32, 26 and 33 per cent, respectively. Sarma and Ramana (1993) concluded that plant uptake of NPK was increased with N application upto 80 kg ha<sup>-1</sup> in Alfisols at Hyderabad (Andhra Pradesh).

Suraj Bhan *et al.* (1998) reported that increasing rates of N application upto 60 kg ha<sup>-1</sup> had increased N uptake in sorghum. Chitdeswari *et al.* (1998) found that application of N at the rate of 40 kg ha<sup>-1</sup> did increase the NPK content and NPK uptake at Kovilpatti (Tamil Nadu). Hirpara *et al.* (1999) found that total uptake of P by sorghum was significantly improved with the increase in each level of N. Maximum P uptake was recorded when N was applied at the rate of 120 kg ha<sup>-1</sup>. Application of N at the rate of 40, 80 and 120 kg ha<sup>-1</sup> had increased P uptake by 133, 208 and 283 per cent over control (0 kg N ha<sup>-1</sup>) in medium black soils of Targhadia (Gujarat).

#### 2.1.4.1.5 Effect of nitrogen on the efficiency and monetary returns in sorghum

Porwal and Pushpendra Singh (1992) concluded that increasing N levels (0, 50 and 100 kg ha<sup>-1</sup>) had increased net monetary returns at Udaipur. Balasubramanian *et al.* (1993) inferred that rainfall use efficiency and net returns were increased with the increase in N application from 20 to 40 kg ha<sup>-1</sup>.

The economics of N application showed that it was profitable to apply 80 kg N ha<sup>-1</sup> to sorghum in shallow soils of Andhra Pradesh (Sarma and Ramana, 1993). Suraj Bhan *et al.* (1995) reported that water use and water use efficiency were increased with the increasing levels of N and reached the maximum under 80 kg N ha<sup>-1</sup>. Increasing water use efficiency with the increasing levels of N had also been reported by Tripathi and Bhan (1993).

Ram Mohan Rao *et al.* (1995) reported that application of 38 and 33 kg N ha<sup>-1</sup> under good and bad rainfall years, respectively, gave the highest economic returns at the research farm whereas in farmers' field during good rainfall years the relationship was linear and during bad rainfall years 27 kg N ha<sup>-1</sup> gave the highest net return.

farm whereas in farmers' field during good rainfall years the relationship was linear and during bad rainfall years 27 kg N ha<sup>-1</sup> gave the highest net return.

#### 2.1.4.2 Effect of phosphorus on rainfed sorghum

##### 2.1.4.2.1 Effect of phosphorus on the yield of rainfed sorghum

Patel *et al.* (1989) reported that application of P did increase sorghum grain yield and the increase was 25 and 29 percent over control when 40 and 80 kg N ha<sup>-1</sup> were applied. Mahakulkar *et al.* (1992) conducted field trials at Akola (Maharashtra) and found that grain yield of sorghum was increased with P application upto 13.2 kg P ha<sup>-1</sup> and while it was 26.4 kg P ha<sup>-1</sup> for fodder yield.

Ishwar Singh *et al.* (1993) found that in sandy loam soil at Sumerpur (Rajasthan), grain yield of sorghum was increased with the rate of P application. Grain yield and straw yield of sorghum were increased by 10 to 22.6 and 3.4 to 14.4 per cent respectively, due to P application (0 to 50 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup>) and the grain and straw yields were highest with 25 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> in a *Vertic ustropept* soil at Solapur of Maharashtra (Patil *et al.*, 1996).

Sahrawat *et al.* (1995) reported that sorghum responded to P application upto 40 kg P ha<sup>-1</sup> and the increase in the grain yield was highest with 40 kg P ha<sup>-1</sup>. Sahrawat *et al.* (1998) inferred that fertilizer P had increased grain and stalk yields of sorghum in calcareous *Vertisols* at the ICRISAT centre, Patancheru (Andhra Pradesh) under rainfed condition.

Sutaria *et al.* (1999) found that application of 15, 30 and 45 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> resulted in 12, 16 and 32 per cent increase in sorghum grain yield over control (0 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup>). The fodder yield also was 7, 5 and 16 per cent higher over control.

Hirpara *et al.* (1999) found that P application significantly affected the grain yield of sorghum. Application of 20 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> recorded the highest grain yield, which was higher by 8 per cent in comparison to control (0 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup>). However fodder yield remained unaffected due to P fertilization.

#### **2.1.4.2.2 Effect of phosphorus on nitrogen, phosphorus and potassium uptake**

Sahrawat *et al.* (1998) reported higher uptake of N, P and K by sorghum due to application of P up to 40 kg P ha<sup>-1</sup> in calcareous *Vertisols* at ICRISAT centre, Patancheru (Andhra Pradesh).

Hirpara *et al.* (1999) observed that application of P significantly affected N and P contents in sorghum grain and straw and highest N and P contents in grain and straw were obtained when P was applied @ 60 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup>. The N and P uptake also highest when P was applied @ 60 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup>.

#### **2.1.4.2.3 Effect of phosphorus application on the efficiency and monetary returns in sorghum**

Hirpara *et al.* (1999) conducted field experiments on medium black soils at Junagadh and found that application of P @ 20 kg P<sub>2</sub>O<sub>5</sub>ha<sup>-1</sup> had increased total income (Rs. 22,746 ha<sup>-1</sup>), additional net benefit (Rs. 1548 ha<sup>-1</sup>) and net Internal Cost Benefit Ratio (1: 3.30).

#### **2.1.4.3 Effect of nitrogen and phosphorus on dryland sorghum**

##### **2.1.4.3.1 Effect of nitrogen and phosphorus on the yield of dryland sorghum**

Patel *et al.* (1989) reported that application of 80 kg N + 40 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> gave the highest grain yield of 4.14 t ha<sup>-1</sup> at Surat (Gujarat) under rainfed condition.

Pal *et al.* (1996) found that under rainfed condition at Pantnagar (Uttar Pradesh), increasing levels of N and P application did increase the grain and straw yields. Application of 100 kg N + 50 kg P ha<sup>-1</sup> gave 41.8 and 32.6 per cent higher grain and straw yields than application of 20 kg N + 10 kg P ha<sup>-1</sup>.

Katayama *et al.* (1999) conducted field experiments on *Vertisols* at Patancheru (Andhra Pradesh) and found that application of NP fertilizers in combination resulted in highest grain yield as compared to application of N or P or K fertilizers alone or in various combinations.

##### **2.1.4.3.2 Effect of nitrogen and phosphorus on nitrogen, phosphorus and potassium uptake**

Pal *et al.* (1996) found that increasing levels of NP fertilizer application had increased the NPK uptake in sorghum under rainfed condition at Pantnagar (Uttar Pradesh).

### **2.1.5 Soil water balance to evaluate crop performance in drylands**

Any attempt to control the quantity and availability of soil moisture to plants must be based on a thorough understanding and quantitative knowledge on the dynamic balance of water in the soil. The field water balance was like a financial statement and it was an account of all quantities of water added to, subtracted from, and stored within a given volume of soil during a given period of time (Daniel Hillel, 1982). Mathematical models had been used more recently to calculate crop-related factors such as evapotranspiration, soil water, the development rate of crops and crop growth, yield and production (Robertson, 1983a and 1983b). To evaluate crop performance in relation to available soil water in the SAT, it was necessary to determine how crop productivity was related to water use, and how crops were affected by water shortage (Landsberg, 1988).

#### **2.1.5.1 Soil moisture prediction through water balance method**

Some indication on the availability of soil water and of surplus water was given by a simple soil water balance using long term values of monthly rainfall and potential evapotranspiration (Thornthwaite, 1948). The falling rate of soil water budget was used to calculate daily soil water content (Thornthwaite and Mather, 1955). To improve Thornthwaite method, Baier and Robertson (1965), developed versatile soil water budget, which involved several soil layers, rooting depths and habits of specific crop, soil water holding capacity and water-release characteristics of each soil layer.

The results of limited rain water budgeting studies (Oswal and Dakshinamurti, 1975 and Malik *et al.*, 1987) carried out for Delhi and Bawal (Haryana) regions revealed that depending upon the amount and distribution of rainfall and soil texture, 75 to 90 per cent, 0 to 10 per cent and 7 to 15 per cent of the total rainfall was lost as evapotranspiration, deep percolation, and soil moisture storage respectively, when pearl millet was grown.

Sanjeeva Rao *et al.* (1990) utilised water balance technique and represented the availability of soil moisture as per cent ratio of actual to potential evapotranspiration. Using water balance model, Adhikari and Rama Mohan Rao (1998) reported that the average soil moisture stored in pre-sowing and utilised in post-sowing period in sorghum crop was 130 mm on an average, where the annual rainfall was 500 mm.

#### **2.1.5.2 Estimation of water requirement and water use by water balance studies**

Water requirement of a crop is defined as the depth of water needed to meet the water loss through evapotranspiration of a disease free crop growing in large field under unlimited soil moisture condition (Doorenbos and Pruitt, 1984).

Richardson and Ritchie (1973) developed a soil water balance model based on ET requirement to predict plant water requirement. Several methods had been used in water balance models to estimate potential evapotranspiration. Saxton *et al.* (1974) and Retta and Hanks (1981) used daily pan evaporation. Van Keulen (1975) used the Penman evapotranspiration equation. Stockle and Campbell (1985) and Stockle (1985) used the equation of Priestley and Taylor (1972). Wright (1982) introduced the crop coefficient concept to estimate the water requirements in water balance studies. The crop evapotranspiration (ET<sub>c</sub>) was estimated by multiplying PET with a crop coefficient (K<sub>c</sub>), which accounted for the crop characteristics (Monteny *et al.*, 1985 and Gururaja Rao *et al.*, 1988).

Klajj and Vachaud (1992) used water balance model to indicate the mean cumulative Evaporation (E) and Drainage (D) and they were 211 and 207 mm, respectively for the unfertilized crop and 268 and 148 mm for the fertilized pearl millet crop when 440 mm of rainfall was received during the crop's cycle.

Soil water content monitored by soil water dynamics model in drained *Vertisols* indicated that maize could be grown as sole or with legumes as intercrops. The Actual Soil Water (ASW) in the topsoil layer (10-50 cm) was found 184 mm for maize at its full vegetative stage (Astatke *et al.*, 1995).

Frere and Popov's (1979) water balance model worked out for different dates of sowing (37<sup>th</sup> MSW; Sep 10<sup>th</sup>-16<sup>th</sup>, 38<sup>th</sup> MSW; Sep 17<sup>th</sup>-23<sup>rd</sup> and 39<sup>th</sup> MSW; Sep 24<sup>th</sup>-30<sup>th</sup>) showed a general trend for all the water balance components studied except

for surplus water. All the components like cumulative total rainfall, water requirement (AET), effective rainfall, water use and soil moisture change at harvest decreased as sowing date was delayed from 37<sup>th</sup> MSW to 39<sup>th</sup> MSW. A deficit of 28.58 mm under CO 1 (late maturity group variety) was same for all the three sowing dates, whereas there was no water deficit for UMH 28 and UMH 42 (medium maturity group hybrids). Though not significant with higher AET, sowing at 37<sup>th</sup> and 38<sup>th</sup> MSW produced higher grain yield than 39<sup>th</sup> MSW sowing (Somasundaram, 2000).

## **2.2 Part II Evaluation of DSSAT V.3.5 Decision Support System for different crops and its uses in farm decision making**

### **2.2.1 Evaluation of DSSAT V.3.5 Decision Support System for sorghum**

Crop growth models are useful tools to quantify the environmental limits to crop production. Their application minimizes the requirement for costlier and lengthy experimentation (Loomis *et al.*, 1979). The CERES-Sorghum model was developed and validated by Ritchie and Algarswamy (1989) by using data from multilocation sorghum modeling experiments (Huda, 1987) in which sorghum hybrid CSH 1 was grown at several locations in India. Their results indicated that model was capable of simulating phasic development reasonably well. However, yield predictions were poor.

Varshneya *et al.* (1998) conducted experiments in *Rabi* seasons of 1993-'94 and 1994-'95 at Rahuri to validate CERES-Sorghum model's growth subroutine and the results indicated that phenology was well predicted. Error in panicle initiation (8 per cent), anthesis (11.6 per cent) and physiological maturity (6.4 per cent) was less than or nearer to 10 per cent. But grain yield (48 per cent), kernel weight (44.6 per cent), straw (39 per cent) and biomass (29 per cent) predictions were poor. Yield prediction in 1994-'95 was much less than observed. Yield predictions for timely sown under adequate soil moisture were better than late sown and stressed crops.

Varshneya *et al.* (1998) reviewed the results of the field experiments which were conducted from 1989-1998 at Centre of Advanced Studies in Agricultural Meteorology (CASAM), Pune for validation of CERES-Sorghum model under Indian condition. Mean of observed and predicted growth and phenological parameters of sorghum across these experiments indicated that mean of observed number of days for

panicle initiation (29.72), anthesis (68.96) and physiological maturity (104.59) matched well with predicted values of 28.41, 67.52 and 97.51, respectively. The per cent of Root Mean Square Error (RMSE) with observed values were 6.12, 11.51 and 7.32 per cent only. Since, the error was less than or approximately equal to 10 per cent, prediction of phasic development was considered true. However, in growth parameters like LAI (4.49), there was under prediction (3.50) and error was 34.52 per cent. Because of larger values of errors in LAI, error in biomass and straw (21.28 and 26.12 per cent, respectively) were also higher. Similarly, mean observed grain yield (5076.72 kg ha<sup>-1</sup>) was over predicted (8582.20 kg ha<sup>-1</sup>) by 33.28 per cent. Error in mean kernel weight (20.36 per cent), number of grains panicle<sup>-1</sup> (22.73 per cent) and number of grains per square meter (25.18 per cent) were also high.

### 2.2.2 Evaluation of DSSAT V.3.5 Decision Support System for other crops

Otter- Nacke *et al.* (1986) reported satisfactory performance of CERES-Wheat model, under diverse set of environments. Porter *et al.* (1993) compared three wheat models (AFRCWHEAT, CERES-Wheat and SWHEAT) under non limiting N and water availability conditions using two cultivars and found that best prediction for all the parameters was given not always by the same model.

Chipanshi *et al.* (1997) simulated wheat yields at three locations in Saskatchewan (Swift current, Saskatoon and Melfort) using the CERES-Wheat model. The simulations were made using climate data of selected years from the start of the growing season up to the prediction date; data for the remainder of the season were taken from 1960-1990 climate records. Predictions using this method were found to agree well with the measured data, suggesting that simulations made using a combination of historical climate records and current weather data as inputs did provide good indications of yield.

A validation study for CERES-Wheat model (V.2.1) was conducted at Ludhiana (Punjab) using the field data of eight consecutive crop seasons from 1985 to 1993 by Hundal and Prabhjot Kaur (1997).<sup>\*</sup> The simulated anthesis and physiological maturity dates, grain and total biomass yields of wheat were compared with actual observations for the commonly grown cultivar, HD 2329. The simulated and actual dates of phenological events showed deviations from (-) 9 to (+) 6 days for anthesis and (-) 6 to (+) 3 days for physiological maturity of the crop. The model

estimated the kernel weight to be within the range of 88 to 113 per cent (mean 100 per cent) of the actual kernel weight. The model predicted the grain yields from 80 to 115 per cent (mean 97.5 per cent) of the observed grain yield. Biomass yields were predicted from 93 to 128 per cent (mean 110.5 per cent) of the observed yields.

Shekh *et al.* (1999) conducted field experiments for two consecutive years during *Rabi* season on maize cv. Ganga Safed 2 for validating CERES-Maize model at middle Gujarat agro-climatic region of Anand. The results revealed that prediction of silking date using CERES model showed a deviation which varied from (–) 11 days to (+) 2 days with mean difference of (–) 2.3 days. In case of physiological maturity, error ranged from (–) 10 to (+) 5 days with mean difference of (–) 3.7 days. Grain and straw yields prediction using CERES model showed (–) 28.9 to (+) 18.4 and (–) 8 to (+) 16.2 per cent error, respectively. Biomass prediction showed (–) 15.6 to (+) 17.5 per cent error.

Tripathi *et al.* (1999) reported that the mean simulated yields of irrigated rice through CERES-Rice model were slightly higher than those obtained in experimental fields at Pantnagar (Uttar Pradesh). Per cent variation in simulated over observed values was ranged from (+) 4.3 to (–) 4.5. Coefficients of Variation (CV) of observed and simulated yield was also very close to each other and this confirmed that the model could be suitably applied for simulating the rice yields at the selected locations and for selected varieties of rice.

Attri *et al.* (1999) conducted field experiments for validating CERES-Wheat model for cultivars WH 592 at Hisar and HD 2329 at Jaipur and Ludhiana. The results indicated that the predicted flowering dates by the model were within the range of 6 per cent of observed values at Ludhiana and 11 per cent at Jaipur. As far as the predictions of physiological maturity dates were concerned, these were lying within range of 12 per cent and 10 per cent at Ludhiana and Jaipur, respectively. The grain yield predicted by the model fell within a range of 12 per cent in both the locations. Average total biomass ( $\text{kg ha}^{-1}$ ), stalk yield ( $\text{kg ha}^{-1}$ ) and number of grains  $\text{ear}^{-1}$  predicted by the model for various treatments fell within range of 8, 11 and 6 per cent for WH 542 and 9, 10 and 7 per cent for HD 2329, respectively.

### 2.2.3 Uses of decision support system for farm decision making

CERES-Maize model was calibrated and evaluated in Malawi using field experiments and the results indicated that the model performed well for the locations tested. It was demonstrated that useful information on planting windows, plant population, fertilizer regimes, and variety selection could be selected by carrying out simulation experiments replicated over many different season types (Singh *et al.*, 1993).

The IBSNAT crop growth models (their inputs and outputs) and associated DSSAT had been coupled to Geographic Information Systems (GIS), to produce maps of predicted yield, both on a regional scale (Jones, 1993; Lal *et al.*, 1993) and for single fields with small subunits (Engel and Jones, 1995). Thornton *et al.* (1997) developed a regional yield forecasting application for early warning of famines by combining components of DSSAT with GIS.

Kushwaha and Rai (1999) opined that the SPAW (Soil-Plant-Atmospheric-Water) model developed by Saxton *et al.* (1974) could successfully be used for scheduling the irrigation for wheat crop by developing some coefficients to make corrections in simulated values for accurate estimation of evapotranspiration. After making these modifications, the model output could successfully be used for particular location in formulating the agro advisory service bulletins to advice the farmers for efficient water management in wheat crop.

A dynamic rice growth and yield simulation model CERES-Rice had been used as a tool to evaluate various agronomic practices in rice production under Punjab condition (Hundal and Prabhjyot Kaur, 1999). Attri *et al.* (1999) concluded that CERES-Wheat model could be utilised to predict development, growth, yield, yield attributes, N utilisation and photosynthesis partitioning. The strategy analysis program together with the crop model was used to make long term simulations and to analyse effect of sowing dates, fertilizers and irrigation for maximising production under varied agroclimatic conditions. Besides these, good prediction of date of maturity could help the farmer to plan for harvesting and marketing their produce.

An evaluated crop model (such as CERES-Maize model) coupled with real time weather would facilitate and enhanced both the ability to forecast yields under limiting conditions and to fine tune crop management to minimize deleterious effects (Singh and Wilkens, 1999).

From the review, it is inferred that so far no attempt was made in sorghum to identify optimum time of sowing to match crop duration with the moisture availability period, and also to identify optimum fertilizer dose for improved cultivars especially for drylands. Similarly DSS is also not used so far under dryland condition for decision making.

Hence there is a need to produce information as stipulated in the present study for the benefit of farmers to meet the challenges from malevolent weather.

## **MATERIALS AND METHODS**

---

---

## CHAPTER III

### MATERIALS AND METHODS

Field experiments were conducted at Tamil Nadu Agricultural University, Coimbatore during Northeast monsoon seasons of 1999 and 2000 under dryland condition to evaluate the performance of two sorghum (*Sorghum bicolor* (L.) Moench.) varieties under different sowing dates and levels of Nitrogen and Phosphorus. The other objective was to evaluate DSSAT V.3.5 of Decision Support System (CERES-Sorghum model) for key management practices like choice of varieties, times of sowing and nutrient levels. The details on materials used and methods adopted during the course of investigation are detailed here under.

#### 3.1 Part I Main experiment

##### 3.1.1 Materials

###### 3.1.1.1 Location

In both the years, field experiments were conducted in the same field (field number 36B) of Eastern Block of Agricultural College and Research Institute, Tamil Nadu Agricultural University, Coimbatore situated at 11°N latitude and 77°E longitude. The mean altitude is 426.7 m above mean sea level.

###### 3.1.1.2 Climate and weather

Coimbatore, having the climate of Semi-Arid Tropics (SAT) experiences an annual average rainfall of 670 mm distributed over 43 rainy days and this annual rainfall is distributed as 23.2 mm in cold weather period (January-February), 136.0 mm in hot weather period (March-May), 205.4 mm in Southwest monsoon season (June-September) and 305.4 mm in Northeast monsoon season (October-December). The mean maximum and minimum temperatures ranged from 27.0 to 31.5°C and 14.6 to 21.2°C, respectively.

The weather data prevailed during the cropping periods (1999-2000 and 2000-2001) were collected from Department of Agricultural Meteorology, Tamil Nadu Agricultural University, Coimbatore and presented in Tables 1 and 2 and also in Fig. 1 and 2, respectively. In the years of experimentation (1999-2000 and 2000-2001), the rainfall was 427.6 mm in 27 rainy days and 284 mm in 18 rainy days, respectively. The mean maximum and minimum temperatures during the cropping

Table 1. Weather parameters prevailed during the crop growth period (Northeast monsoon 1999)

Standard weeks	Period	Mean temp. (°C)		Mean R.H. (%)		Total rainfall (mm)	Total rainy days	Mean sunshine (hrs day <sup>-1</sup> )	Mean evaporation (mm day <sup>-1</sup> )	Mean wind velocity (km h <sup>-1</sup> )	Mean solar radiation (MJ m <sup>-2</sup> day <sup>-1</sup> )
		Max.	Min.	0722 hours	1422 hours						
37	10 – 16 Sept	33.0	21.4	83	43	0.0	0	9.3	6.9	20.3	18.4
38	17 – 23	33.7	22.4	89	50	0.0	0	5.6	5.6	12.9	16.4
39	24 – 30	33.5	22.9	91	46	36.6	4	3.7	3.7	8.2	14.7
40	01 – 07 Oct	29.9	22.5	94	68	78.4	4	2.8	2.8	6.0	11.8
41	08 – 14	30.9	22.3	93	60	26.5	2	4.2	4.2	3.1	16.2
42	15 – 21	29.5	21.9	95	74	170.4	5	1.9	1.9	2.7	11.8
43	22 – 28	29.8	22.5	94	65	26.9	4	2.6	2.6	-	19.1
44	29 – 04	30.2	20.2	94	64	1.0	0	3.2	3.2	-	16.3
45	05 – 11 Nov	29.9	19.8	91	51	27.8	2	2.5	2.5	-	17.6
46	12 – 18	29.7	18.4	88	47	0.0	0	3.6	3.6	1.7	19.4
47	19 – 25	27.4	21.0	93	71	34.9	2	3.0	3.0	3.3	12.3
48	26 – 02 Dec	28.4	21.0	91	63	5.7	1	3.2	3.2	3.5	15.6
49	03 – 09	28.3	19.1	91	59	1.0	0	2.7	2.7	2.2	16.2
50	10 – 16	26.2	19.3	91	62	4.0	1	2.9	2.9	1.9	15.4
51	17 – 23	27.9	18.3	88	57	0.0	0	2.9	2.9	3.0	13.5
52	24 – 31	26.8	19.3	90	54	9.0	1	3.2	3.2	4.4	17.4
1	01 – 07 Jan	28.3	19.9	87	52	0.0	0	3.4	3.4	4.9	15.9
2	08 – 14	28.1	20.5	87	62	5.4	1	3.5	3.5	6.1	11.8
3	15 – 21	30.5	18.1	91	39	0.0	0	4.1	4.1	6.2	16.9
4	22 – 28	31.6	16.9	90	35	0.0	0	9.5	4.7	4.1	16.2

Table 2. Weather parameters prevailed during the crop growth period (Northeast monsoon 2000)

Standard weeks	Period	Mean temp. (°c)		Mean R.H. (%)		Total rainfall (mm)	Total rainy days	Mean sunshine (hrs day <sup>-1</sup> )	Mean evaporation (mm day <sup>-1</sup> )	Mean wind velocity (km h <sup>-1</sup> )	Mean solar radiation (MJ m <sup>-2</sup> day <sup>-1</sup> )
		Max.	Min.	0722 hours	1422 hours						
38	17 - 23	31.9	22.5	89	60	100.9	3	5.2	3.8	3.8	13.8
39	24 - 30	29.6	22.3	92	70	89.2	4	4.5	3.2	3.8	12.1
40	01 - 07 Oct	29.3	21.4	91	65	7.9	2	3.5	4.5	4.0	12.7
41	08 - 14	30.9	21.6	90	60	12.1	3	5.7	4.1	3.0	14.2
42	15 - 21	31.1	21.7	93	63	2.4	0	4.7	3.9	2.5	14.2
43	22 - 28	31.7	19.4	91	46	0.0	0	7.3	4.5	3.1	15.8
44	29 - 04	30.8	21.2	89	54	0.0	0	7.0	3.3	2.6	15.1
45	05 - 11 Nov	31.0	21.5	89	48	0.0	0	7.9	4.5	5.2	17.6
46	12 - 18	30.0	21.4	87	49	0.0	0	5.7	4.3	6.2	15.4
47	19 - 25	28.2	21.8	93	66	34.3	3	3.2	2.4	4.8	10.2
48	26 - 02 Dec	29.0	18.0	92	50	29.2	2	6.5	3.7	6.3	14.5
49	03 - 09	28.9	19.1	88	50	0.0	0	7.8	3.5	5.1	17.2
50	10 - 16	28.5	15.2	88	35	0.0	0	10.5	4.2	5.1	21.6
51	17 - 23	28.7	17.3	88	41	0.0	0	8.8	4.2	5.2	18.8
52	24 - 31	28.6	19.4	87	53	12.8	2	5.3	5.3	6.4	14.0
1	01 - 07 Jan	30.0	20.9	91	48	0.0	0	6.3	3.7	1.1	15.6
2	08 - 14	30.0	19.4	88	43	0.0	0	7.4	4.3	5.1	17.6
3	15 - 21	30.2	17.8	90	40	0.0	0	7.9	4.5	7.3	18.7
4	22 - 28	31.2	20.8	80	44	0.0	0	5.0	4.8	5.6	17.1

**Fig. 1. Weather parameters prevailed during crop growth period (1999-2000)**

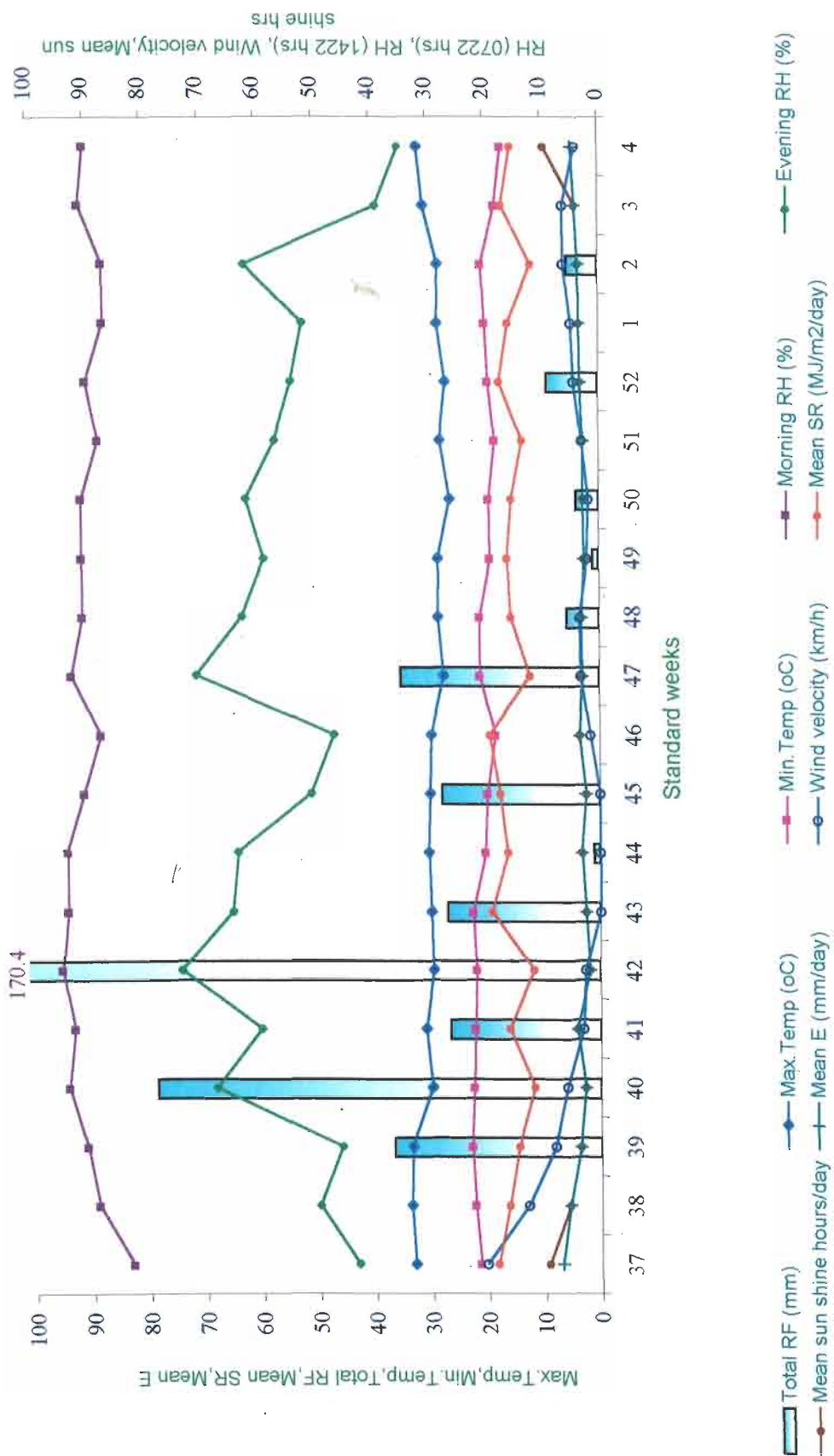
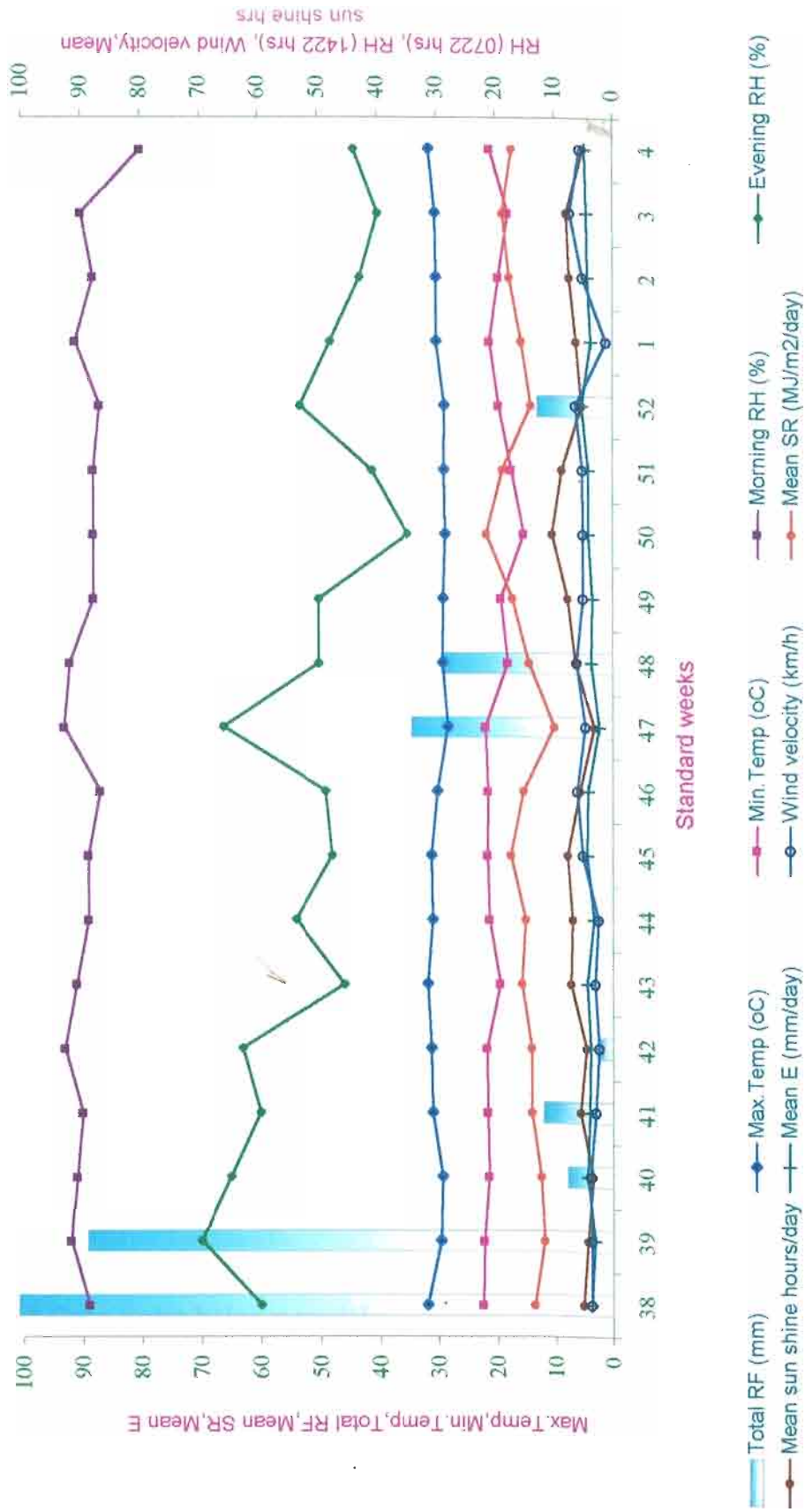


Fig. 2. Weather parameters prevailed during crop growth period (2000-2001)



season were 35.5°C and 14.0°C for 1999-2000 and 33.0°C and 13.0°C for 2000-2001, respectively.

### **3.1.1.3 Soil**

The soil of the experimental field was well drained sandy clay loam. The soil was low in available nitrogen (120 and 131 kg ha<sup>-1</sup> for 1999-2000 and 2000-2001, respectively), medium in available phosphorus (13 and 11.5 kg ha<sup>-1</sup> for 1999-2000 and 2000-2001, respectively) and high in available potassium (370 and 395 kg ha<sup>-1</sup> for 1999-2000 and 2000-2001, respectively). The physico-chemical properties of the soil are furnished in Table 3.

### **3.1.1.4 Crop and variety**

Sorghum varieties CO 26 and CSV 15 were used in these two experiments. CO 26 seeds were obtained from Central Farm, Tamil Nadu Agricultural University, Coimbatore and CSV 15 seeds were obtained from National Research Centre for Sorghum (NRCS), Hyderabad and both the varieties were tested for germination before sowing and it was 94 per cent. The important characteristics of CO 26 and CSV 15 are furnished in Table 4.

## **3.1.2 Methods**

### **3.1.2.1 Experimental design**

The experiment was laid out in split plot design in both the years and the treatments were replicated thrice. The data required for Minimum Data Set (MDS) which were used for evaluating DSSAT V.3.5 CERES-Sorghum model were also collected from these three replications. Adjacent to the main experimental plots, two separate plots with the dimensions of 8.10 x 4.95 m were laid down during 1999-2000 and in these plots CO 26 and CSV 15 were raised with unlimited supply of nutrients and water. From these two plots, the data (MDS) required for the computation of genetic coefficient of CO 26 and CSV 15 were collected. The field layout plans for 1999-2000 and 2000-2001 are given in Fig. 3 and 4.

### **3.1.2.2 Treatment details**

#### **3.1.2.2.1 Crop water balance model**

Weekly water balance with Water Requirement Satisfaction Index (WRSI) was computed using the cumulative crop water balance model of Frere and Popov

Table 3. Soil characteristics of the experimental field

Particulars	1999-2000	2000-2001
<b>A. Mechanical composition (Piper, 1966)</b>		
Coarse sand (%)	20.0	20.0
Fine sand (%)	28.5	28.5
Silt (%)	19.5	19.5
Clay (%)	31.5	31.5
Texture	Sandy clay loam	Sandy clay loam
<b>B. Physical properties (Piper, 1966)</b>		
Field capacity (%)	18.08	18.08
Permanent wilting point (%)	10.69	10.69
AWHC (mm 100 cm depth <sup>-1</sup> )	100.00	100.00
Bulk density (g cc <sup>-1</sup> )	1.36	1.36
<b>C. Chemical properties</b>		
EC (dSm <sup>-1</sup> ) (1:2 water suspension) (Jackson, 1973)	0.41	0.44
pH (1:2 water suspension) (Jackson, 1973)	7.90	7.80
Available N (kg ha <sup>-1</sup> ) (Subbiah and Asija, 1956)	120.0	131.0
Available P (kg ha <sup>-1</sup> ) (Olsen <i>et al.</i> , 1954)	13.0	11.5
Available K (kg ha <sup>-1</sup> ) (Stanford and English, 1949)	370.0	395.0

Table 4. Characteristics of sorghum cultivars

Characters	CO 26	CSV 15
Parentage	Derivative of MS 8271 x IS 3691	Derivative of SPV 475 x SPV 462
Duration (days)	105-110	107-112
Rainfed / Irrigated	Both	Both
Grain yield (kg ha <sup>-1</sup> )		
Irrigated	6000	5800
Rainfed	4500	4250
Height (cm)	160-190	232
Sheath colour	Green	Green
Node	Green	Green
Earhead	Long cylindrical	Long cylindrical
Compactness	Semi compact	Semi compact
Grain colour	Pearly white	Pearly white
Reference	Crop Production Guide (1999)	Annual Report (1997-98)

Fig. 3. Field lay out of experiment (1999 – 2000)

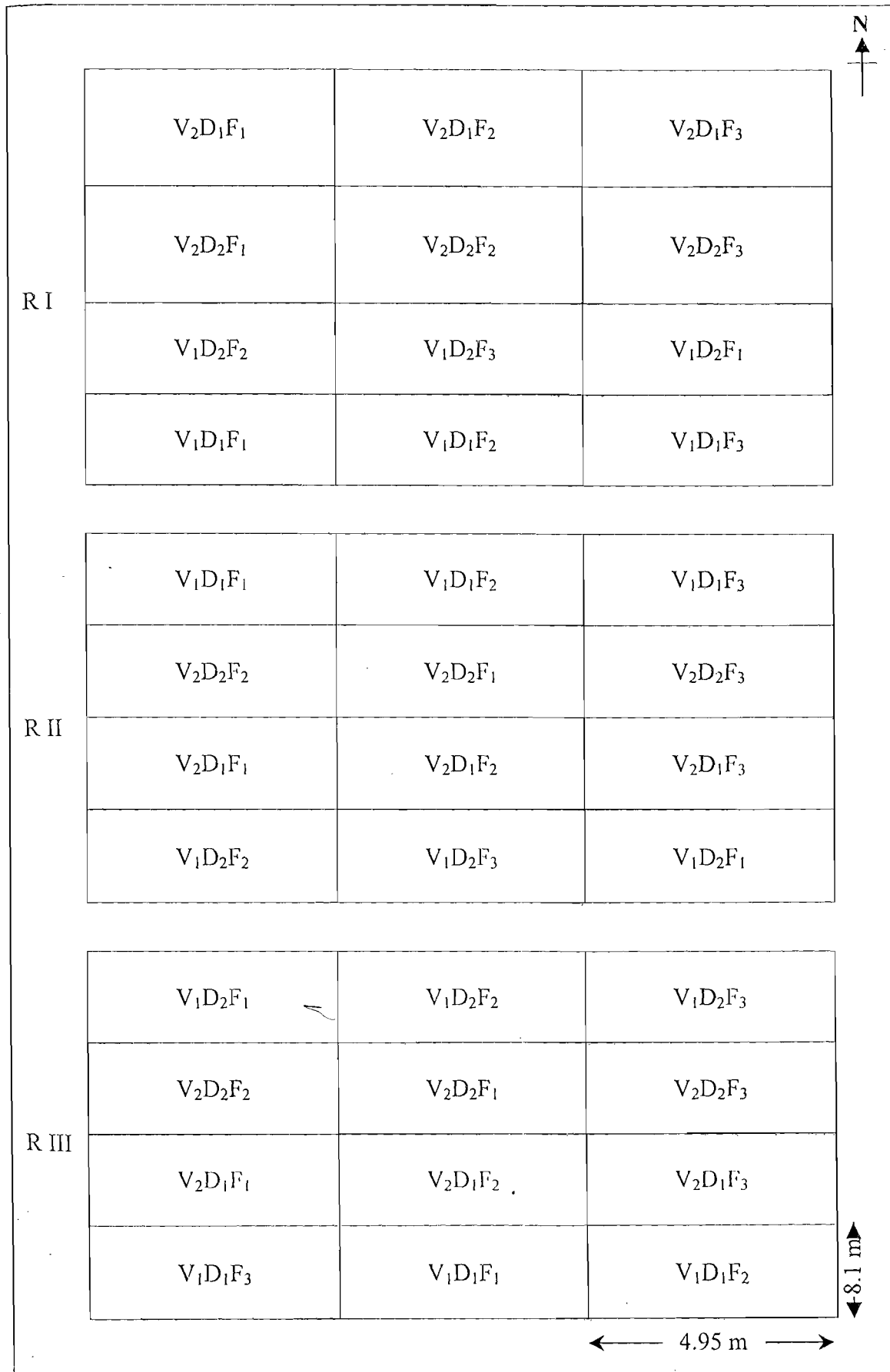
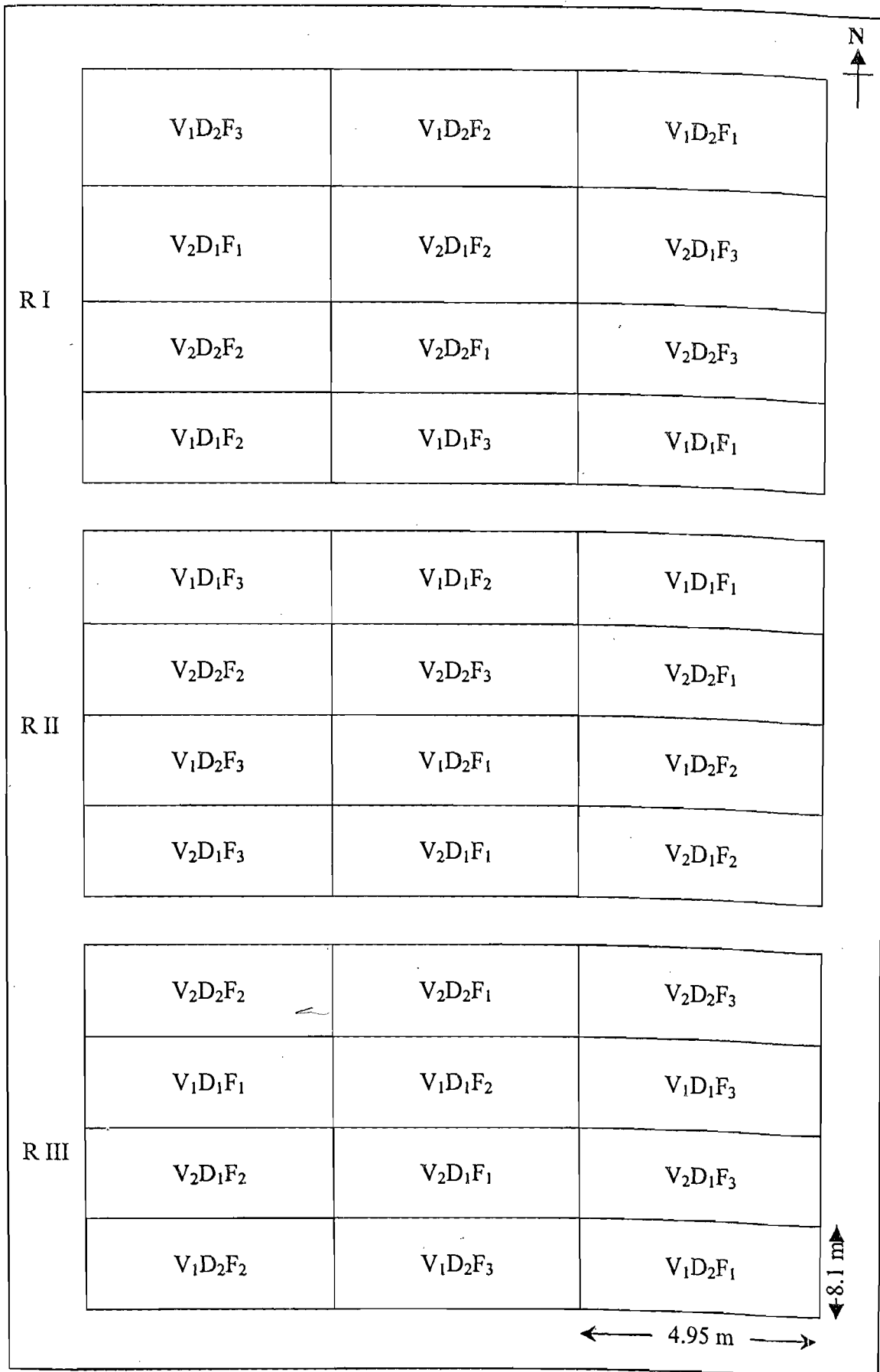


Fig. 4. Field lay out of experiment (2000 – 2001)



(1979) to identify different dates of sowing for dryland condition. Weekly rainfall, potential evapotranspiration (PET), soil available water holding capacity and Kc values of sorghum were used as inputs for this model and the related details are given in Appendix I in respect of sowing dates undertaken in the present investigation.

### 3.1.2.2.2 Treatment structure

#### Main plot treatments

##### A. Times of sowing

- Dry seeding  
(sowing before the receipt of seasonal rainfall) : D<sub>1</sub>
- Monsoon sowing  
(sowing after the receipt of seasonal rainfall) : D<sub>2</sub>

##### B. Varieties

- CO 26 : V<sub>1</sub>
- CSV 15 : V<sub>2</sub>

#### Subplot treatments

##### Nutrient levels

- Control (No nutrient application) : F<sub>1</sub>
- 40 : 20 : 0 kg of N : P<sub>2</sub>O<sub>5</sub> : K<sub>2</sub>O ha<sup>-1</sup> : F<sub>2</sub>
- 60 : 30 : 0 kg of N : P<sub>2</sub>O<sub>5</sub> : K<sub>2</sub>O ha<sup>-1</sup> : F<sub>3</sub>

Potassium was not included in the experiment as per the recommendation given in Crop Production Guide (1999).

### 3.1.2.3 Size of the plots

Gross plot : 8.10 x 4.95 m

Net plot : 4.35 x 3.15 m

### 3.1.3 Cultivation details

#### 3.1.3.1 Field preparation (1999-2000 and 2000-2001)

The experimental field was ploughed with mould board plough during March and twice with cultivator before the start of the cropping season. The clods were

broken with the help of tractor drawn rotovator. Then the field was levelled and layout was done as per the treatments as shown in the layout plan (Fig. 3 and 4).

#### **3.1.3.2 Sowing (1999-2000 and 2000-2001)**

A seed rate of 15 kg ha<sup>-1</sup> was adopted. The seeds were treated with two per cent potassium di-hydrogen phosphate (KH<sub>2</sub>PO<sub>4</sub>) for 12 hours as seed hardening treatment and shade dried until the seeds reached its original moisture level of 14 per cent. Just before sowing, peat based *Azospirillum* culture treatment @ 600 g 15 kg<sup>-1</sup> seeds was given and shade dried for an hour. Lines were drawn deeply up to five cm in the plots at 45 cm interval, in which, the fertilizers were applied as per the treatment schedule. Adjacent to these lines, sowing lines were formed and the sorghum seeds were dibbled at two seeds hill<sup>-1</sup>, adopting a spacing of 45 cm between rows and 15 cm within the row.

#### **3.1.3.3 Manures and fertilizers (both years of experimentation)**

Farmyard manure at the rate of 12.5 t ha<sup>-1</sup> was incorporated uniformly over the field before last ploughing. Just before sowing, N and P fertilizers were applied basally in fertilizer lines as per the treatment schedule. Nitrogen was applied as urea (46 per cent N), while P<sub>2</sub>O<sub>5</sub> was given through single super phosphate (16 per cent P<sub>2</sub>O<sub>5</sub>).

#### **3.1.3.4 After cultivation (both years of experimentation)**

Gap filling was done 7 Days After Sowing (DAS) and thinning was done on 10 DAS to maintain single plant hill<sup>-1</sup> so as to maintain 14.8 plants m<sup>-2</sup>. Hoeing and weeding were done manually at 15 and 30 DAS.

#### **3.1.3.5 Plant protection (both years of experimentation)**

Carbofuron three per cent granules (10 kg ha<sup>-1</sup>) were applied in the leaf whorls on 20 DAS. The crop was sprayed with insecticides (0.1 per cent endosulphan and 0.1 per cent monochrotophos) against sucking pests as a prophylactic measure at vegetative and flower initiation stages. To control the incidence of midges during early maturity stage, carbaryl dust (4 per cent) was dusted in the early morning hours.

#### **3.1.3.6 Harvesting and threshing (both years of experimentation)**

The crop was harvested at physiological maturity stage and the relevant details are given in Table 5. The border rows were harvested first and the earheads from the

Table 5. Particulars on dates of sowing, and dates of harvest for different treatments

Treatment	Dates of sowing	Dates of harvest
<b>1999-2000</b>		
D <sub>1</sub>	13-09-1999*	V <sub>1</sub> D <sub>1</sub> = 18-01-2000 V <sub>2</sub> D <sub>1</sub> = 18-01-2000
D <sub>2</sub>	01-10-1999	V <sub>1</sub> D <sub>2</sub> = 24-01-2000 V <sub>2</sub> D <sub>2</sub> = 18-01-2000
* Soaking rainfall received on 26-09-1999		
<b>2000-2001</b>		
D <sub>1</sub>	18-09-2000**	V <sub>1</sub> D <sub>1</sub> = 19-01-2001 V <sub>2</sub> D <sub>1</sub> = 19-01-2001
D <sub>2</sub>	29-09-2000	V <sub>1</sub> D <sub>2</sub> = 19-01-2001 V <sub>2</sub> D <sub>2</sub> = 19-01-2001
** Soaking rainfall received on 22-09-2000		

net plot area of each treatment were harvested separately. The earheads were dried, threshed and grains were dried. The grain yield was recorded at 14 per cent seed moisture and reported as grain yield  $\text{kg ha}^{-1}$ . The stalks were cut above the ground level and sun dried in the field and weighed and expressed in  $\text{kg ha}^{-1}$ .

### **3.1.4 Biometric observations**

#### **3.1.4.1 Growth characters**

Five plants in each plot in net area were selected at random and permanently tagged for taking periodical growth measurements.

##### **3.1.4.1.1 Plant height (1999-2000 and 2000-2001)**

The height of the plant from ground level to the tip of the longest leaf was measured in cm at weekly interval from 14 DAS onwards as given in Table 6.

##### **3.1.4.1.2 Dry matter production (1999-2000 and 2000-2001)**

Dry matter accumulation was estimated at weekly interval from 14 DAS onwards and finally at harvest as given in Table 6. For this, seven plants (1.05 m row length) were removed from the sample rows left for this purpose, air dried and then oven dried at  $80 \pm 2^\circ \text{C}$  till the attainment of constant weight and dry matter production was calculated and expressed in  $\text{kg ha}^{-1}$ .

##### **3.1.4.1.3 Leaf area (1999-2000 and 2000-2001)**

Plants removed for dry matter estimation at various stages (Table 6) were used for measuring leaf area. All the leaves were stripped out and fed to the leaf area meter (Model LI 3100 area meter, LI-COR, Lincoln, USA) and the leaf area was expressed in  $\text{cm}^2 \text{plant}^{-1}$ .

##### **3.1.4.1.4 Root volume (1999-2000 and 2000-2001)**

Root volume was estimated by water displacement method at 7 days interval from the plant rows left for destructive sampling for dry matter production as given in Table 6 and expressed in cubic  $\text{cm plant}^{-1}$ . The surface soil of the plants was wetted on the previous day itself and the plants were uprooted with the help of digging fork without any disturbance to the roots and subsequently washed carefully as per standard procedure and measured.

Table 6. Particulars of biometric observations taken in the experimental plots during 1999-2000 and 2000-2001

Observation (DAS)	Vegetative stage							Flowering stage				Maturity stage		
	14	21	28	35	42	49	56	63	70	77	84	91	At Harvest	
	1999 – 2000 (I crop)													
Plant height	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Dry matter production	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Leaf area	X	X	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Root volume	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	X	X	✓	✓
Root: Shoot ratio	✓	X	✓	X	✓	X	✓	X	✓	✓	X	X	✓	✓
2000 – 2001 (II crop)														
Plant height	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Dry matter production	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Leaf area	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Root volume	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	X	X	✓	✓
Root: Shoot ratio	✓	X	✓	X	✓	X	✓	X	✓	✓	X	X	✓	✓

DAS: Days After Sowing

✓ - Observation taken

X - Observation was not taken

Table 7. Kc values for sorghum

Stage of the crop	Standard week	Period	Kc value
Seedling stage	36	03-09 Sep	0.58
	37	10-16 Sep	0.39
	38	17-23 Sep	0.32
	39	24-30 Sep	0.33
Average			0.41
Vegetative stage	40	01-07 Oct	0.79
	41	08-14 Oct	0.95
	42	15-21 Oct	1.09
	43	22-28 Oct	1.65
Average			1.12
Flowering stage	44	29-04 Nov	1.47
	45	05-11 Nov	0.92
	46	12-18 Nov	1.27
	47	19-25 Nov	1.61
	48	26-02 Dec	1.18
Average			1.29
Maturity stage	49	03-09 Dec	0.98
	50	10-16 Dec	1.24
	51	17-23 Dec	0.63
	52	24-31 Dec	1.15
Average			0.99

### 3.1.4.1.5 Root: Shoot ratio and Shoot: Root ratio (1999-2000 and 2000-2001)

Samples taken for estimating root volume were used to find Root: Shoot ratio (R: S ratio) and Shoot: Root ratio (S: R ratio). The respective root and shoot were oven dried. The ratios were estimated as given below.

$$\text{R: S ratio} = \frac{\text{Root weight (g)}}{\text{Shoot weight (g)}}$$

$$\text{S: R ratio} = \frac{\text{Shoot weight (g)}}{\text{Root weight (g)}}$$

### 3.1.4.2 Growth analysis (1999-2000 and 2000-2001)

#### 3.1.4.2.1 Leaf area index (1999-2000 and 2000-2001)

Leaf Area Index (LAI) was calculated by using the following formula.

$$\text{LAI} = \frac{\text{Leaf area}}{\text{Land area occupied by the plant}}$$

#### 3.1.4.2.2 Crop growth rate

The Crop Growth Rate (CGR) during the crop period was calculated as suggested by Buttery (1970) at 14-28, 28-42, 42-56, 56-70, 70-84 DAS and 84 DAS-harvest for both 1999-2000 and 2000-2001.

$$\text{CGR} = \frac{w_2 - w_1}{t_2 - t_1} \cdot \text{g m}^{-2} \text{ day}^{-1}$$

Where,

$w_1$  and  $w_2$  = initial and final dry weight of plant materials per unit ground area (g), respectively.

$t_1$  and  $t_2$  = initial and final day of a period of observation, respectively.

### 3.1.4.2.3 Relative growth rate (1999-2000 and 2000-2001)

The Relative Growth Rate (RGR) during crop growth period was calculated as suggested by Enyi (1962) at 14-28, 28-42, 42-56, 56-70, 70-84 DAS and 84 DAS-harvest for both 1999-2000 and 2000-2001.

$$\text{RGR} = \frac{\log_e w_2 - \log_e w_1}{t_2 - t_1} \text{ g g}^{-1} \text{ day}^{-1}$$

Where,

$w_1$  and  $w_2$  = initial and final dry weight of plant materials per unit ground area (g), respectively.

$t_1$  and  $t_2$  = initial and final day of a period of observation, respectively.

### 3.1.4.2.4 Net assimilation rate (1999-2000 and 2000-2001)

The Net Assimilation Rate (NAR) was worked out by using the following formula as suggested by Enyi (1962) at 28-42, 42-56, 56-70, 70-84 DAS and 84 DAS-Harvest for 1999-2000 and 14-28, 28-42, 42-56, 56-70, 70-84 DAS and 84 DAS-Harvest for 2000-2001.

$$\text{NAR} = \frac{w_2 - w_1}{t_2 - t_1} \times \frac{\log_e L_2 - \log_e L_1}{L_2 - L_1} \text{ g m}^{-2} \text{ day}^{-1}$$

Where,

$w_1$  and  $w_2$  = initial and final dry weight of plant materials per unit ground area (g), respectively.

$t_1$  and  $t_2$  = initial and final day of a period of observation, respectively.

$L_1$  and  $L_2$  = initial and final leaf area of a period of observation, respectively.

### 3.1.4.3 Yield components (1999-2000 and 2000-2001)

#### 3.1.4.3.1 Length of earhead

The length of the earhead was measured from the base of the lower most primary rachis to the tip of the earhead and expressed in cm (Ayyangar *et al.*, 1935).

#### 3.1.4.3.2 Number of grains per earhead

The total number of grains in earheads of the sample plants was counted and the mean grain number earhead<sup>-1</sup> was calculated.

#### 3.1.4.3.3 Thousand grain weight

One thousand grains were counted from the representative sample taken from each treatment. The grains were dried to 14 per cent moisture level and then weighed in an electrical top pan balance and the thousand grain weight was expressed in grams (g).

### 3.1.4.4 Yield (1999-2000 and 2000-2001)

#### 3.1.4.4.1 Yield of grain

The grain yield was recorded from the net plot at 14 per cent moisture and expressed in kg ha<sup>-1</sup>.

#### 3.1.4.4.2 Yield of straw

The dry weight of straw was recorded after completely drying in the sun at field and expressed in kg ha<sup>-1</sup>.

### 3.1.4.5 Harvest index

This was found out by calculating the ratio between biological and economic yield as under.

$$\text{Harvest index} = \frac{\text{Economic yield}}{\text{Total biological yield}}$$

### 3.1.5 Chemical analysis (both years of experimentation)

#### 3.1.5.1 Plant analysis

Plant samples collected at varying periods for estimating the dry matter production were ground by a willey mill and used for estimating the NPK contents.

The per cent concentration of these nutrients were multiplied by the respective dry matter content and their uptake values were thus arrived at.

### 3.1.5.1.1 Nitrogen uptake

Nitrogen content was estimated by Microkjeldahl method as suggested by Humphries (1956). The uptake was calculated and expressed in  $\text{kg ha}^{-1}$ .

### 3.1.5.1.2 Phosphorus uptake

The total phosphorus content was estimated by di-acid digestion method as given by Jackson (1973) and the uptake was expressed as  $\text{kg ha}^{-1}$ .

### 3.1.5.1.3 Potassium uptake

Total potassium content of the plant samples was estimated from the di-acid digested material using flame photometer (Jackson, 1973) and the uptake was expressed as  $\text{kg ha}^{-1}$ .

### 3.1.5.2 Soil analysis

Mechanical composition of the soil was analysed as suggested by Piper (1966), before laying out the experiment. Soil samples collected at pre-sowing and post harvest stages were analysed for available N, P and K and expressed as  $\text{kg ha}^{-1}$ . The procedure followed and the author who suggested it for each are given below.

Nutrient	Method	Suggested by
Available Nitrogen	Alkaline permanganate method	Subbiah and Asija (1956)
Available Phosphorus	Olsen's method	Olsen <i>et al.</i> (1954)
Available Potassium	Ammonium acetate extract using flame photometer	Stanford and English (1949)

#### 3.1.5.2.1 Actual soil moisture (1999-2000 and 2000-2001)

Gravimetric method was followed for estimating actual soil moisture. Samples from each plot were drawn at weekly interval from 14 DAS and finally at harvest at 0-15 and 15-30 cm depths using screw auger. The samples were oven dried at  $100 \pm 5^\circ\text{C}$  till constant weight recorded. The amount of moisture on depth basis was expressed in mm as under.

$$\text{Soil moisture} = \frac{\text{Per cent available soil moisture}}{100} \times \text{Bulk density (g cc}^{-1}\text{)} \times \text{depth (cm)}$$

Where,

$$\text{Bulk density of the soil} = 1.36 \text{ g cc}^{-1}$$

### 3.1.6 Soil water balance

A simple daily soil water balance was computed for the entire crop period using the model developed by Gupta *et al.* (1972). Daily rainfall, Potential Evapotranspiration (PET), Sorghum Kc values and soil water holding capacity were used as inputs for this model.

#### 3.1.6.1 Computation of PET from open pan evaporimeter

Computation of PET (Penman, 1948) was done from open pan evaporimeter reading as follows:

$$\text{PET} = K_p \cdot E_o$$

Where,

$$\text{PET} = \text{Reference evapotranspiration (mm day}^{-1}\text{)}$$

$$K_p = \text{Pan coefficient (0.7) - (Doorenbos and Pruitt, 1984)}$$

$$E_o = \text{Pan evaporation (mm day}^{-1}\text{)}$$

#### 3.1.6.2 Estimation of ET

Crop evapotranspiration was estimated by using the following formula.

$$\text{ET} = K_c \times \text{PET}$$

Where,

$$\text{ET} = \text{Crop evapotranspiration (mm day}^{-1}\text{)}$$

$$K_c = \text{Crop coefficient}$$

Sorghum Kc values for different stages are given in Table 7. (Subramanian *et al.*, 1998)

#### 3.1.6.3 Soil water balance

Soil water balance was computed using the method suggested by Gupta *et al.* (1972).

$$W_n = W_{n-1} + RF_n - ET_n$$

Where,

- $W_n$  = soil water on  $n^{\text{th}}$  day  
 $RF_n$  = rainfall on  $n^{\text{th}}$  day  
 $ET_n$  = evapotranspiration on  $n^{\text{th}}$  day  
 $W_{n-1}$  = previous day soil water

#### 3.1.6.4 Effective rainfall

Effective rainfall was calculated as the difference between rainfall and water loss through runoff.

$$ER_n = ET_n - S_n$$

Where,

- $ER_n$  = effective rainfall  
 $ET_n$  = evapotranspiration on  $n^{\text{th}}$  day  
 $S_n$  = water loss (The rainfall received after the soil profile saturation was considered as ineffective and accounted for water loss).

#### 3.1.7 Resource use efficiency (1999-2000 and 2000-2001)

##### 3.1.7.1 Total rainfall use efficiency

Total Rainfall Use Efficiency (TRUE) was worked out by using the following formula and expressed as  $\text{kg ha}^{-1} \text{mm}^{-1}$ .

$$\text{TRUE} = \frac{\text{Grain yield (kg ha}^{-1}\text{)}}{\text{Rainfall during cropping period (mm)}}$$

##### 3.1.7.2 Effective rainfall use efficiency

The formula given below was used to find out the Effective Rainfall Use Efficiency (ERUE) and expressed as  $\text{kg ha}^{-1} \text{mm}^{-1}$ .

$$\text{ERUE} = \frac{\text{Grain yield (kg ha}^{-1}\text{)}}{\text{Effective rainfall during cropping period (mm)}}$$

### 3.1.7.3 Water use efficiency

Water Use Efficiency (WUE) was worked out by using the following formula and expressed as  $\text{kg ha}^{-1} \text{mm}^{-1}$ .

$$\text{WUE} = \frac{\text{Grain yield (kg ha}^{-1}\text{)}}{\text{Total evapotranspiration (mm)}}$$

### 3.1.8 Cost and returns (1999-2000 and 2000-2001)

Gross returns  $\text{ha}^{-1}$  was calculated with the prevailing prices at the time of harvest. Net returns were calculated by subtracting the respective total cost of cultivation from the corresponding gross return. The benefit cost ratio was also worked out by dividing the gross return by the cost of cultivation.

### 3.1.9 Statistical analysis (1999-2000 and 2000-2001)

The data collected were analysed statistically, using the procedure as given by Panse and Sukhatme (1978) to find out the treatment differences at 5 per cent level.

## 3.2 Part II Evaluation of DSSAT V.3.5 Decision Support System (CERES-Sorghum model) for key management practices in rainfed sorghum

### 3.2.1 Crop growth models

For the question of “why build crop models?” Whisler *et al.* (1986) catalogued the reason into three broad categories. They were i) as an aid to interpret experimental result ii) as an agronomic research tool, and iii) as an agronomic growth tool. While the first category was aimed to understand and quantify the process involved in cropping systems, *viz.*, soil and water management, nutrient balance, stomatal control and plant growth processes, the second category attempted to answer questions on “what happened if some changes were made in the system?”. The third category was built from precised laboratory result, growth chamber and/ or field data with an ultimate goal of grower uses, where the grower had to choose the profitability of the management options available.

Crop growth simulation models thus played a vital role in bringing out the specific relationship between weather condition and productivity and provided an opportunity for transferring agricultural production technology from sites of origin to

new locations (Ramakrishna, 1990). These dynamic models not only helped in understanding the climate-crop interaction and the processes that contribute to the growth and yield of crops but also assisted in evaluating the potential of various soil and crop management options (Hoogenboom *et al.*, 1997) and form an important component in system approach research (Ritchie, 1989).

Many of the models are multipurpose in nature and have wide ranging utilities varying from screening genotypes for their suitability to a given environment to long range strategic planning for sustainable production over large areas.

### 3.2.2 Decision support system for agrotechnology transfer

The International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT) was initiated in 1982 for developing a systems analysis approach for addressing a wide range of agricultural, environmental and economic problems in developing countries. The mandate of the project was to develop crop simulation models for 12 most important crops. A major outcome of this project besides model development was a special software system known as Decision Support System for Agrotechnology Transfer (DSSAT).

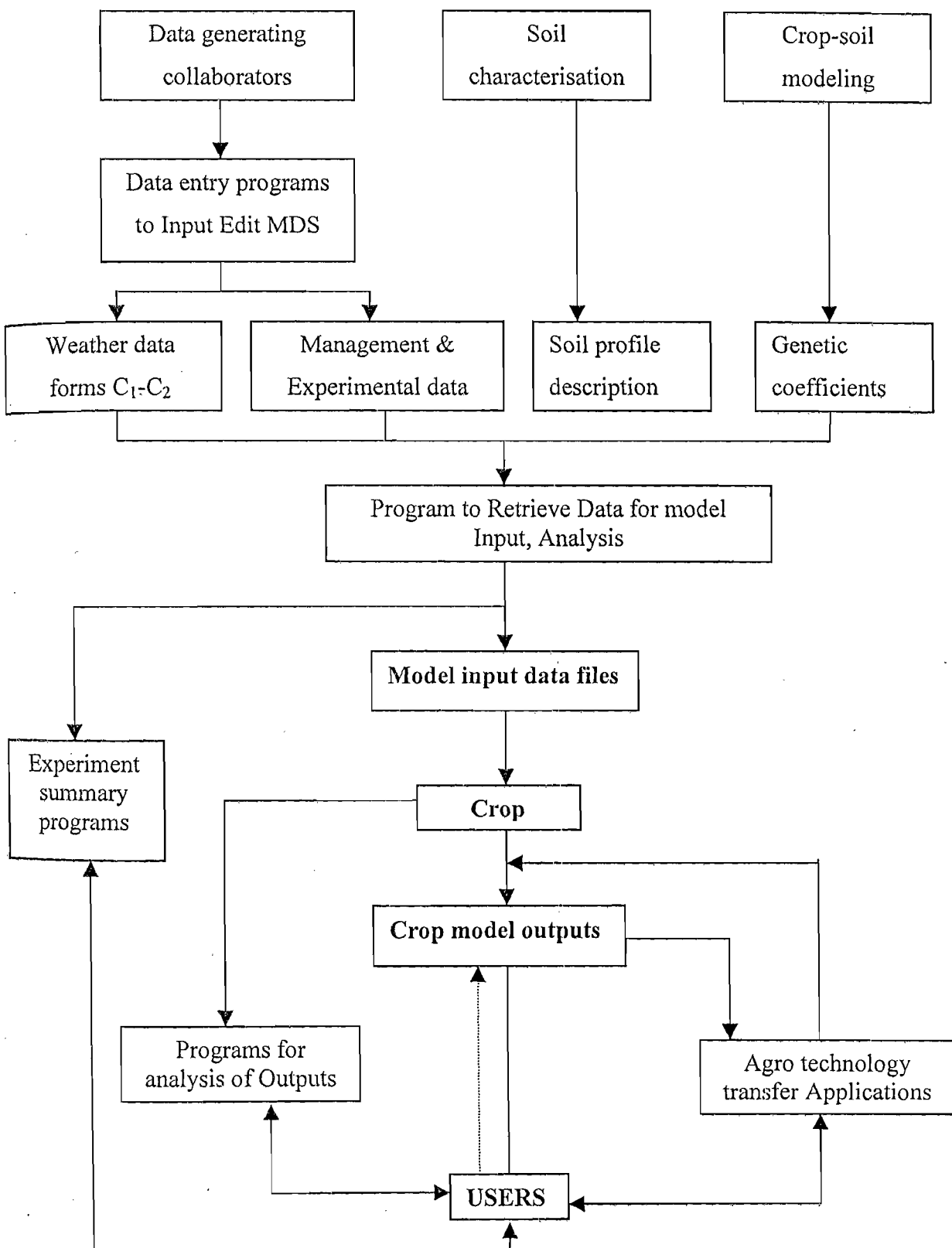
The DSSAT (Fig. 5 and 6) is a program shell that integrates three elements – crop simulation models, a data base management system and a management/ risk assessment program. DSSAT has been designed to easily create “experiments” on computers to simulate outcomes of the complex interactions between various agricultural practices, soil and weather conditions. This program is to suggest appropriate solutions to the site specific problems. DSSAT relies heavily on crop simulation models to predict the performance of crops for making a wide range of decisions. In DSSAT, the CERES (Crop Environment REsource Synthesis) family of crop models is used to predict the performance of six grain crops *viz.*, rice, wheat, barley, maize, sorghum and pearl millet.

The DSSAT crop models are mathematical representation of daily biological and physical processes and are used to predict harvestable yield, plant growth and development, nitrogen dynamics and water balance in response to uncontrolled (weather) variables.

Fig. 5. Structure of DSSAT program

U S E R  I N T E R F A C E	<b>Control program</b>	
	<b>Knowledge base</b>	<b>Crop Growth Models</b> CERES Maize CERES Wheat CERES Rice CERES Sorghum CERES Pearl millet CERES Barley SOYGRO PNUTGRO
		Socioeconomic analysis Strategy evaluation
		<b>Weather generators</b> Richardson Hargreaves
		<b>Expert systems</b> ACID 4
		Pest models
	<b>Data base management System</b>	<b>Data entry and retrieval</b> Soil data base Cultivar data base Experiment data base Daily weather data Fertilizer data base
		Utility Print forms Format conversion Setup Summary

Fig. 6. Schematic drawing of DSSAT components



The DSSAT model simulates the effects of weather, soil, water, cultivar and soil nitrogen dynamics on crop growth and yield. In order to predict crops potential, DSSAT crop model requires the following information.

- ♦ Daily weather data consisting of maximum and minimum air temperatures (°C), solar radiation ( $\text{MJ m}^{-2} \text{ day}^{-1}$ ) and precipitation.
- ♦ The standard soil description including data on key soil properties as a function of depth.
- ♦ Information on sowing date, plant population, amounts and dates of irrigation and amounts and dates of N fertilizer application.
- ♦ Genetic information related to maturity type, photoperiod sensitivity and yield components needed to evaluate optimum efficiencies with in the constraints of weather and soil.

As far as sorghum is concerned, number of simulation models (SORGF, SORKAM, RESCAP and CERES) have been developed. Out of these models, DSSAT's CERES-Sorghum model has wider applicability because of its better support system.

### 3.2.3 CERES-Sorghum model

The CERES-Sorghum model uses a minimum of readily available weather, soil and variety specific genetic inputs. To simulate growth, development and yield, the model takes into account of following processes:

- ♦ Phenological development, especially as it is affected by genotype and weather. The model simulates the effect of photoperiod and temperature on the timing of panicle initiation and the duration of each major growth stage.
- ♦ Extension growth of leaves, stems and roots.
- ♦ Biomass accumulation and partitioning, especially as phenological development that affect the development and growth of vegetative and reproductive organs.
- ♦ Water balance that simulates the daily evaporation, runoff, percolation and crop water uptake under fully irrigated condition and rainfed condition.

- ♦ Soil N transformations associated with mineralization/ immobilization, urea hydrolysis, nitrification, denitrification, ammonia volatilization, losses of N associated with runoff and percolation and uptake and utilization of N by the crop.

### 3.2.4 Evaluation of CERES-Sorghum model

Model evaluation is a process in which model predictions are compared with field observations. Lemon (1977) had defined validation as a “comparison of verified models to the real world and determination if it is suitable for its intended purpose”. Later, Whisler *et al.* (1986) defined the validation as “comparison of the predictions of a verified model with experimental observations other than those used to build and calibrate the model”. Validated models can be used to reliably simulate crop yields and other output variables under different environments. Identification and correction of errors in the model will continue until the model is suitable for its intended purpose. Hence, validation is the corner stone of evaluation.

### 3.2.5 Minimum data set requirement for evaluating CERES-Sorghum model

For the evaluation of CERES-Sorghum model, a Minimum Data Set (MDS) – data on management of the crop, macro and micro environmental parameters associated with the weather and the soil are required as input.

#### 3.2.5.1 Weather information

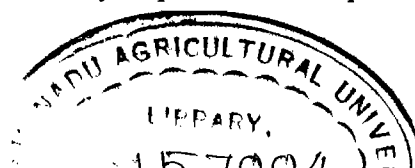
The daily weather data on maximum air temperature ( $^{\circ}\text{C}$ ), minimum air temperature ( $^{\circ}\text{C}$ ), solar radiation ( $\text{MJ m}^{-2} \text{day}^{-1}$ ) and precipitation (mm) for 41 years (1960–2000) were collected from Department of Agricultural Meteorology, Tamil Nadu Agricultural University, Coimbatore and used for creating weather file for running DSSAT’s CERES-Sorghum model.

#### 3.2.5.2 Soil information

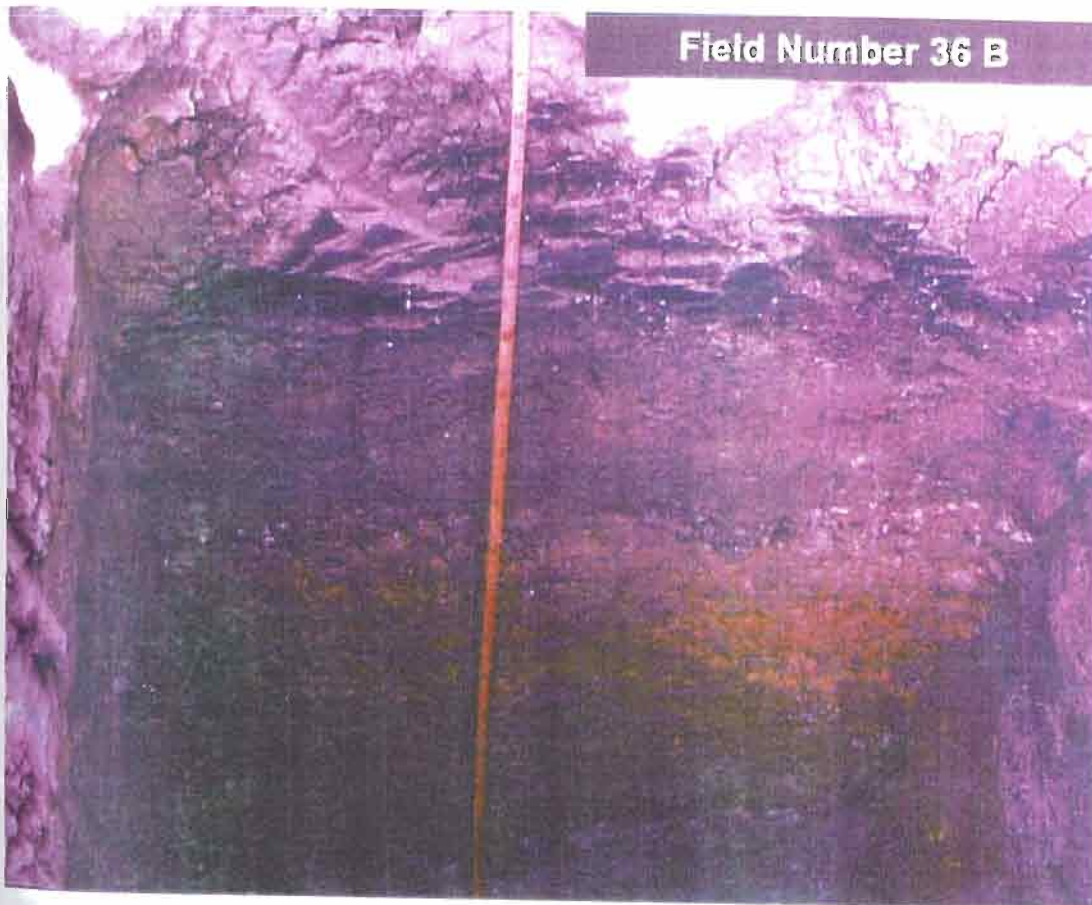
A profile was opened up in field number 36B near the experimental site and layer wise soil samples were collected for obtaining layer wise data on soil physicochemical characteristics. The details are given in Appendix II and Plate 1.

#### 3.2.5.3 Crop management

The cultivation details were similar to the one already explained in chapter 3.1.3.



**Plate 1. Soil profile**



### **3.2.5.3.1 Biometric observations (1999-2000 and 2000-2001)**

Biometric observations like dry matter production and leaf area index and date of occurrence of phenological stages, yield components and yield were taken both from the main experimental plots and from the genetic coefficient plots for constructing the MDS for the DSSAT V.3.5 CERES-Sorghum model evaluation as well as for the computation of genetic coefficient of CO 26 and CSV 15, as per the procedure (Fig. 7) given by IBSNAT (1990).

#### **3.2.5.3.1.1 Dry matter production**

Dry matter accumulation was estimated for MDS at weekly interval from 14 DAS to harvest as already described in chapter 3.1.4.1.2.

#### **3.2.5.3.1.2 Leaf area index**

Leaf Area Index (LAI) was calculated by using the formula given in chapter 3.1.4.2.1.

#### **3.2.5.3.1.3 Date of occurrence of phenological stages**

Five plants were tagged at random in each treatment of all the three replications. Daily observations were made on the phenological development of the crop and the date of occurrence of various developmental stages as given in Appendix III (Zadoks *et al.*, 1974) as well as date of panicle initiation (Vanderlip and Reeves, 1972) for different treatments were recorded.

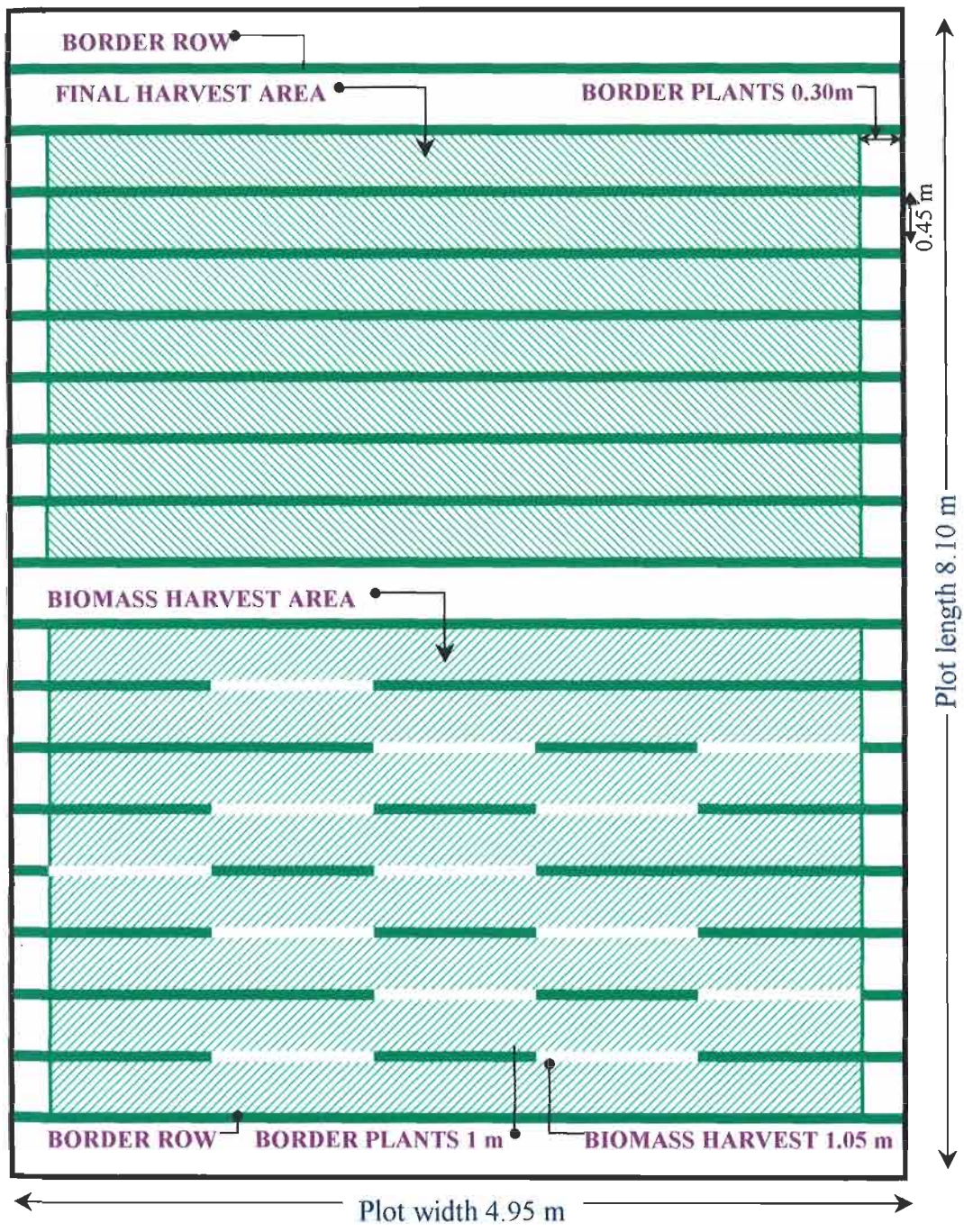
#### **3.2.5.3.2 Yield components and yield**

The final harvest was done at the growth stage of 92–94 DAS (soon after 80 per cent of grains are hard and difficult to break with finger nails or teeth) in all the plots. The methodology for recording the yield components and yield were similar to the one that already described in chapter 3.1.4.3 and 3.1.4.4.

### **3.2.5.4 Computation of economical optimum dose of nitrogen application under sensitivity analysis**

Economically viable dose of nitrogen application was worked out by comparing the cost involved (fertilizer cost) and returns obtained (grain yield) between two consecutive levels of nitrogen application in the sensitivity analysis option available in DSSAT V.3.5 CERES-Sorghum model.

Fig. 7 Plot diagram of harvest area for collecting MDS for DSSAT v 3.5 CERES Sorghum



### **3.2.5.5 Computation of returning period for the Northeast monsoon of Coimbatore district**

Returning period of rainfall refers to its repeatability and helps to know at what frequency a specific quantum of rainfall occurs (Veeraputhiran *et al.*, 1999). The details are furnished in Appendix VI.

## **EXPERIMENTAL RESULTS**

---

## CHAPTER IV

### EXPERIMENTAL RESULTS

Field experiments were conducted at Tamil Nadu Agricultural University Farm, Coimbatore in dryland *Vertisols* during Northeast monsoon seasons of 1999 and 2000 to investigate the performance of different varieties of sorghum (*Sorghum bicolor* (L.) Moench.) under different sowing times and levels of Nitrogen and Phosphorus. This experiment also aimed to evaluate DSSAT V.3.5 Decision Support System for Agrotechnology Transfer (CERES-Sorghum model) for key management practices like choice of varieties, times of sowing and nutrient levels. The results of the experiments are presented in this chapter under two parts.

#### 4.1 Part I Main experiment

##### 4.1.1 Growth parameters

###### 4.1.1.1 Plant height

The data on mean plant height recorded for the two seasonal crops at vegetative stage (14, 21, 28, 35, 42 and 49 DAS), flowering stage (56, 63, 70 and 77 DAS) and maturity stage (84, 91 DAS and at harvest) are presented in Tables 8 and 9.

In general, the sorghum crop had grown taller with the advancement in age. Except at 14 DAS of first crop (1999-2000), the varieties did not differ significantly for plant height at vegetative stage. At 14 DAS of first crop, the entry V<sub>2</sub> (CSV 15) had grown taller over the other entry V<sub>1</sub> (CO 26) significantly. There was no significant difference between the two varieties evaluated at flowering stage in both the crops studied. Except at 84 DAS of first crop at maturity stage, in other days of observation, there was no statistical difference between varieties evaluated. Even though in the first crop, significance was exhibited between varieties evaluated at 84 DAS, they were at par only.

With reference to the different times of sowing studied, there was no much difference in respect of plant height studied in both first (1999-2000) and second crop (2000-2001), except at 49 DAS of the first crop (vegetative stage), where in D<sub>2</sub> sowing gave significantly taller plants than D<sub>1</sub> sowing. At flowering and maturity

Table 8. Effect of varieties, times of sowing and nutrient levels on plant height (cm) of sorghum at vegetative stage

Treatments	14 DAS		21 DAS		28 DAS		35 DAS		42 DAS		49 DAS	
	I crop	II crop	I crop	II crop	I crop	II crop	I crop	II crop	I crop	II crop	I crop	II crop
V <sub>1</sub>	20.6	22.0	34.8	42.9	56.6	62.0	78.8	77.7	112.3	89.4	148.3	93.9
V <sub>2</sub>	24.0	24.3	36.7	45.3	61.5	64.3	86.1	79.1	122.9	92.3	158.7	97.9
SEd	0.83	2.04	1.94	2.07	3.76	2.54	5.46	3.41	5.52	5.63	6.17	6.36
CD (P=0.05)	2.04	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
D <sub>1</sub>	22.4	26.4	35.0	46.9	58.7	64.8	81.9	77.5	113.8	92.2	145.6	96.6
D <sub>2</sub>	22.1	21.9	36.6	42.5	59.4	61.5	83.0	79.2	121.4	89.4	161.4	95.2
SEd	0.83	2.04	1.94	2.07	3.76	2.54	5.46	3.41	5.52	5.63	6.17	6.36
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	15.10	NS
F <sub>1</sub>	20.2	21.6	32.4	42.6	50.0	63.5	70.9	76.8	102.2	89.9	139.5	94.5
F <sub>2</sub>	23.0	23.5	36.7	44.5	61.5	61.6	84.0	79.1	118.9	90.9	153.6	95.8
F <sub>3</sub>	23.7	24.3	38.3	45.4	65.6	64.4	92.3	79.2	131.7	91.7	167.3	97.5
SEd	0.64	2.93	1.50	2.98	2.99	3.26	4.00	3.58	5.50	4.90	5.56	5.30
CD (P=0.05)	1.36	NS	3.18	NS	6.35	NS	8.49	NS	11.6	NS	11.78	NS
V x D												
SEd	1.18	2.88	2.74	2.93	5.31	3.22	7.71	4.83	7.80	7.96	8.73	6.17
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
V at F												
SEd	1.12	3.95	2.60	3.99	5.10	4.42	7.15	5.36	8.41	7.99	8.90	6.61
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
F at V												
SEd	0.91	4.14	2.12	4.18	4.23	4.86	5.66	5.06	7.78	6.93	7.86	6.08
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
D at F												
SEd	1.16	3.95	2.60	3.99	5.10	4.42	7.15	5.36	8.41	7.99	8.90	6.61
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
F at D												
SEd	0.91	4.14	2.12	4.18	4.23	4.86	5.66	5.06	7.78	6.93	7.86	6.08
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

I crop: 1999 NEM

II crop: 2000 NEM

NS = Not significant

Table 9. Effect of varieties, times of sowing and nutrient levels on plant height (cm) of sorghum at flowering and maturity stages

Treatments	Flowering stage						Maturity stage							
	56 DAS		63 DAS		70 DAS		77 DAS		84 DAS		91 DAS		At harvest	
	I crop	II crop	I crop	II crop	I crop	II crop	I crop	II crop	I crop	II crop	I crop	II crop	I crop	II crop
V <sub>1</sub>	178.7	113.9	206.3	116.3	228	128.2	233.1	136.5	232.9	139.9	232.2	139.7	232.1	139.7
V <sub>2</sub>	184.7	115.9	208.0	118.5	219.4	130.7	223.4	137.4	223.4	139.0	223.8	138.9	222.3	138.8
SEd	5.63	7.43	5.47	7.37	4.48	8.2	4.08	8.41	4.00	5.37	4.03	4.96	4.01	4.96
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	9.80	NS	NS	NS	NS	NS
D <sub>1</sub>	182.0	118.8	202.0	124.8	222.2	136.8	228.4	143.6	229.4	144.8	229.3	144.6	229.1	144.5
D <sub>2</sub>	181.3	108.0	212.3	109.9	225.1	120.1	228.0	125.3	226.9	134.2	226.7	134.0	226.3	134.0
SEd	5.63	7.43	5.47	7.37	4.48	8.2	4.08	8.41	4.00	5.37	4.03	4.96	4.01	4.96
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
F <sub>1</sub>	169.5	113.4	197.6	114.3	218.5	127.0	225.5	136.2	224.6	138.5	224.8	138.4	224.5	138.2
F <sub>2</sub>	182.0	115.1	207.8	116.9	224.2	129.5	229.3	138.5	229.4	141.2	229.0	141.0	229.1	140.8
F <sub>3</sub>	193.6	116.1	216.2	118.5	228.4	129.0	230.1	136.4	230.5	131.9	230.4	138.6	230.3	138.5
SEd	4.74	5.49	4.14	5.51	3.47	6.35	3.86	6.57	4.05	4.24	3.61	4.02	3.59	4.00
CD (P=0.05)	10.05	NS	8.77	NS	7.35	NS	NS	NS	NS	NS	NS	NS	NS	NS
V x D														
SEd	7.97	8.51	7.74	8.42	6.34	10.58	5.77	10.9	5.66	5.76	5.70	5.60	5.69	5.58
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
V at F														
SEd	7.85	9.76	7.26	9.73	6.01	10.2	6.04	10.3	6.16	5.95	5.80	4.30	5.81	4.26
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
F at V														
SEd	6.70	7.76	5.85	7.77	4.90	9.42	5.46	9.82	5.73	5.44	5.11	4.87	5.12	4.59
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
D at F														
SEd	7.85	9.76	7.26	9.73	6.01	10.2	6.04	10.3	6.16	5.95	5.80	4.30	5.81	4.26
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
F at D														
SEd	6.7	7.76	5.85	7.77	4.90	9.42	5.46	9.82	5.73	5.44	5.11	4.87	5.12	4.59
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

NS = Not significant

II crop: 2000 NEM

I crop: 1999 NEM

stages of both the crops, there was no statistical difference between treatments evaluated.

At the vegetative stage of the first crop, the treatment F<sub>3</sub> (60: 30: 0 kg of N: P<sub>2</sub>O<sub>5</sub>: K<sub>2</sub>O ha<sup>-1</sup>) was at par with F<sub>2</sub> (40: 20: 0 kg of N: P<sub>2</sub>O<sub>5</sub>: K<sub>2</sub>O ha<sup>-1</sup>) and significantly superior to F<sub>1</sub> (control). This trend was noticed up to 35 DAS, while at 42 and 49 DAS, F<sub>3</sub> was significantly superior to F<sub>2</sub> and F<sub>1</sub> nutrient levels. At flowering stage (56, 63 and 70 DAS), F<sub>3</sub> was significantly superior over to F<sub>2</sub> and F<sub>1</sub> at 56 DAS, while such trend was not noticed at 63 and 70 DAS. At 77 DAS, there was no statistical difference between the levels studied. At maturity stage, for the first crop, nutrient levels did not alter the plant height significantly.

Even though such trend was obtained in the second crop, the different nutrient levels studied did not differ significantly at any of the stages studied in altering the plant height.

Interactions were not significant through out different stages of both first and second crop.

#### 4.1.1.2 Dry matter production

The data on mean Dry Matter Production (DMP) recorded at vegetative stage (14, 21, 28, 35, 42 and 49 DAS), at flowering stage (56, 63, 70 and 77 DAS) and at maturity stage (84, 91 DAS and at harvest) are presented in Tables 10 and 11.

In general, with the advancement in crop growth, the DMP had increased irrespective of the treatments imposed in both the crops of the study.

Varieties exerted a significant change in DMP at all the vegetative, flowering and maturity stages in both the crops of study, except at 35 and 42 DAS in vegetative stage and at 63 DAS in flowering stage of first crop (1999-2000) and 21 DAS in vegetative stage of second crop (2000-2001). The variety V<sub>2</sub> (CSV 15) recorded significantly higher DMP as compared to V<sub>1</sub> (CO 26).

Between the two times of sowing evaluated, D<sub>1</sub> produced significantly higher dry matter at all the stages of second crop except at 35 DAS in which D<sub>2</sub> produced significantly higher dry matter than D<sub>1</sub>, while in the first crop, even though the same

Table 10. Effect of varieties, times of sowing and nutrient levels on dry matter production ( $\text{kg ha}^{-1}$ ) of sorghum at vegetative stage

Treatments	14 DAS		21 DAS		28 DAS		35 DAS		42 DAS		49 DAS	
	I crop	II crop	I crop	II crop	I crop	II crop	I crop	II crop	I crop	II crop	I crop	II crop
V <sub>1</sub>	10.0	6.8	41	201	144	347	467	715	948	911	2522	1913
V <sub>2</sub>	14.1	7.5	55	192	194	407	579	517	1160	960	3034	2036
SEd	1.37	0.16	2.5	4.7	19.9	9.0	70.3	15.8	89.5	19.4	72.8	45.1
CD (P=0.05)	3.35	0.39	6.2	NS	48.7	22.0	NS	38.6	NS	47.4	178.2	110.4
D <sub>1</sub>	10.6	7.7	52	212	183	403	540	574	969	965	3010	2154
D <sub>2</sub>	13.5	6.6	44	194	156	351	506	658	1138	905	2546	1795
SEd	1.37	0.16	2.5	4.7	19.9	9.0	70.3	15.8	89.5	19.4	72.8	45.1
CD (P=0.05)	NS	0.39	6.2	11.6	NS	22.0	NS	38.6	NS	47.4	178.2	110.4
F <sub>1</sub>	8.6	6.0	24	113	94	260	244	420	525	706	1735	1278
F <sub>2</sub>	11.4	7.3	45	229	168	380	568	614	1132	988	2838	2198
F <sub>3</sub>	16.0	8.2	74	258	246	491	757	814	1504	1111	3761	2448
SEd	1.10	0.34	4.0	10.2	20.7	16.5	74.5	30.5	127.1	45.5	244.9	97.0
CD (P=0.05)	2.37	0.72	8.5	21.6	43.9	35.0	158.0	64.5	269.5	96.4	519.3	205.7
V x D												
SEd	1.94	0.29	3.6	6.7	28.2	12.7	99.4	22.3	126.5	27.4	103	63.8
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	67.0	NS	NS
V at F												
SEd	1.87	0.42	5.3	12.7	31.1	21.1	111.1	38.5	171.9	56.0	292.1	120.8
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
F at V												
SEd	1.56	0.48	5.7	14.4	29.3	23.3	105.4	43.1	179.8	64.3	346.4	137.2
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
D at F												
SEd	1.87	0.42	5.3	12.7	31.1	21.1	111.1	38.5	171.9	56.0	292.1	120.8
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
F at D												
SEd	1.56	0.48	5.7	14.4	29.3	23.3	105.4	43.1	179.8	64.3	346.4	137.2
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

I crop: 1999 NEM

II crop: 2000 NEM

NS = Not significant

Table 11. Effect of varieties, times of sowing and nutrient levels on dry matter production ( $\text{kg ha}^{-1}$ ) of sorghum at flowering and maturity stages

Treatments	Flowering stage												Maturity stage					
	56 DAS		63 DAS		70 DAS		77 DAS		84 DAS		91 DAS		At harvest					
	I crop	II crop	I crop	II crop	I crop	II crop	I crop	II crop	I crop	II crop	I crop	II crop	I crop	II crop				
V <sub>1</sub>	3174	2997	4581	3547	5337	3881	4356	5651	4356	6683	5222	8666	5773	10093	5965			
V <sub>2</sub>	3682	3273	4720	3955	6033	4546	5599	6805	5599	7632	5886	10292	6180	11511	6395			
SEd	192.1	69.2	201.0	79.2	237.0	82.4	94.3	258.4	94.3	260.1	95.7	282.8	111.6	304.3	160.2			
CD (P=0.05)	470.1	169.4	NS	193.8	579.9	201.7	230.8	632.2	230.8	636.4	234.1	692.1	273.1	744.6	392.1			
D <sub>1</sub>	3510	3413	5006	4048	5637	4496	5124	6380	5124	7162	5751	10015	6162	11552	6381			
D <sub>2</sub>	3346	2857	4295	3454	5733	3931	4830	6076	4830	7153	5319	8943	5791	10051	5979			
SEd	192.1	69.2	201.0	79.2	237.0	82.4	94.3	258.4	94.3	260.1	95.7	282.8	111.6	304.3	160.2			
CD (P=0.05)	NS	169.4	492.0	193.8	579.9	201.7	230.8	NS	230.8	NS	234.1	692.1	273.1	744.6	392.1			
F <sub>1</sub>	2290	2498	3505	3123	4137	3482	4213	4655	4213	5317	4661	7377	4904	8616	5049			
F <sub>2</sub>	3364	3384	4630	3944	5856	4631	5438	6304	5438	7294	6185	9691	6611	10765	6841			
F <sub>3</sub>	4629	3523	5817	4186	7062	4528	5281	7726	5281	8861	5817	11370	6416	13025	6650			
SEd	263.7	149.1	319.1	179.2	343.5	202.2	239.9	366.8	239.9	328.4	241.3	429.6	284.4	446.8	236.8			
CD (P=0.05)	559.0	316.1	678.3	379.8	728.2	428.7	508.5	777.7	508.5	696.1	511.6	910.7	602.8	947.1	502.0			
V x D	217.7	97.9	301.1	112.0	335.1	116.6	133.4	365.4	133.4	367.8	135.3	400.0	157.8	430.3	226.6			
SEd	NS	NS	NS	274.0	NS	285.3	NS	NS	NS	NS	NS	NS	NS	NS	NS			
CD (P=0.05)	NS	NS	NS	274.0	NS	285.3	NS	NS	NS	NS	NS	NS	NS	NS	NS			
V at F	360.0	185.6	384.2	221.1	462.1	247.6	292.6	496.2	292.6	459.8	294.6	571.0	346.8	599.0	316.9			
SEd	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS			
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS			
F at V	372.9	210.9	452.5	253.4	485.8	286.0	339.3	518.8	339.3	464.4	341.3	607.5	402.2	631.8	334.9			
SEd	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS			
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS			
D at F	360.0	185.6	384.2	221.5	462.0	247.6	292.6	496.2	292.6	459.8	294.6	571.0	346.8	598.9	316.9			
SEd	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS			
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS			
F at D	372.9	210.9	452.5	253.4	485.8	286.0	339.3	518.8	339.3	464.4	341.3	607.5	402.2	631.8	334.9			
SEd	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS			
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS			

I crop: 1999 NEM

II crop: 2000 NEM

NS = Not significant

result was observed at 21, 49, 63, 91 DAS and at harvest, at 70 DAS, D<sub>1</sub> sowing was at par with D<sub>2</sub> sowing.

The perusal of mean data between levels of nutrients evaluated, the treatment F<sub>3</sub> (60: 30: 0 kg of N: P<sub>2</sub>O<sub>5</sub>: K<sub>2</sub>O ha<sup>-1</sup>) had recorded significantly higher DMP in the first crop at all the stages of study. While in the second crop, such significance was noticed for F<sub>3</sub> treatment up to vegetative stage, there after F<sub>2</sub> level (40: 20: 0 kg of N: P<sub>2</sub>O<sub>5</sub>: K<sub>2</sub>O ha<sup>-1</sup>) had produced higher DMP and at par with F<sub>3</sub> level.

The interaction between varieties and times of sowing showed significant difference at 42, 63 and 70 DAS during the second crop in which V<sub>2</sub> produced significantly higher DM when sown on D<sub>1</sub> compared to all other treatments (Table 12). But the interaction was not significant during the first crop. In the second crop at 42, 63 and 70 DAS, D<sub>1</sub> date of sowing was significantly superior over D<sub>2</sub> sowing irrespective of the varieties evaluated in terms of dry matter production. Similarly, in respect of varieties, V<sub>2</sub> produced significantly higher dry matter than V<sub>1</sub> irrespective of times of sowing at 42, 63 and 70 DAS.

#### 4.1.1.3 Leaf area index

The data on mean Leaf Area Index (LAI) recorded at vegetative stage, flowering stage and maturity stage are presented in Tables 13 and 14.

In general, there was a steady increase in LAI from vegetative stage to flowering stage and then a declining trend was noted up to maturity stage in both the crops (1999-2000 and 2000-2001).

Between varieties, there was no significant difference in respect of LAI at vegetative stage for both the crops. At flowering stage of first crop, except 56 DAS, the variety V<sub>1</sub> (CO 26) registered higher LAI over V<sub>2</sub> (CSV 15), where as in the second crop, there was no significant difference between varieties in terms of LAI at flowering stage. During both the years, LAI was not differed significantly between varieties studied at maturity stage, except at 84 and 91 DAS of first crop in which CO 26 did produce significantly higher LAI over CSV 15.

With reference to times of sowing evaluated, there was no significant difference between the two sowings in both the years at vegetative stage, except at 28

Table 12. Interaction effect of varieties and times of sowing on dry matter production ( $\text{kg ha}^{-1}$ ) of sorghum during 2000-2001 (second crop)

V x D	42 DAS			63 DAS			70 DAS		
	D <sub>1</sub>	D <sub>2</sub>	Mean	D <sub>1</sub>	D <sub>2</sub>	Mean	D <sub>1</sub>	D <sub>2</sub>	Mean
V <sub>1</sub>	901	920	911	3719	3374	3547	4016	3746	3881
V <sub>2</sub>	1029	890	960	4377	3533	3955	4976	4116	4546
Mean	965	905	-	4048	3454	-	4496	3931	-

	SEd	CD (P=0.05)	SEd	CD (P=0.05)	SEd	CD (P=0.05)
V	19.4	47.4	79.2	193.8	82.4	201.7
D	19.4	47.4	79.2	193.8	82.4	201.7
V x D	27.4	67.0	112.0	274.1	116.6	285.3

Table 13. Effect of varieties, times of sowing and nutrient levels on leaf area index of sorghum at vegetative stage

Treatments	14 DAS		21 DAS		28 DAS		35 DAS		42 DAS		49 DAS	
	II crop	II crop	I crop	II crop	I crop	II crop	I crop	II crop	I crop	II crop	I crop	II crop
V <sub>1</sub>	0.16	0.25	0.34	0.31	0.84	0.64	1.58	0.97	3.31	1.24	3.31	1.24
V <sub>2</sub>	0.23	0.30	0.32	0.32	0.82	0.73	1.51	1.13	3.15	1.36	3.15	1.36
SEd	0.050	0.048	0.012	0.039	0.097	0.055	0.190	0.110	0.183	0.131	0.183	0.131
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
D <sub>1</sub>	0.23	0.31	0.42	0.35	0.83	0.60	1.49	0.97	3.36	1.35	3.36	1.35
D <sub>2</sub>	0.17	0.25	0.24	0.29	0.81	0.77	1.60	1.12	3.46	1.24	3.46	1.24
SEd	0.050	0.048	0.012	0.039	0.097	0.055	0.190	0.110	0.183	0.131	0.183	0.131
CD (P=0.05)	NS	NS	0.029	NS	NS	0.135	NS	NS	NS	NS	NS	NS
F <sub>1</sub>	0.16	0.24	0.22	0.32	0.61	0.69	1.19	1.08	2.56	1.26	2.56	1.26
F <sub>2</sub>	0.21	0.28	0.36	0.31	0.90	0.67	1.56	1.01	3.43	1.28	3.43	1.28
F <sub>3</sub>	0.22	0.29	0.40	0.33	1.01	0.70	1.90	1.05	3.69	1.36	3.69	1.36
SEd	0.053	0.054	0.014	0.036	0.070	0.075	0.139	0.101	0.228	0.092	0.228	0.092
CD (P=0.05)	NS	NS	0.029	NS	0.158	NS	0.294	NS	0.483	NS	0.483	NS
V x D												
SEd	0.071	0.068	0.017	0.055	0.138	0.078	0.268	0.156	0.259	0.185	0.259	0.185
CD (P=0.05)	NS	NS	0.014	NS	NS	NS	NS	NS	NS	NS	NS	NS
V at F												
SEd	0.080	0.079	0.020	0.057	0.130	0.102	0.248	0.161	0.320	0.169	0.320	0.169
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
F at V												
SEd	0.076	0.076	0.019	0.051	0.105	0.106	0.196	0.143	0.242	0.130	0.242	0.130
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
D at F												
SEd	0.080	0.079	0.020	0.057	0.130	0.102	0.248	0.161	0.320	0.169	0.320	0.169
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
F at D												
SEd	0.076	0.076	0.019	0.051	0.105	0.106	0.196	0.143	0.242	0.130	0.242	0.130
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

I crop: 1999 NEM II crop: 2000 NEM NS = Not significant

\*Leaf area was not measured in first crop at 14 and 21 DAS due to fault in leaf area meter

Table 14. Effect of varieties, times of sowing and nutrient levels on leaf area index of sorghum at flowering and maturity stages

Treatments	Flowering stage						Maturity stage							
	56 DAS		63 DAS		70 DAS		77 DAS		84 DAS		91 DAS		At harvest	
	I crop	II crop	I crop	II crop	I crop	II crop	I crop	II crop	I crop	II crop	I crop	II crop	I crop	II crop
V <sub>1</sub>	4.34	1.70	4.64	1.53	3.61	1.47	3.03	1.38	2.63	1.05	2.21	0.94	1.72	0.79
V <sub>2</sub>	4.20	1.83	3.87	1.66	3.03	1.55	2.54	1.46	2.24	1.16	1.87	1.02	1.42	0.86
SEd	0.228	0.132	0.178	0.130	0.154	0.116	0.118	0.112	0.126	0.102	0.115	0.108	0.134	0.077
CD (P=0.05)	NS	NS	0.435	NS	0.377	NS	0.289	NS	0.308	NS	0.281	NS	NS	NS
D <sub>1</sub>	4.35	1.66	4.78	1.49	3.46	1.31	2.96	1.22	2.54	1.09	2.19	1.01	1.75	0.90
D <sub>2</sub>	4.18	1.87	3.72	1.70	3.18	1.71	2.61	1.62	2.33	0.98	1.89	0.95	1.39	0.75
SEd	0.228	0.132	0.178	0.130	0.154	0.116	0.118	0.112	0.126	0.102	0.115	0.108	0.134	0.077
CD (P=0.05)	NS	NS	0.435	NS	0.284	NS	0.289	NS	0.283	NS	0.281	NS	0.328	NS
F <sub>1</sub>	3.74	1.81	4.03	1.65	3.22	1.45	2.73	1.35	2.36	1.04	2.04	0.88	1.66	0.70
F <sub>2</sub>	4.37	1.76	4.28	1.59	3.31	1.52	2.77	1.47	2.43	1.09	2.03	1.04	1.51	0.90
F <sub>3</sub>	4.70	1.72	4.45	1.55	3.43	1.56	2.86	1.43	2.53	1.13	2.05	1.05	1.54	0.89
SEd	0.312	0.125	0.214	0.125	0.162	0.086	0.132	0.086	0.134	0.075	0.099	0.069	0.097	0.064
CD (P=0.05)	0.661	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.146	NS	0.136
V x D														
SEd	0.322	0.187	0.251	0.187	0.218	0.164	0.167	0.164	0.178	0.142	0.166	0.152	0.190	0.109
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
V at F														
SEd	0.426	0.196	0.305	0.196	0.242	0.152	0.193	0.152	0.200	0.173	0.164	0.134	0.175	0.107
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
F at V														
SEd	0.441	0.177	0.303	0.177	0.228	0.121	0.187	0.111	0.190	0.165	0.140	0.098	0.137	0.091
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
D at F														
SEd	0.426	0.196	0.305	0.196	0.242	0.152	0.193	0.132	0.200	0.173	0.164	0.134	0.175	0.107
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
F at D														
SEd	0.441	0.177	0.303	0.177	0.228	0.121	0.187	0.111	0.190	0.165	0.140	0.098	0.137	0.091
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

I crop: 1999 NEM

II crop: 2000 NEM

NS = Not significant

DAS of first crop in which  $D_1$  registered significantly higher LAI as compared to  $D_2$  and at 35 DAS of second crop,  $D_2$  sowing did produce significantly higher LAI over  $D_1$  sowing.

At flowering stage of first crop,  $D_1$  recorded significantly higher LAI than  $D_2$  at 63 and 77 DAS, where as in the second crop,  $D_2$  registered significantly higher LAI than  $D_1$  at 70 and 77 DAS. At maturity stage, the LAI of  $D_1$  was significantly superior over to  $D_2$  sowing at 91 DAS and at harvest of first crop. In the second crop, there was no significant difference between  $D_1$  and  $D_2$  sowings at the maturity stage.

Among the nutrient levels evaluated,  $F_3$  (60: 30: 0 kg of N:  $P_2O_5$ :  $K_2O$   $ha^{-1}$ ) registered higher LAI than  $F_2$  (40: 20: 0 kg of N:  $P_2O_5$ :  $K_2O$   $ha^{-1}$ ) and  $F_1$  (control) in the first crop and the difference was significant at 28 and 42 DAS, while  $F_3$  was at par with  $F_2$  at 35 and 49 DAS of vegetative stage. Such significance was absent for the second crop at this stage. At flowering stage of the first crop, the result was not significant except at 56 DAS, where in  $F_3$  and  $F_2$  were at par. At maturity stage the result was not significant for first crop, while at 91 DAS and at harvest of second crop,  $F_3$  and  $F_2$  nutrient levels were at par. The least LAI was produced by  $F_1$  nutrient level.

In the investigation, all the interactions were not significant in both the crops (1999-2000 and 2000-2001).

#### 4.1.1.4 Crop growth rate

The computed data on Crop Growth Rate (CGR) are presented in Tables 15 and 16.

There was increase in CGR up to 42-56 DAS and there after declining trend was observed in both the crops (1999-2000 and 2000-2001).

In the first crop (1999-2000), the varieties studied did not differ significantly; while in the second crop (2000-2001),  $V_2$  (CSV 15) was significantly superior to the entry  $V_1$  (CO 26) at 14-28, 42-56 and 56-70 DAS.

In respect of times of sowing evaluated, statistical difference was observed for 28-42 DAS in the first crop and 42-56 DAS in the second crop. The sowing date  $D_2$

Table 15. Effect of varieties, times of sowing and nutrient levels on crop growth rate

(g m<sup>-2</sup> day<sup>-1</sup>) of sorghum during 1999-2000 (first crop)

Treatments	14-28 DAS	28-42 DAS	42-56 DAS	56-70 DAS	70-84 DAS	84 DAS- Harvest
V <sub>1</sub>	0.90	5.74	15.50	15.45	10.01	12.18
V <sub>2</sub>	1.29	6.90	18.01	16.80	11.42	13.85
SEd	<b>0.141</b>	<b>0.530</b>	<b>1.468</b>	<b>1.878</b>	<b>1.704</b>	<b>1.585</b>
CD (P=0.05)	NS	NS	NS	NS	NS	NS
D <sub>1</sub>	1.23	5.62	17.75	15.20	11.29	15.68
D <sub>2</sub>	1.02	7.02	15.77	17.05	10.14	10.35
SEd	<b>0.141</b>	<b>0.530</b>	<b>1.468</b>	<b>1.878</b>	<b>1.704</b>	<b>1.585</b>
CD (P=0.05)	NS	1.297	NS	NS	NS	NS
F <sub>1</sub>	0.61	3.08	12.61	13.19	8.44	11.78
F <sub>2</sub>	1.12	6.89	15.94	17.20	10.87	12.40
F <sub>3</sub>	1.64	8.99	21.73	17.98	12.84	14.87
SEd	<b>0.147</b>	<b>0.918</b>	<b>1.658</b>	<b>3.060</b>	<b>2.563</b>	<b>1.371</b>
CD (P=0.05)	<b>0.311</b>	<b>1.947</b>	<b>3.515</b>	NS	NS	NS
V x D						
SEd	<b>0.199</b>	<b>0.750</b>	<b>2.077</b>	<b>2.655</b>	<b>2.410</b>	<b>2.242</b>
CD (P=0.05)	NS	NS	NS	NS	NS	NS
V at F						
SEd	<b>0.220</b>	<b>1.185</b>	<b>2.413</b>	<b>4.001</b>	<b>3.415</b>	<b>2.241</b>
CD (P=0.05)	NS	NS	NS	NS	NS	NS
F at V						
SEd	<b>0.207</b>	<b>1.298</b>	<b>2.345</b>	<b>4.328</b>	<b>3.624</b>	<b>1.939</b>
CD (P=0.05)	NS	NS	NS	NS	NS	NS
D at F						
SEd	<b>0.220</b>	<b>1.185</b>	<b>2.413</b>	<b>4.001</b>	<b>3.415</b>	<b>2.241</b>
CD (P=0.05)	NS	NS	NS	NS	NS	NS
F at D						
SEd	<b>0.207</b>	<b>1.298</b>	<b>2.345</b>	<b>4.328</b>	<b>3.624</b>	<b>1.939</b>
CD (P=0.05)	NS	NS	NS	NS	NS	NS

NS = Not significant

Table 16. Effect of varieties, times of sowing and nutrient levels on crop growth rate  
(g m<sup>-2</sup> day<sup>-1</sup>) of sorghum during 2000-2001 (second crop)

Treatments	14-28 DAS	28-42 DAS	42-56 DAS	56-70 DAS	70-84 DAS	84 DAS- Harvest
V <sub>1</sub>	2.32	4.03	14.90	6.37	9.58	3.87
V <sub>2</sub>	2.78	5.68	16.55	9.09	9.57	2.47
SEd	0.098	1.606	0.348	0.159	0.399	0.926
CD (P=0.05)	0.241	NS	0.851	0.389	NS	NS
D <sub>1</sub>	2.64	4.09	17.52	7.74	9.93	2.69
D <sub>2</sub>	2.46	5.62	13.94	7.73	9.22	3.65
SEd	0.098	1.606	0.348	0.159	0.399	0.926
CD (P=0.05)	NS	NS	0.851	NS	NS	NS
F <sub>1</sub>	1.82	3.18	12.80	7.03	8.42	2.02
F <sub>2</sub>	2.66	4.35	17.11	8.91	11.10	3.32
F <sub>3</sub>	3.17	7.04	17.27	7.26	9.21	4.17
SEd	0.203	1.948	0.753	0.426	0.575	0.970
CD (P=0.05)	0.430	NS	1.597	0.902	1.218	NS
V x D						
SEd	0.139	2.271	0.492	0.248	0.564	1.309
CD (P=0.05)	NS	NS	NS	NS	NS	NS
V at F						
SEd	0.254	2.764	0.937	0.517	0.774	1.453
CD (P=0.05)	NS	NS	NS	NS	NS	NS
F at V						
SEd	0.287	2.755	1.065	0.602	0.813	1.372
CD (P=0.05)	NS	NS	NS	NS	NS	NS
D at F						
SEd	0.254	2.764	0.937	0.517	0.774	1.453
CD (P=0.05)	NS	NS	NS	NS	NS	NS
F at D						
SEd	0.287	2.755	1.065	0.602	0.813	1.372
CD (P=0.05)	NS	NS	NS	NS	NS	NS

NS = Not significant

was significant in the first crop, while the reverse trend was observed in the second crop.

With reference to nutrient levels studied during first crop, F<sub>3</sub> (60: 30: 0 kg of N: P<sub>2</sub>O<sub>5</sub>: K<sub>2</sub>O ha<sup>-1</sup>) recorded significantly higher CGR than F<sub>2</sub> (40: 20: 0 kg of N: P<sub>2</sub>O<sub>5</sub>: K<sub>2</sub>O ha<sup>-1</sup>) and F<sub>1</sub> (control) at 14-28, 28-42 and 42-56 DAS and there after the result was not significant. In the second crop, F<sub>3</sub> registered significantly superior CGR over F<sub>2</sub> and F<sub>1</sub> at 14-28 DAS. But at 56-70 and 70-84 DAS, F<sub>2</sub> recorded significantly higher CGR over F<sub>3</sub> and F<sub>1</sub> nutrient levels.

All the interactions were statistically absent.

#### 4.1.1.5 Relative growth rate

The data on mean Relative Growth Rate (RGR) are presented in Tables 17 and 18.

In general, RGR exhibited a declining trend as the growth progressed from vegetative stage to maturity stage in both the crops (1999-2000 and 2000-2001).

Both the varieties V<sub>2</sub> (CSV 15) and V<sub>1</sub> (CO 26) recorded their highest RGR at 14-28 DAS in both the crops. The result was significant only at 28-42 DAS for the second crop where in V<sub>1</sub> did have higher RGR, while at no interval, the result was significant for the first crop.

At 28-42 DAS and between 84 DAS and at harvest of first crop, the result was significant for dates of sowing evaluated where in D<sub>2</sub> registered higher RGR than D<sub>1</sub> at 28-42 DAS and D<sub>1</sub> did produce higher RGR at 84 DAS to harvest. In the second crop, at 28-42 DAS, the first crop result was in evidence.

Among the various nutrient levels evaluated, the RGR did not differ significantly at all the stages of first and second crops except at 84 DAS and harvest of first crop (1999-2000) and at 14-28, 28-42 and 70-84 DAS of second crop (2000-2001). In the second crop, at early stage (14-28 and 28-42 DAS) F<sub>2</sub> (40: 20: 0 kg of N: P<sub>2</sub>O<sub>5</sub>: K<sub>2</sub>O ha<sup>-1</sup>) and F<sub>3</sub> (60: 30: 0 kg of N: P<sub>2</sub>O<sub>5</sub>: K<sub>2</sub>O ha<sup>-1</sup>) levels were at par and better than F<sub>1</sub> level (control), while in the first crop, F<sub>1</sub> level was significantly promising (84 DAS-harvest).

Table 17. Effect of varieties, times of sowing and nutrient levels on relative growth rate ( $\text{g g}^{-1} \text{day}^{-1}$ ) of sorghum during 1999-2000 (first crop)

Treatments	14-28 DAS	28-42 DAS	42-56 DAS	56-70 DAS	70-84 DAS	84 DAS- Harvest
V <sub>1</sub>	0.1837	0.1355	0.0910	0.0397	0.0180	0.0144
V <sub>2</sub>	0.1858	0.1265	0.0874	0.0365	0.0167	0.0154
SEd	0.00958	0.00514	0.00921	0.00484	0.00295	0.00186
CD (P=0.05)	NS	NS	NS	NS	NS	NS
D <sub>1</sub>	0.1984	0.1178	0.0981	0.0367	0.0178	0.0176
D <sub>2</sub>	0.1712	0.1442	0.0804	0.0395	0.0169	0.0122
SEd	0.00958	0.00514	0.00921	0.00484	0.00295	0.00186
CD (P=0.05)	NS	0.01259	NS	NS	NS	0.00455
F <sub>1</sub>	0.1706	0.1215	0.0880	0.0433	0.0187	0.0172
F <sub>2</sub>	0.1889	0.1400	0.0786	0.0386	0.0169	0.0137
F <sub>3</sub>	0.1948	0.1316	0.0802	0.0325	0.0164	0.0138
SEd	0.00921	0.01164	0.00995	0.00773	0.00438	0.00144
CD (P=0.05)	NS	NS	NS	NS	NS	0.00306
V x D						
SEd	0.01355	0.00728	0.01303	0.00685	0.00417	0.00263
CD (P=0.05)	NS	NS	NS	NS	NS	NS
V at F						
SEd	0.01431	0.01440	0.01473	0.01016	0.00586	0.00249
CD (P=0.05)	NS	NS	NS	NS	NS	NS
F at V						
SEd	0.01303	0.01647	0.01407	0.01093	0.00620	0.00204
CD (P=0.05)	NS	NS	NS	NS	NS	NS
D at F						
SEd	0.01431	0.01440	0.01473	0.01016	0.00586	0.00249
CD (P=0.05)	NS	NS	NS	NS	NS	NS
F at D						
SEd	0.01303	0.01647	0.01407	0.01093	0.00620	0.00204
CD (P=0.05)	NS	NS	NS	NS	NS	NS

NS = Not significant

Table 18. Effect of varieties, times of sowing and nutrient levels on relative growth rate  
(g g<sup>-1</sup> day<sup>-1</sup>) of sorghum during 2000-2001 (second crop)

Treatments	14-28 DAS	28-42 DAS	42-56 DAS	56-70 DAS	70-84 DAS	84 DAS- Harvest
V <sub>1</sub>	0.2765	0.0738	0.1279	0.0193	0.0208	0.0070
V <sub>2</sub>	0.2889	0.0619	0.0884	0.0232	0.0193	0.0040
SEd	0.00607	0.00198	0.04270	0.01489	0.00088	0.00147
CD (P=0.05)	NS	0.00485	NS	NS	NS	NS
D <sub>1</sub>	0.2783	0.0650	0.1346	0.0193	0.0199	0.0044
D <sub>2</sub>	0.2871	0.0706	0.0817	0.0231	0.0202	0.0066
SEd	0.00607	0.00198	0.04270	0.01489	0.00088	0.00147
CD (P=0.05)	NS	0.00485	NS	NS	NS	NS
F <sub>1</sub>	0.2672	0.0736	0.0904	0.0239	0.0207	0.0043
F <sub>2</sub>	0.2828	0.0690	0.0875	0.0223	0.0212	0.0053
F <sub>3</sub>	0.2980	0.0609	0.1466	0.0175	0.0181	0.0069
SEd	0.00767	0.00229	0.05230	0.01626	0.00107	0.00166
CD (P=0.05)	0.01626	0.00486	NS	NS	0.00227	NS
V x D						
SEd	0.00858	0.00281	0.06038	0.02100	0.00124	0.00208
CD (P=0.05)	NS	NS	NS	NS	NS	NS
V at F						
SEd	0.01074	0.00331	0.07396	0.02388	0.00152	0.00242
CD (P=0.05)	NS	NS	NS	NS	NS	NS
F at V						
SEd	0.01085	0.00325	0.07371	0.02299	0.00144	0.00235
CD (P=0.05)	NS	NS	NS	NS	NS	NS
D at F						
SEd	0.01074	0.00331	0.07396	0.02388	0.00152	0.00242
CD (P=0.05)	NS	NS	NS	NS	NS	NS
F at D						
SEd	0.01085	0.00325	0.07371	0.02299	0.00144	0.00235
CD (P=0.05)	NS	NS	NS	NS	NS	NS

NS = Not significant

All the interactions studied were not significant in both the crops.

#### 4.1.1.6 Net assimilation rate

The data on mean Net Assimilation Rate (NAR) are presented in Tables 19 and 20.

Between varieties, V<sub>2</sub> (CSV 15) recorded higher NAR significantly at 28-42 DAS and between 84 DAS and harvest of the first crop (1999-2000) as well as between 56 and 70 DAS in the second crop (2000-2001). It was reverse between 84 DAS and harvest in the second crop where in superiority of V<sub>1</sub> (CO 26) was noted.

In both the crops, the times of sowing had not altered the NAR significantly except at 28-42 DAS of first crop in which D<sub>2</sub> registered significantly higher NAR as compared to D<sub>1</sub>.

Among the nutrient levels, during first crop, F<sub>3</sub> (60: 30: 0 kg of N: P<sub>2</sub>O<sub>5</sub>: K<sub>2</sub>O ha<sup>-1</sup>) registered higher NAR which was at par with F<sub>2</sub> (40: 20: 0 kg of N: P<sub>2</sub>O<sub>5</sub>: K<sub>2</sub>O ha<sup>-1</sup>) at 28-42 DAS. During the second crop, F<sub>3</sub> recorded the highest NAR and was at par with F<sub>2</sub> at 14-28, 28-42, 42-56 and between 70-84 DAS, while at 56-70 DAS, F<sub>2</sub> level did produce higher NAR significantly over other levels evaluated.

All the interactions were not significant in both the crops evaluated for treatments.

#### 4.1.1.7 Root Volume

The mean data on root volume as influenced by various treatments studied at various stages of crop growth are presented in Tables 21 and 22.

From the data, it was inferred that there was a steady increase in the root volume and it reached its maximum at the flowering stage (63 DAS) and then started declining towards the maturity stage.

At vegetative stage of both the crops, the root volume recorded under V<sub>2</sub> was significantly more than V<sub>1</sub> at 42 and 49 DAS of first crop (1999-2000) and at 21 and 49 DAS of second crop (2000-2001). This trend was observed at reproductive and

Table 19. Effect of varieties, times of sowing and nutrient levels on net assimilation rate ( $\text{g m}^{-2} \text{ day}^{-1}$ ) of sorghum during 1999-2000 (first crop)

Treatments	28-42 DAS	42-56 DAS	56-70 DAS	70-84 DAS	84 DAS- Harvest
V <sub>1</sub>	0.0108	0.0086	0.0059	0.0049	0.0087
V <sub>2</sub>	0.0132	0.0106	0.0070	0.0065	0.0117
SEd	0.00066	0.00125	0.00093	0.00107	0.00083
CD (P=0.05)	0.00161	NS	NS	NS	0.00204
D <sub>1</sub>	0.0096	0.0105	0.0057	0.0060	0.0110
D <sub>2</sub>	0.0144	0.0087	0.0072	0.0053	0.0093
SEd	0.00066	0.00125	0.00093	0.00107	0.00083
CD (P=0.05)	0.00161	NS	NS	NS	NS
F <sub>1</sub>	0.0083	0.0089	0.0059	0.0042	0.0093
F <sub>2</sub>	0.0134	0.0088	0.0066	0.0060	0.0101
F <sub>3</sub>	0.0143	0.0111	0.0068	0.0068	0.0112
SEd	0.00153	0.00141	0.00111	0.00140	0.00135
CD (P=0.05)	0.00324	NS	NS	NS	NS
V x D					
SEd	0.00093	0.00176	0.00131	0.00152	0.00165
CD (P=0.05)	NS	NS	NS	NS	NS
V at F					
SEd	0.00189	0.00205	0.00158	0.00194	0.00176
CD (P=0.05)	NS	NS	NS	NS	NS
F at V					
SEd	0.00216	0.00200	0.00156	0.00198	0.00162
CD (P=0.05)	NS	NS	NS	NS	NS
D at F					
SEd	0.00189	0.00205	0.00158	0.00194	0.00176
CD (P=0.05)	NS	NS	NS	NS	NS
F at D					
SEd	0.00216	0.00200	0.00156	0.00198	0.00162
CD (P=0.05)	NS	NS	NS	NS	NS

NS = Not significant

Table 20. Effect of varieties, times of sowing and nutrient levels on net assimilation rate (g m<sup>-2</sup> day<sup>-1</sup>) of sorghum during 2000-2001 (second crop) 74

Treatments	14-28 DAS	28-42 DAS	42-56 DAS	56-70 DAS	70-84 DAS	84 DAS- Harvest
V <sub>1</sub>	0.0158	0.0088	0.0166	0.0060	0.0049	0.0047
V <sub>2</sub>	0.0154	0.0079	0.0165	0.0081	0.0065	0.0027
SEd	0.00326	0.00092	0.00147	0.00054	0.00105	0.00083
CD (P=0.05)	NS	NS	NS	0.00133	NS	0.00204
D <sub>1</sub>	0.0127	0.0072	0.0181	0.0076	0.0060	0.0030
D <sub>2</sub>	0.0185	0.0094	0.0150	0.0066	0.0053	0.0044
SEd	0.00326	0.00092	0.00147	0.00054	0.00105	0.00083
CD (P=0.05)	NS	NS	NS	NS	NS	NS
F <sub>1</sub>	0.0104	0.0064	0.0131	0.0067	0.0042	0.0028
F <sub>2</sub>	0.0148	0.0091	0.0182	0.0080	0.0060	0.0038
F <sub>3</sub>	0.0216	0.0095	0.0185	0.0065	0.0068	0.0044
SEd	0.00346	0.00094	0.00134	0.00050	0.00078	0.00135
CD (P=0.05)	0.00733	0.00199	0.00283	0.00105	0.00166	NS
V x D						
SEd	0.00461	0.00130	0.00208	0.00077	0.00148	0.00118
CD (P=0.05)	NS	NS	NS	NS	NS	NS
V at F						
SEd	0.00515	0.00142	0.00213	0.00079	0.00139	0.00177
CD (P=0.05)	NS	NS	NS	NS	NS	NS
F at V						
SEd	0.00489	0.00133	0.00189	0.00070	0.00111	0.00191
CD (P=0.05)	NS	NS	NS	NS	NS	NS
D at F						
SEd	0.00515	0.00142	0.00213	0.00079	0.00139	0.00177
CD (P=0.05)	NS	NS	NS	NS	NS	NS
F at D						
SEd	0.00489	0.00133	0.00189	0.00070	0.00111	0.00191
CD (P=0.05)	NS	NS	NS	NS	NS	NS

NS = Not significant

Table 21. Effect of varieties, times of sowing and nutrient levels on root volume (cc) of sorghum at vegetative stage

Treatments	14 DAS		21 DAS		28 DAS		35 DAS		42 DAS		49 DAS	
	I crop	II crop	I crop	II crop	I crop	II crop	I crop	II crop	I crop	II crop	I crop	II crop
V <sub>1</sub>	0.42	0.52	1.25	1.56	2.60	3.17	10.33	11.58	19.60	20.00	25.25	22.67
V <sub>2</sub>	0.44	0.52	1.40	1.86	2.70	3.42	11.67	12.24	22.50	21.25	32.50	28.60
SEd	0.034	0.031	0.101	0.063	0.220	0.166	0.901	0.690	0.871	0.768	0.698	0.947
CD (P=0.05)	NS	NS	NS	0.153	NS	NS	NS	NS	2.131	NS	1.705	2.317
D <sub>1</sub>	0.44	0.53	1.60	2.05	3.67	4.00	15.10	16.20	19.58	23.34	29.10	27.81
D <sub>2</sub>	0.42	0.50	1.25	1.37	1.90	2.59	11.25	9.65	22.61	17.92	25.50	23.47
SEd	0.034	0.031	0.101	0.063	0.220	0.166	0.901	0.690	0.871	0.768	0.698	0.947
CD (P=0.05)	NS	NS	0.247	0.153	0.538	0.406	2.205	1.688	2.131	1.880	1.708	2.317
F <sub>1</sub>	0.40	0.53	0.90	1.23	1.68	2.38	7.75	8.20	13.75	12.25	18.75	18.11
F <sub>2</sub>	0.43	0.53	1.38	1.67	2.75	3.45	12.38	12.80	20.10	18.25	27.50	27.48
F <sub>3</sub>	0.45	0.60	1.98	2.24	3.63	4.06	15.50	14.75	29.50	26.15	35.60	31.32
SEd	0.044	0.053	0.121	0.056	0.375	0.172	1.006	0.506	1.433	1.196	0.797	1.470
CD (P=0.05)	NS	0.112	0.255	0.118	0.975	0.365	2.133	1.072	3.038	2.536	1.690	3.116
V x D												
SEd	0.048	0.044	0.143	0.089	0.341	0.235	1.275	0.976	1.232	1.086	0.985	1.339
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
V at F												
SEd	0.060	0.068	0.172	0.090	0.336	0.259	1.470	0.904	1.870	1.581	1.154	1.944
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
F at V												
SEd	0.062	0.075	0.170	0.079	0.311	0.244	1.423	0.715	2.027	1.692	1.127	2.079
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
D at F												
SEd	0.060	0.068	0.172	0.090	0.336	0.259	1.470	0.904	1.870	1.581	1.154	1.944
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
F at D												
SEd	0.062	0.075	0.170	0.079	0.311	0.244	1.423	0.715	2.027	1.692	1.127	2.079
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

I crop: 1999 NEM

II crop: 2000 NEM

NS = Not significant

Table 22. Effect of varieties, times of sowing and nutrient levels on root volume (cc) of sorghum at flowering and maturity stages

Treatments	Flowering stage						Maturity stage			
	56 DAS		63 DAS		70 DAS		77 DAS		At harvest	
	I crop	II crop	I crop	II crop	I crop	II crop	I crop	II crop	I crop	II crop
V <sub>1</sub>	28.50	26.00	30.75	25.15	20.85	19.83	20.33	20.46	18.25	15.00
V <sub>2</sub>	39.15	31.50	38.75	28.50	26.25	23.75	25.83	19.33	20.00	13.75
SEd	<b>0.923</b>	<b>1.409</b>	<b>1.450</b>	<b>0.310</b>	<b>0.511</b>	<b>1.151</b>	<b>0.437</b>	<b>0.627</b>	<b>0.777</b>	<b>0.774</b>
CD (P=0.05)	<b>2.259</b>	<b>3.449</b>	<b>3.548</b>	<b>0.759</b>	<b>1.252</b>	<b>2.817</b>	<b>1.069</b>	NS	<b>1.902</b>	NS
D <sub>1</sub>	33.33	29.42	38.33	27.11	25.83	22.50	24.50	20.42	18.33	15.83
D <sub>2</sub>	31.67	27.94	29.15	26.42	21.25	21.08	21.67	19.38	17.92	12.92
SEd	<b>0.923</b>	<b>1.409</b>	<b>1.450</b>	<b>0.310</b>	<b>0.511</b>	<b>1.151</b>	<b>0.437</b>	<b>0.627</b>	<b>0.777</b>	<b>0.774</b>
CD (P=0.05)	NS	NS	<b>3.548</b>	NS	<b>1.252</b>	NS	<b>1.069</b>	NS	NS	<b>1.894</b>
F <sub>1</sub>	24.38	22.63	23.75	20.50	15.63	16.25	15.50	14.38	12.50	11.25
F <sub>2</sub>	34.38	29.92	35.00	28.50	23.15	25.63	23.75	20.94	18.75	16.88
F <sub>3</sub>	38.75	30.75	42.50	26.75	31.88	24.50	30.00	18.33	23.13	15.00
SEd	<b>1.183</b>	<b>1.368</b>	<b>1.621</b>	<b>0.588</b>	<b>0.687</b>	<b>1.692</b>	<b>0.610</b>	<b>0.906</b>	<b>0.912</b>	<b>1.307</b>
CD (P=0.05)	<b>2.509</b>	<b>2.900</b>	<b>3.437</b>	<b>1.245</b>	<b>1.457</b>	<b>3.587</b>	<b>1.292</b>	<b>1.921</b>	<b>1.933</b>	<b>2.771</b>
V x D										
SEd	<b>1.305</b>	<b>1.993</b>	<b>2.050</b>	<b>0.439</b>	<b>0.723</b>	<b>1.628</b>	<b>0.618</b>	<b>0.887</b>	<b>1.009</b>	<b>1.095</b>
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
V at F										
SEd	<b>1.192</b>	<b>2.117</b>	<b>2.368</b>	<b>0.746</b>	<b>0.944</b>	<b>2.268</b>	<b>0.829</b>	<b>1.220</b>	<b>1.309</b>	<b>1.696</b>
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
F at V										
SEd	<b>0.924</b>	<b>1.934</b>	<b>2.293</b>	<b>0.831</b>	<b>0.972</b>	<b>2.393</b>	<b>0.862</b>	<b>1.281</b>	<b>1.290</b>	<b>1.849</b>
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
D at F										
SEd	<b>1.192</b>	<b>2.117</b>	<b>2.368</b>	<b>0.746</b>	<b>0.944</b>	<b>2.268</b>	<b>0.829</b>	<b>1.220</b>	<b>1.309</b>	<b>1.696</b>
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
F at D										
SEd	<b>0.924</b>	<b>1.934</b>	<b>2.293</b>	<b>0.831</b>	<b>0.972</b>	<b>2.393</b>	<b>0.862</b>	<b>1.281</b>	<b>1.290</b>	<b>1.849</b>
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

I crop: 1999 NEM

II crop: 2000 NEM

NS = Not significant

maturity stages of both the crops significantly except at 77 DAS and at harvest of second crop, where the result was not significant.

With reference to times of sowing except at 14 DAS of first and second crop, all the observations made in the vegetative stage of both the crops, D<sub>1</sub> recorded significantly higher root volume than D<sub>2</sub>, except at 42 DAS of first crop. This trend was continued at 63, 70 and 77 DAS of first crop and at harvest of the second crop.

Among the nutrient levels evaluated in the first and second crop, the superior performance was noticed for F<sub>3</sub> (60: 30: 0 kg of N: P<sub>2</sub>O<sub>5</sub>: K<sub>2</sub>O ha<sup>-1</sup>) level in increasing the root volume significantly through out the observations made in vegetative stage except at 14 DAS of first crop. The same performance was observed in the flowering and maturity stages of first crop, while in the second crop under these two stages, F<sub>2</sub> (40: 20: 0 kg of N: P<sub>2</sub>O<sub>5</sub>: K<sub>2</sub>O ha<sup>-1</sup>) and F<sub>3</sub> were at par in registering higher root volume.

The results on interactions were not significant.

#### 4.1.1.8 Root: Shoot ratio

The mean data on Root: Shoot ratio (R: S ratio) recorded at 14, 28, 42, 56, 70 and 77 DAS and at harvest for both the crops are presented in Tables 23 and 24.

From the results it was inferred that V<sub>2</sub> recorded significantly higher R: S ratio than V<sub>1</sub> in all the stages of crop growth in both the crops (1999-2000 and 2000-2001), except at 77 DAS of first crop in which V<sub>1</sub> recorded significantly higher R: S ratio than V<sub>2</sub>. At harvest stage of both the crops, the result was not significant.

Between times of sowing evaluated, D<sub>1</sub> recorded significantly superior R: S ratio as compared to D<sub>2</sub> in both the crops, except at 42 DAS and at harvest of first crop and 28 DAS of second crop where in D<sub>2</sub> sowing recorded significantly higher R: S ratio over D<sub>1</sub> sowing.

Regarding nutrient levels, F<sub>3</sub> (60: 30: 0 kg of N: P<sub>2</sub>O<sub>5</sub>: K<sub>2</sub>O ha<sup>-1</sup>) stamped its superiority in registering higher R: S ratio over F<sub>2</sub> (40: 20: 0 kg of N: P<sub>2</sub>O<sub>5</sub>: K<sub>2</sub>O ha<sup>-1</sup>) and F<sub>1</sub> (control) levels through out the crop growth period in both the crops except at

Table 23. Effect of varieties, times of sowing and nutrient levels on Root: Shoot ratio of sorghum during 1999-2000 (first crop)

Treatments	14 DAS	28 DAS	42 DAS	56 DAS	70 DAS	77 DAS	At Harvest
V <sub>1</sub>	0.1871	0.1296	0.1360	0.2278	0.2316	0.1907	0.0983
V <sub>2</sub>	0.1858	0.1439	0.1718	0.2362	0.2353	0.1800	0.0945
SEd	0.00022	0.00451	0.00148	0.00105	0.00060	0.00107	0.00398
CD (P=0.05)	0.00054	0.01104	0.00363	0.00258	0.00147	0.00262	NS
D <sub>1</sub>	0.1885	0.1329	0.1517	0.2423	0.2407	0.1976	0.0878
D <sub>2</sub>	0.1845	0.1406	0.1561	0.2217	0.2261	0.1731	0.1050
SEd	0.00022	0.00451	0.00148	0.00105	0.00060	0.00107	0.00398
CD (P=0.05)	0.00054	NS	0.00363	0.00258	0.00147	0.00262	0.00973
F <sub>1</sub>	0.1720	0.1221	0.1337	0.1961	0.2163	0.1680	0.0908
F <sub>2</sub>	0.1865	0.1359	0.1533	0.2384	0.2341	0.1854	0.0984
F <sub>3</sub>	0.2010	0.1522	0.1746	0.2616	0.2499	0.2026	0.1001
SEd	0.00079	0.00518	0.00108	0.00170	0.00085	0.00090	0.00488
CD (P=0.05)	0.00168	0.01098	0.00228	0.00360	0.00180	0.00192	NS
V x D							
SEd	0.00360	0.00638	0.00210	0.00149	0.00084	0.00152	0.00562
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS
V at F							
SEd	0.00094	0.00749	0.00294	0.00222	0.00115	0.00150	0.00789
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS
F at V							
SEd	0.00112	0.00733	0.00252	0.00240	0.00120	0.00128	0.00689
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS
D at F							
SEd	0.00094	0.00749	0.00294	0.00222	0.00115	0.00150	0.00789
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS
F at D							
SEd	0.00112	0.00733	0.00252	0.00240	0.00120	0.00128	0.00689
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS

NS = Not significant

Table 24. Effect of varieties, times of sowing and nutrient levels on Root: Shoot ratio of sorghum during 2000-2001 (second crop)

Treatments	14 DAS	28 DAS	42 DAS	56 DAS	70 DAS	77 DAS	At harvest
V <sub>1</sub>	0.1775	0.1375	0.1465	0.2478	0.2438	0.1923	0.1051
V <sub>2</sub>	0.1989	0.1505	0.1837	0.2704	0.2642	0.1957	0.1072
SEd	0.00109	0.00093	0.00194	0.00161	0.00108	0.00092	0.00517
CD (P=0.05)	0.00266	0.00227	0.00476	0.00395	0.00265	0.00226	NS
D <sub>1</sub>	0.1875	0.1376	0.1640	0.2670	0.2575	0.2030	0.1018
D <sub>2</sub>	0.1889	0.1503	0.1662	0.2512	0.2505	0.1850	0.1105
SEd	0.00109	0.00093	0.00194	0.00161	0.00108	0.00092	0.00517
CD (P=0.05)	NS	0.00227	NS	0.00395	0.00265	0.00226	NS
F <sub>1</sub>	0.1713	0.1257	0.1430	0.2280	0.2378	0.1798	0.1022
F <sub>2</sub>	0.1878	0.1483	0.1638	0.2600	0.2648	0.2073	0.1047
F <sub>3</sub>	0.2055	0.1580	0.1885	0.2894	0.2595	0.1950	0.1116
SEd	0.00112	0.00119	0.00146	0.00210	0.00093	0.00101	0.00626
CD (P=0.05)	0.00237	0.00252	0.00309	0.00446	0.00196	0.00214	NS
V x D							
SEd	0.00154	0.00131	0.00275	0.00228	0.00153	0.00131	0.00732
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS
V at F							
SEd	0.00169	0.00166	0.00257	0.00292	0.00152	0.00149	0.00888
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS
F at V							
SEd	0.00158	0.00168	0.00206	0.00298	0.00131	0.00143	0.00885
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS
D at F							
SEd	0.00169	0.00166	0.00257	0.00292	0.00152	0.00149	0.00888
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS
F at D							
SEd	0.00158	0.00168	0.00206	0.00298	0.00131	0.00143	0.00885
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS

NS = Not significant

70 and 77 DAS of second crop in which F<sub>2</sub> registered significantly higher R: S ratio than F<sub>3</sub> and F<sub>1</sub> levels. The result was not significant at harvest stage of both the crops.

All the interactions were absent statistically.

#### 4.1.2 Yield components

##### 4.1.2.1 Earhead length

The data on mean length of earhead measured are presented in Table 25.

The perusal of the data revealed that in the first crop (1999-2000), earhead length was not significantly differed between varieties. However, in the second crop (2000-2001), V<sub>2</sub> (CSV 15) recorded significantly longer earhead as compared to V<sub>1</sub> (CO 26).

The different times of sowing had no significant influence on the earhead length in both the crops of study.

Among the nutrient levels, F<sub>3</sub> (60: 30: 0 kg of N: P<sub>2</sub>O<sub>5</sub>: K<sub>2</sub>O ha<sup>-1</sup>) produced the lengthiest earheads in first and second crop, which was significantly different from F<sub>2</sub> (40: 20: 0 kg of N: P<sub>2</sub>O<sub>5</sub>: K<sub>2</sub>O ha<sup>-1</sup>) and F<sub>1</sub> (control) levels. The nutrient levels F<sub>2</sub> and F<sub>1</sub> were at par.

All the interactions were failed to influence this parameter in both the crops.

##### 4.1.2.2 Number of grains per earhead

The data recorded on mean number of grains earhead<sup>-1</sup> are given in Table 25.

From the data presented, it was clear that the variety V<sub>2</sub> (CSV 15) had contained significantly higher number of grains earhead<sup>-1</sup> as compared to V<sub>1</sub> (CO 26) in both the crops (1999-2000 and 2000-2001).

Similarly, dates of sowing also had influenced the number of grains earhead<sup>-1</sup>. In the first crop, D<sub>1</sub> sowing did produce significantly higher number of grains earhead<sup>-1</sup> as compared to D<sub>2</sub> sowing, while in the second crop D<sub>1</sub> was at par with D<sub>2</sub> date of sowing.

Table 25. Effect of varieties, times of sowing and nutrient levels on ear head length (cm), grain number per ear head and test weight (g) of sorghum

Treatments	Ear head length (cm)		Grain number ear head <sup>-1</sup>		Test weight (g)	
	I crop	II crop	I crop	II crop	I crop	II crop
V <sub>1</sub>	22.8	14.5	906	304	26.4	23.3
V <sub>2</sub>	23.0	16.7	1120	389	26.1	23.2
SEd	0.47	0.26	29.6	19.1	0.57	0.53
CD (P=0.05)	NS	0.63	72.4	46.6	NS	NS
D <sub>1</sub>	23.3	15.3	1102	369	26.2	23.3
D <sub>2</sub>	22.4	14.9	924	324	26.3	23.3
SEd	0.47	0.26	29.6	19.1	0.57	0.53
CD (P=0.05)	NS	NS	72.4	NS	NS	NS
F <sub>1</sub>	21.6	13.7	895	281	26.0	23.1
F <sub>2</sub>	22.6	14.1	1028	388	26.2	23.2
F <sub>3</sub>	24.4	17.6	1116	371	26.5	23.6
SEd	0.59	0.57	51.4	27.4	0.51	0.49
CD (P=0.05)	1.24	1.21	109.0	58.2	NS	NS
V x D						
SEd	0.67	0.37	41.8	26.9	0.81	0.74
CD (P=0.05)	NS	NS	NS	NS	NS	NS
V at F						
SEd	0.83	0.71	66.3	37.0	0.82	0.77
CD (P=0.05)	NS	NS	NS	NS	NS	NS
F at V						
SEd	0.81	0.78	72.7	38.8	0.72	0.70
CD (P=0.05)	NS	NS	NS	NS	NS	NS
D at F						
SEd	0.83	0.71	66.3	37.0	0.82	0.77
CD (P=0.05)	NS	NS	NS	NS	NS	NS
F at D						
SEd	0.81	0.78	72.7	38.8	0.72	0.70
CD (P=0.05)	NS	NS	NS	NS	NS	NS

I crop: 1999 NEM

II crop: 2000 NEM

NS = Not significant

The number of grains earhead<sup>-1</sup> was also influenced by the nutrient levels studied. In the first crop, F<sub>3</sub> (60: 30: 0 kg of N: P<sub>2</sub>O<sub>5</sub>: K<sub>2</sub>O ha<sup>-1</sup>) and F<sub>2</sub> (40: 20: 0 kg of N: P<sub>2</sub>O<sub>5</sub>: K<sub>2</sub>O ha<sup>-1</sup>) levels were at par and produced significantly higher number of grains earhead<sup>-1</sup> over F<sub>1</sub> (control). Similarly, in the second crop, F<sub>2</sub> and F<sub>3</sub> levels were at par and produced significantly higher number of grains earhead<sup>-1</sup> than F<sub>1</sub>.

Interactions were absent in both the crops.

#### 4.1.2.3 Test weight

The mean data on sorghum test weight recorded are presented in Table 25.

The results revealed the failure of treatments in influencing this parameter in both the crops (1999-2000 and 2000-2001) grown across two Northeast monsoon seasons.

### 4.1.3 Yield

#### 4.1.3.1 Grain yield

The mean data on sorghum grain yield recorded at harvest are presented in Table 26.

The results revealed that varieties, dates of sowing and nutrient levels had influenced the grain yield of sorghum raised during Northeast monsoon seasons of 1999 and 2000 (two crops) significantly.

In the first crop, the mean yield over treatments was 2466 kg ha<sup>-1</sup>. While it was only 682 kg ha<sup>-1</sup> in the second crop. It is evidently observed that in the second crop, only 28 per cent of first crop yield was obtained. Even then, the imposed treatments, viz., varieties and nutrient levels did alter the second crop yield significantly, indicating the stability of imposed treatments even under low sorghum yield scenario.

Between the two varieties evaluated, CSV 15 (V<sub>2</sub>) registered significantly higher grain yield (3021 kg ha<sup>-1</sup> and 750 kg ha<sup>-1</sup> in first and second crop, respectively) than CO 26 (1910 kg ha<sup>-1</sup> and 614 kg ha<sup>-1</sup> during 1999-2000 and 2000-2001,

Table 26. Effect of varieties, times of sowing and nutrient levels on the grain yield (kg ha<sup>-1</sup>) of sorghum

Treatments	I crop	II crop
V <sub>1</sub>	1910	614
V <sub>2</sub>	3021	750
SEd	165.6	41.7
CD (P=0.05)	374.7	102.1
D <sub>1</sub>	2691	712
D <sub>2</sub>	2240	652
SEd	165.6	41.7
CD (P=0.05)	374.7	NS
F <sub>1</sub>	1862	503
F <sub>2</sub>	2502	796
F <sub>3</sub>	3033	746
SEd	114.4	43.9
CD (P=0.05)	236.1	93.1
V x D		
SEd	234.2	59.0
CD (P=0.05)	NS	NS
V at F		
SEd	211.9	65.7
CD (P=0.05)	NS	NS
F at V		
SEd	161.8	62.1
CD (P=0.05)	NS	NS
D at F		
SEd	211.9	65.7
CD (P=0.05)	NS	NS
F at D		
SEd	161.8	62.1
CD (P=0.05)	NS	NS

I crop: 1999 NEM

II crop: 2000 NEM

NS = Not significant

respectively) and the increase was 58 and 22 per cent over CO 26 during 1999-2000 and 2000-2001, respectively.

In respect of dates of sowing, D<sub>1</sub> had recorded significantly higher grain yield (2691 kg ha<sup>-1</sup>) over D<sub>2</sub> (2240 kg ha<sup>-1</sup>) which was 20 per cent higher than D<sub>2</sub> in the first crop raised during 1999-2000. But during 2000-2001, the difference in yield was not significant indicating that under low rainfall situation, dates of sowing did not have any role on sorghum grain yield.

Among the nutrient levels evaluated, during 1999-2000 (first crop), F<sub>3</sub> (60: 30: 0 kg of N: P<sub>2</sub>O<sub>5</sub>: K<sub>2</sub>O ha<sup>-1</sup>) recorded significantly higher grain yield (3033 kg ha<sup>-1</sup>) over F<sub>2</sub> (2502 kg ha<sup>-1</sup>) and F<sub>1</sub> (1862 kg ha<sup>-1</sup>) and the increase was 21 and 63 per cent over F<sub>2</sub> and F<sub>1</sub>, respectively. During 2000-2001 (second crop), F<sub>2</sub> (796 kg ha<sup>-1</sup>) and F<sub>3</sub> (746 kg ha<sup>-1</sup>) were at par and registered significantly higher grain yield and the increase was 58 and 48 per cent over F<sub>1</sub> (503 kg ha<sup>-1</sup>).

All the interactions studied were failed to differ significantly in both the crops of study.

Since the ratio between larger error mean square and lesser mean error square was greater than 3 (heterogeneous) pooled analysis was not carried out.

#### 4.1.3.2 Straw yield

The mean data recorded on straw yield of sorghum are presented in Table 27.

The straw yield was not altered significantly by any of the treatments studied viz., varieties, times of sowing and nutrient levels in both the crops (1999-2000 and 2000-2001).

The interactions between varieties and times of sowing were significant during 1999-2000 (Table 27a).

The D<sub>1</sub> date of sowing was significantly superior over to D<sub>2</sub> sowing date for variety V<sub>1</sub>, while the dates of sowing were at par for the variety V<sub>2</sub>. When comparing varieties at each sowing date, under D<sub>2</sub> date of sowing, V<sub>2</sub> was significant over to V<sub>1</sub> while both were at par under D<sub>1</sub> date of sowing. Variety V<sub>2</sub> has performed well both under D<sub>1</sub> and D<sub>2</sub> times of sowing.

Table 27. Effect of varieties, times of sowing and nutrient levels on straw yield (kg ha<sup>-1</sup>) of sorghum

Treatments	I crop	II crop
V <sub>1</sub>	8560	5359
V <sub>2</sub>	9512	5595
<b>SEd</b>	<b>591.2</b>	<b>600.8</b>
<b>CD (P=0.05)</b>	<b>NS</b>	<b>NS</b>
D <sub>1</sub>	9591	5574
D <sub>2</sub>	8481	5379
<b>SEd</b>	<b>591.2</b>	<b>600.8</b>
<b>CD (P=0.05)</b>	<b>NS</b>	<b>NS</b>
F <sub>1</sub>	8794	4973
F <sub>2</sub>	8729	5863
F <sub>3</sub>	9586	5594
<b>SEd</b>	<b>478.3</b>	<b>407.6</b>
<b>CD (P=0.05)</b>	<b>NS</b>	<b>NS</b>
V x D		
<b>SEd</b>	<b>836.0</b>	<b>849.6</b>
<b>CD (P=0.05)</b>	<b>1891.3</b>	<b>NS</b>
V at F		
<b>SEd</b>	<b>809.0</b>	<b>763.2</b>
<b>CD (P=0.05)</b>	<b>NS</b>	<b>NS</b>
F at V		
<b>SEd</b>	<b>676.5</b>	<b>576.5</b>
<b>CD (P=0.05)</b>	<b>NS</b>	<b>NS</b>
D at F		
<b>SEd</b>	<b>809.0</b>	<b>763.2</b>
<b>CD (P=0.05)</b>	<b>NS</b>	<b>NS</b>
F at D		
<b>SEd</b>	<b>676.5</b>	<b>576.5</b>
<b>CD (P=0.05)</b>	<b>NS</b>	<b>NS</b>

I crop: 1999 NEM

II crop: 2000 NEM

NS = Not significant

Table 27a. Interaction effect of varieties and times of sowing on straw yield (kg ha<sup>-1</sup>) of sorghum during 1999-2000 (first crop)

V x D	D <sub>1</sub>	D <sub>2</sub>	Mean
V <sub>1</sub>	9843	7278	8560
V <sub>2</sub>	9340	9685	9512
Mean	9591	8481	-

V x D                      **SEd**                      **CD (P=0.05)**  
                                     **836.0**                      **1891.3**

#### 4.1.4 Harvest index

The mean data on harvest index are presented in Table 28.

Varieties had a significant influence on harvest index in the first crop (1999-2000). The variety, V<sub>2</sub> (CSV 15) recorded significantly higher harvest index as compared to V<sub>1</sub> (CO 26). In the second crop, the difference was statistically absent.

The data presented in Table 28 showed that there was no significant difference between D<sub>1</sub> and D<sub>2</sub> sowings and between three nutrient levels evaluated for both the crops.

There was no significant interaction between the different treatments studied.

#### 4.1.5 Resource use efficiencies

##### 4.1.5.1 Total Rainfall Use Efficiency

The computed data on Total Rainfall Use Efficiency (TRUE) of sorghum are presented in Table 29.

Between varieties, there was a significant difference for TRUE. The entry V<sub>2</sub> (CSV 15) registered significantly higher TRUE over V<sub>1</sub> (CO 26) in both the crops (1999-2000 and 2000-2001).

Regarding times of sowing, the result was significant for the second crop, where in the sowing date D<sub>2</sub> did register significantly higher TRUE as compared to D<sub>1</sub> sowing.

In respect of nutrient levels, F<sub>3</sub> (60: 30: 0 kg of N: P<sub>2</sub>O<sub>5</sub>: K<sub>2</sub>O ha<sup>-1</sup>) was significantly superior over to F<sub>2</sub> (40: 20: 0 kg of N: P<sub>2</sub>O<sub>5</sub>: K<sub>2</sub>O ha<sup>-1</sup>) and F<sub>1</sub> (control) in the first crop (1999-2000) and during 2000-2001 (second crop), F<sub>2</sub> and F<sub>3</sub> were at par and recorded significantly higher TRUE over F<sub>1</sub> level.

Interactions were absent.

Table 28. Effect of varieties, times of sowing and nutrient levels on harvest index (per cent) of sorghum

Treatments	I crop	II crop
V <sub>1</sub>	18.43	10.29
V <sub>2</sub>	26.39	11.64
SEd	<b>1.897</b>	<b>0.855</b>
CD (P=0.05)	<b>4.643</b>	NS
D <sub>1</sub>	23.29	11.06
D <sub>2</sub>	21.53	10.87
SEd	<b>1.897</b>	<b>0.855</b>
CD (P=0.05)	NS	NS
F <sub>1</sub>	21.10	9.97
F <sub>2</sub>	22.97	11.67
F <sub>3</sub>	23.16	11.25
SEd	<b>1.434</b>	<b>0.920</b>
CD (P=0.05)	NS	NS
V x D		
SEd	<b>2.683</b>	<b>1.208</b>
CD (P=0.05)	NS	NS
V at F		
SEd	<b>2.518</b>	<b>1.363</b>
CD (P=0.05)	NS	NS
F at V		
SEd	<b>2.028</b>	<b>1.300</b>
CD (P=0.05)	NS	NS
D at F		
SEd	<b>2.518</b>	<b>1.363</b>
CD (P=0.05)	NS	NS
F at D		
SEd	<b>2.028</b>	<b>1.300</b>
CD (P=0.05)	NS	NS

I crop: 1999 NEM

II crop: 2000 NEM

NS = Not significant

Table 29. Effect of varieties, times of sowing and nutrient levels on resource use efficiency of sorghum

Treatments	Total rainfall use efficiency (kg ha <sup>-1</sup> mm <sup>-1</sup> )		Effective rainfall use efficiency (kg ha <sup>-1</sup> mm <sup>-1</sup> )		Water use efficiency (kg ha <sup>-1</sup> mm <sup>-1</sup> )	
	I crop	II crop	I crop	II crop	I crop	II crop
V <sub>1</sub>	4.56	3.50	9.52	4.65	6.60	1.82
V <sub>2</sub>	7.44	4.29	15.72	5.69	10.58	2.22
SEd	<b>0.527</b>	<b>0.239</b>	<b>1.183</b>	<b>0.308</b>	<b>0.619</b>	<b>0.122</b>
CD (P=0.05)	<b>1.289</b>	<b>0.584</b>	<b>2.895</b>	<b>0.755</b>	<b>1.514</b>	<b>0.299</b>
D <sub>1</sub>	6.28	2.51	12.31	3.58	9.07	2.05
D <sub>2</sub>	5.73	5.29	12.93	6.76	8.11	1.99
SEd	<b>0.527</b>	<b>0.239</b>	<b>1.183</b>	<b>0.308</b>	<b>0.619</b>	<b>0.122</b>
CD (P=0.05)	NS	<b>0.584</b>	NS	<b>0.755</b>	NS	NS
F <sub>1</sub>	4.52	2.87	9.49	3.81	6.47	1.49
F <sub>2</sub>	6.10	4.58	12.83	6.07	8.73	2.36
F <sub>3</sub>	7.37	4.24	15.53	5.63	10.56	2.21
SEd	<b>0.280</b>	<b>0.304</b>	<b>0.566</b>	<b>0.393</b>	<b>0.401</b>	<b>0.132</b>
CD (P=0.05)	<b>0.593</b>	<b>0.645</b>	<b>1.199</b>	<b>0.833</b>	<b>0.851</b>	<b>0.279</b>
V x D						
SEd	<b>0.745</b>	<b>0.337</b>	<b>1.673</b>	<b>0.436</b>	<b>0.875</b>	<b>0.173</b>
CD (P=0.05)	NS	NS	NS	NS	NS	NS
V at F						
SEd	<b>0.618</b>	<b>0.425</b>	<b>1.351</b>	<b>0.549</b>	<b>0.773</b>	<b>0.195</b>
CD (P=0.05)	NS	NS	NS	NS	NS	NS
F at V						
SEd	<b>0.396</b>	<b>0.430</b>	<b>0.800</b>	<b>0.556</b>	<b>0.567</b>	<b>0.186</b>
CD (P=0.05)	NS	NS	NS	NS	NS	NS
D at F						
SEd	<b>0.618</b>	<b>0.425</b>	<b>1.351</b>	<b>0.549</b>	<b>0.773</b>	<b>0.195</b>
CD (P=0.05)	NS	NS	NS	NS	NS	NS
F at D						
SEd	<b>0.396</b>	<b>0.430</b>	<b>0.800</b>	<b>0.556</b>	<b>0.567</b>	<b>0.186</b>
CD (P=0.05)	NS	NS	NS	NS	NS	NS

I crop: 1999 NEM

II crop: 2000 NEM

NS = Not significant

#### 4.1.5.2 Effective rainfall use efficiency

The mean data on Effective Rainfall Use Efficiency (ERUE) are presented in Table 29.

Between varieties, V<sub>2</sub> (CSV 15) had recorded significantly higher ERUE in both the crops as compared to V<sub>1</sub> (CO 26).

With reference to times of sowing, during 1999-2000 (first crop), there was no significant difference between D<sub>1</sub> and D<sub>2</sub>, but during 2000-2001 (second crop), D<sub>2</sub> registered higher ERUE over D<sub>1</sub>.

Among the nutrient levels evaluated, F<sub>3</sub> (60: 30: 0 kg of N: P<sub>2</sub>O<sub>5</sub>: K<sub>2</sub>O ha<sup>-1</sup>) had shown significantly higher ERUE over F<sub>2</sub> (40: 20: 0 kg of N: P<sub>2</sub>O<sub>5</sub>: K<sub>2</sub>O ha<sup>-1</sup>) and F<sub>1</sub> (control) in the first crop, while in the second crop, F<sub>2</sub> and F<sub>3</sub> were at par and recorded significantly higher ERUE than F<sub>1</sub>.

All the interactions were absent in both the crops.

#### 4.1.5.3 Water Use Efficiency

The computed mean data on Water Use Efficiency (WUE) are presented in Table 29.

In both the crops, V<sub>2</sub> (CSV 15) registered significantly higher WUE as compared to V<sub>1</sub> (CO 26).

Between the times of sowing, there was no significant difference in both the crops.

Among nutrient levels studied, WUE was significantly superior in F<sub>3</sub> (60: 30: 0 kg of N: P<sub>2</sub>O<sub>5</sub>: K<sub>2</sub>O ha<sup>-1</sup>) treatment as compared to F<sub>2</sub> (40: 20: 0 kg of N: P<sub>2</sub>O<sub>5</sub>: K<sub>2</sub>O ha<sup>-1</sup>) and F<sub>1</sub> (control) levels in the first crop (1999-2000). In the second crop (2000-2001), F<sub>2</sub> and F<sub>3</sub> were at par and registered significantly higher WUE over F<sub>1</sub>.

There were no significant interactions between the treatments studied in both the crops.

#### **4.1.6 Crop water balance (Not statistically analysed)**

The computed water balance components during the sorghum growing period of 1999-2000 (first crop) and 2000-2001 (second crop) for times of sowing and varieties are presented in Appendix IV (daily values) and in Tables 30 and 32 (cumulative values) and Tables 31 and 33 (mean cumulative values). Since there was no difference in water balance components for different nutrient levels studied in both the years, only times of sowing and varieties were taken into account and presented separately.

The selected components were cumulative rainfall (CRF), Potential Evapotranspiration (PET), Actual Evapotranspiration (AET), Effective Rainfall (ER), Water Use (WU), soil moisture change (Wn), deficit (DEF) and surplus (SPL).

##### **4.1.6.1 Cumulative rainfall**

The data on cumulative rainfall are presented in Tables 30 and 32 and mean cumulative values for varieties and dates of sowing are presented in Tables 31 and 33.

During 1999-2000 and 2000-2001, both the varieties (CO 26 and CSV 15) received same quantity of rainfall in their respective date of sowing.

In case of times of sowing, D<sub>1</sub> sowing received 427.6 and 284 mm of cumulative rainfall during the cropping season of 1999-2000 and 2000-2001 and D<sub>2</sub> sowing received 391 and 123.3 mm of cumulative rainfall during the cropping season of 1999-2000 and 2000-2001, respectively. In terms of percentage, D<sub>1</sub> sowing received 9.36 and 130.33 per cent higher cumulative rainfall over D<sub>2</sub> sowing during the cropping season of 1999-2000 and 2000-2001, respectively.

##### **4.1.6.2 Water requirement**

The data on water requirement (AET) are presented in Tables 30 and 32 and data on mean water requirement are presented in Tables 31 and 33.

For both the varieties (CO 26 and CSV 15), the water requirement was same (286.79 mm) when sown earlier (D<sub>1</sub>) and when sowing date was delayed, the water

Table 30. Effect of varieties and times of sowing on water balance components (cumulative values) of sorghum during 1999-2000 (first crop) (statistically not analysed)

Treatment	CRF (mm)	ERF (mm)	PET (mm)	AET (mm)	SPL (mm)	DEF (mm)	WU (mm)	Wn (mm)
V <sub>1</sub> D <sub>1</sub>	427.60	218.78	307.20	286.79	208.82	67.85	218.94	(-) 67.85
V <sub>1</sub> D <sub>2</sub>	391.00	173.10	314.92	295.96	217.90	88.26	207.70	(-) 88.26
V <sub>2</sub> D <sub>1</sub>	427.60	218.78	307.20	286.79	208.82	67.85	218.94	(-) 67.85
V <sub>2</sub> D <sub>2</sub>	391.00	173.10	314.92	273.61	217.90	88.26	207.70	(-) 65.91

V<sub>1</sub> = CO 26

V<sub>2</sub> = CSV 15

D<sub>1</sub> = sowing before the receipt of monsoon rainfall (13-09-1999)

D<sub>2</sub> = sowing after the receipt of monsoon rainfall (01-10-1999)

CRF = Cumulative rainfall (mm)

PET = Potential Evapotranspiration (mm)

AET = Actual Evapotranspiration (or) Water requirement (mm)

ERF = Effective rainfall (mm)

SPL = Surplus (mm)

DEF = Deficit (mm)

WU = Water use (mm)

Wn = Soil moisture change at harvest (mm)

Table 31. Effect of varieties and times of sowing on mean water requirements of sorghum during 1999-2000 (first crop) (statistically not analysed)

V/D	D <sub>1</sub>	D <sub>2</sub>	AET (mm)	CRF (mm) (mean of D <sub>1</sub> and D <sub>2</sub> )	% of Rf as AET
V <sub>1</sub>	286.79	295.96	291.375	409.3	71.19
V <sub>2</sub>	286.79	273.61	280.2	409.3	68.46
AET (mm)	286.79	284.785	-	-	-
CRF (mm) (mean of V <sub>1</sub> and V <sub>2</sub> )	427.6	391	-	-	-
% of Rf as AET	67.07	72.84	-	-	-

V<sub>1</sub> = CO 26

V<sub>2</sub> = CSV 15

D<sub>1</sub> = sowing before the receipt of monsoon rainfall (13-09-1999)

D<sub>2</sub> = sowing after the receipt of monsoon rainfall (01-10-1999)

CRF = Cumulative rainfall (mm)

AET = Actual Evapotranspiration (or) Water requirement (mm)

**Table 32. Effect of varieties and times of sowing on water balance components (cumulative values) of sorghum during 2000-2001 (second crop) (statistically not analysed)**

Treatment	CRF (mm)	ERF (mm)	PET (mm)	AET (mm)	SPL (mm)	DEF (mm)	WU (mm)	Wn (mm)
V <sub>1</sub> D <sub>1</sub>	284.00	198.80	376.00	345.72	85.20	138.77	206.95	(-) 138.77
V <sub>1</sub> D <sub>2</sub>	123.30	96.46	351.20	327.89	26.84	131.43	196.46	(-) 131.43
V <sub>2</sub> D <sub>1</sub>	284.00	198.80	376.00	345.72	85.20	138.77	206.95	(-) 138.77
V <sub>2</sub> D <sub>2</sub>	123.30	96.46	351.20	327.89	26.84	131.43	196.46	(-) 131.43

V<sub>1</sub> = CO 26

V<sub>2</sub> = CSV 15

D<sub>1</sub> = sowing before the receipt of monsoon rainfall (18-09-2000)

D<sub>2</sub> = sowing after the receipt of monsoon rainfall (29-09-2000)

CRF = Cumulative rainfall (mm)

PET = Potential Evapotranspiration (mm)

AET = Actual Evapotranspiration (or) Water requirement (mm)

ERF = Effective rainfall (mm)

SPL = Surplus (mm)

DEF = Deficit (mm)

WU = Water use (mm)

Wn = Soil moisture change at harvest (mm)

Table 33. Effect of varieties and times of sowing on mean water requirements of sorghum during 2000-2001 (second crop) (statistically not analysed)

V/D	D <sub>1</sub>	D <sub>2</sub>	AET (mm)	CRF (mm) (mean of D <sub>1</sub> and D <sub>2</sub> )	% of Rf as AET
V <sub>1</sub>	345.72	327.89	336.81	203.65	165.39
V <sub>2</sub>	345.72	327.89	336.81	203.65	165.39
AET (mm)	345.72	327.89	-	-	-
CRF (mm) (mean of V <sub>1</sub> and V <sub>2</sub> )	284	123.3	-	-	-
% of Rf as AET	121.73	265.59	-	-	-

V<sub>1</sub> = CO 26

V<sub>2</sub> = CSV 15

D<sub>1</sub> = sowing before the receipt of monsoon rainfall (18-09-2000)

D<sub>2</sub> = sowing after the receipt of monsoon rainfall (29-09-2000)

CRF = Cumulative rainfall (mm)

AET = Actual Evapotranspiration (or) Water requirement (mm)

requirement was higher for CO 26 (295.96 mm) than CSV 15 (273.61 mm) during 1999-2000.

During 2000-2001, the data on water requirement showed a decreasing trend (from 345.72 mm to 327.89 mm) as sowing date was delayed from D<sub>1</sub> to D<sub>2</sub> for both varieties. When the mean water requirement of the varieties was estimated, it was 291.38 mm for V<sub>1</sub> and 280.20 mm for V<sub>2</sub>, which accounted 71.2 and 68.5 per cent of the cumulative mean rainfall received during the growing period of 1999-2000 and 336.81 mm for both V<sub>1</sub> and V<sub>2</sub>, which accounted 165.4 per cent of the cumulative mean rainfall received during the growing period of 2000-2001.

In respect of dates of sowing, the mean cumulative water requirement was estimated as 286.79 mm for D<sub>1</sub> and 284.79 mm for D<sub>2</sub>, which accounted to 67.1 and 72.8 per cent of the mean cumulative rainfall received during the cropping period of 1999-2000 and 345.72 mm for D<sub>1</sub> and 327.89 mm for D<sub>2</sub>, which accounted to 121.7 and 265.6 per cent of the mean cumulative rainfall received during the cropping period of 2000-2001.

#### **4.1.6.3 Water use**

The data on sorghum water balance (Tables 30 and 32) indicated that for both varieties at D<sub>1</sub>, the crop water requirement (AET) was not satisfied due to a deficit of 67.85 mm of soil water at maturity stage during 1999-2000. At D<sub>2</sub>, the deficit was 88.26 mm for V<sub>1</sub> (CO 26) and 65.91 mm for V<sub>2</sub> (CSV 15) during 1999-2000.

During 2000-2001, D<sub>1</sub> encountered a soil moisture deficit of 138.77 mm for both the varieties and for D<sub>2</sub>, the deficit was 131.43 mm for both varieties, respectively.

#### **4.1.6.4 Effective rainfall**

The data from Tables 30 and 32 showed that considerable opportunity was seen to shift water towards effective rainfall by advancing the sowing date.

During 1999-2000 and 2000-2001, D<sub>1</sub> registered higher effective rainfall (218.78 mm and 198.8 mm for 1999-2000 and 2000-2001, respectively) over D<sub>2</sub>

(173.1 mm and 96.46 mm for 1999-2000 and 2000-2001, respectively) irrespective of the quantum of rainfall received during the crop growth period.

#### 4.1.6.5 Surplus water

A general comparison of water loss as runoff with rainfall revealed that the former accounted a major share of the total rainfall during the cropping season irrespective of sowing dates.

During 1999-2000, D<sub>2</sub> sowing registered higher water loss of 217.90 mm (56 per cent of the total rainfall received during the cropping season) as compared to D<sub>1</sub> sowing (49 per cent of the total rainfall received during the cropping season) and during 2000-2001, 85.20 and 26.84 mm of rainfall received during the cropping season were lost as runoff in D<sub>1</sub> sowing (30 per cent of the total rainfall received during the cropping season) and D<sub>2</sub> sowing (22 per cent of the total rainfall received during the cropping season), respectively.

#### 4.1.6.6 Soil moisture dynamics

The data on effect of varieties and dates of sowing on available soil moisture dynamics, computed by crop water balance model (simulated by using Gupta model) and gravimetric method (measured) are presented in Tables 34, 34a, 35 and 35a and in Appendix V.

Water balance model developed by Gupta *et al.* (1972) generated the following outputs.

During 1999-2000, both varieties and sowing dates recorded higher soil moisture content during the vegetative stage. As the crop approached to the maturity stage, the moisture content of the soil reached to Permanent Wilting Point (PWP). According to the model, the soil moisture deficit at harvest for D<sub>1</sub> was 67.85 mm for both the varieties and 82.26 and 65.91 mm for V<sub>1</sub> and V<sub>2</sub>, respectively when sowing was delayed (D<sub>2</sub>). Hence the model expressed fair distribution of the soil moisture through out the crop growth period, especially during the vegetative and flowering stages.

Table 34. Effect of varieties and times of sowing on available soil moisture dynamics at different stages of sorghum-simulated values (water balance model)- Gupta *et al.*, 1972) in mm per m depth during 1999-2000 (first crop) (statistically not analysed)

Treatment	Initial	Vegetative stage (DAS)							Flowering stage (DAS)				Maturity stage (DAS)	
		7	14	21	28	35	42	49	56	63	70	77	84	Harvest
V <sub>1</sub> D <sub>1</sub>	0	83.87	96.98	99.58	100	88.11	92.86	69.84	70.66	53.23	33.35	17.53	(-) 2.69	(-) 67.85
V <sub>1</sub> D <sub>2</sub>	33.69	98.65	100	100	97.46	98.48	79.33	59.68	61.02	45.23	23.97	9.19	(-) 3.07	(-) 82.26
V <sub>2</sub> D <sub>1</sub>	0	83.87	96.98	99.58	100	88.11	92.86	69.84	70.66	53.23	33.35	17.53	(-) 2.69	(-) 67.85
V <sub>2</sub> D <sub>2</sub>	33.69	98.65	100	100	97.46	98.48	79.33	59.68	61.02	45.23	23.97	9.19	(-) 3.07	(-) 82.26

Table 34a. Effect of varieties and times of sowing on available soil moisture dynamics at different stages of sorghum-estimated values (Gravimetric method)\* in mm per m depth during 1999-2000 (first crop) (statistically not analysed)

Treatment	Initial	Vegetative stage (DAS)							Flowering stage (DAS)				Maturity stage (DAS)	
		7	14	21	28	35	42	49	56	63	70	77	84	Harvest
V <sub>1</sub> D <sub>1</sub>	0	51.28	51.39	Rain	68.73	24.78	22.10	0	Rain	31.28	15.15	13.56	5.74	0
V <sub>1</sub> D <sub>2</sub>	43.21	74.15	Rain	80.09	52.05	26.27	0	Rain	19.32	28.02	4.54	0.62	11.90	0
V <sub>2</sub> D <sub>1</sub>	0	88.56	55.20	Rain	44.34	11.56	30.29	0	Rain	10.75	14.62	4.95	0	0
V <sub>2</sub> D <sub>2</sub>	43.59	79.61	Rain	84.69	49.19	25.07	0	Rain	19.70	7.08	0	0	0	0

Soil type : Sandy clay loam Bulk density : 1.36 g cc<sup>-1</sup>

Field capacity : 18.87 % Permanent wilting point : 10.69 %

Average water holding capacity : 100 mm m<sup>-1</sup> depth of soil

\* Zero was assigned when the moisture level decreased beyond permanent wilting point

Table 35. Effect of varieties and times of sowing on available soil moisture dynamics at different stages of sorghum-simulated values (water balance model- Gupta *et al.*, 1972) in mm per m depth during 2000-2001 (second crop) (statistically not analysed)

Treatment	Initial	Vegetative stage (DAS)							Flowering stage (DAS)				Maturity stage (DAS)	
		7	14	21	28	35	42	49	56	63	70	77	84	Harvest
V <sub>1</sub> D <sub>1</sub>	3.66	97.68	96.38	95.34	94.60	75.26	56.56	31.97	(-) 9.48	7.28	7.79	(-) 16.36	(-) 49.18	(-) 138.77
V <sub>1</sub> D <sub>2</sub>	99.20	97.26	92.35	87.23	79.09	65.44	40.82	19.71	26.35	27.48	(-) 0.39	(-) 29.49	(-) 61.28	(-) 131.43
V <sub>2</sub> D <sub>1</sub>	3.66	97.68	96.38	95.34	94.60	75.26	56.56	31.97	(-) 9.48	7.28	7.79	(-) 16.36	(-) 49.18	(-) 138.77
V <sub>2</sub> D <sub>2</sub>	99.20	97.26	92.35	87.23	79.09	65.44	40.82	19.71	26.35	27.48	(-) 0.39	(-) 29.49	(-) 61.28	(-) 131.43

Table 35a. Effect of varieties and times of sowing on available soil moisture dynamics at different stages of sorghum-estimated values (Gravimetric method)\* in mm per m depth during 2000-2001 (second crop) (statistically not analysed)

Treatment	Initial	Vegetative stage (DAS)							Flowering stage (DAS)				Maturity stage (DAS)	
		7	14	21	28	35	42	49	56	63	70	77	84	Harvest
V <sub>1</sub> D <sub>1</sub>	0	94.9	53.9	29.1	6	0	0	0	0	2.6	3.9	0	0	0
V <sub>1</sub> D <sub>2</sub>	88.9	52.8	55.4	17.1	0	0	0	0	0	8.2	0	0	0	0
V <sub>2</sub> D <sub>1</sub>	0	95.8	55.9	30.9	5.8	0	0	0	0	3.1	3.7	0	0	0
V <sub>2</sub> D <sub>2</sub>	90.2	55.5	50	19.8	0	0	0	0	0	0	0	0	0	0

Soil type : Sandy clay loam Bulk density : 1.36 g cc<sup>-1</sup>

Field capacity : 18.87 % Permanent wilting point : 10.69 %

Average water holding capacity : 100 mm m<sup>-1</sup> depth of soil

\* Zero was assigned when the moisture level decreased beyond permanent wilting point

During 2000-2001, soil moisture content was higher at vegetative stage and it showed a declining trend for both varieties and sowing dates there after. As the crop entered into the flowering stage, the soil moisture was depleted at faster rate by the crop and since there was no enough rainfall to recharge the soil moisture, the soil moisture content fell below the PWP from 77 DAS onwards for both varieties of D<sub>1</sub> and from 70 DAS onwards for both varieties of D<sub>2</sub>.

In respect of the data presented for actual observed data through gravimetric method, the trend of the available soil moisture was same as that of the trend obtained in the model output observed, but there was a wide variation in quantity of soil moisture observed between Gupta model (simulated values) and gravimetric method (actual observed data).

During 1999-2000, the data on actual soil moisture revealed that at D<sub>1</sub>, there was a soil moisture stress at 49 DAS for both varieties and this stress was terminated by the rainfall received at 56 DAS. In case of D<sub>2</sub>, the soil moisture stress was observed at 42 DAS and the rainfall was received at 49 DAS for both the varieties. The data also revealed that there was a moisture stress for the crop at its maturity stage especially for the variety V<sub>2</sub>.

During 2000-2001, the actual observed data revealed that both the varieties sown at D<sub>1</sub> experienced a severe moisture stress from 35 DAS to 56 DAS and from 77 DAS to harvest. The soil moisture content at 63 and 70 DAS was also of very less in quantity. In respect of D<sub>2</sub>, both the varieties experienced a severe moisture stress from 28 DAS to harvest except at 63 DAS in which the soil moisture content was above the PWP for V<sub>1</sub>.

Thus it is clear that the values were magnified in the model output, even though the trend was akin to actual measured data, and it led to the conclusion that the water balance model developed by Gupta *et al.* (1972) needs refinement to local condition.

#### 4.1.7 Nutrient uptake

##### 4.1.7.1 Nitrogen uptake

The mean data on N uptake at vegetative, flowering and maturity stages are presented in Tables 36 and 37.

In general, between the varieties, V<sub>2</sub> (CSV 15) recorded significantly higher N uptake than V<sub>1</sub> (CO 26) in all the vegetative, flowering and maturity stages of both the crops, except at 42 and 63 DAS of first crop (1999-2000), where the result was not significant and also at 14, 84 DAS and at harvest of second crop (2000-2001).

In respect of dates of sowing, in all the stages of both the crops, D<sub>1</sub> registered its superiority in higher N uptake over D<sub>2</sub> significantly except at 14, 42, 56, 70, 77, 84 and 91 DAS of first crop and also at 14, 21, 35, 49 DAS and at harvest of second crop.

Among the nutrient levels studied, during 1999-2000 (first crop), in all the vegetative, flowering and maturity stages, F<sub>3</sub> (60: 30: 0 kg of N: P<sub>2</sub>O<sub>5</sub>: K<sub>2</sub>O ha<sup>-1</sup>) recorded significantly higher N uptake over F<sub>2</sub> (40: 20: 0 kg of N: P<sub>2</sub>O<sub>5</sub>: K<sub>2</sub>O ha<sup>-1</sup>) and F<sub>1</sub>(control).

The next best treatment was F<sub>2</sub> which also recorded significantly higher N uptake as compared to F<sub>1</sub>. The treatment F<sub>1</sub> recorded the lowest N uptake in all the stages. During 2000-2001, the level F<sub>2</sub> was at par with F<sub>3</sub> in registering higher N uptake at 21, 49, 56, 63, 70, 77, 84 DAS and at harvest, while F<sub>3</sub> was independently superior at 28, 42 and 91 DAS. The result was not significant at 14 and 35 DAS.

All the interactions were absent in both the crops.

##### 4.1.7.2 Phosphorus uptake

The mean data on P uptake recorded at various stages of crop growth are presented in Tables 38 and 39.

Between varieties, V<sub>2</sub> (CSV 15) registered significantly higher P uptake as compared to V<sub>1</sub> (CO 26) in all the vegetative, flowering and maturity stages of both

Table 36. Effect of varieties, times of sowing and nutrient levels on N uptake ( $\text{kg ha}^{-1}$ ) of sorghum at vegetative stage

Treatments	14 DAS		21 DAS		28 DAS		35 DAS		42 DAS		49 DAS	
	I crop	II crop	I crop	II crop	I crop	II crop	I crop	II crop	I crop	II crop	I crop	II crop
V <sub>1</sub>	0.20	0.13	0.78	3.98	2.74	6.14	10.21	9.06	17.08	18.25	45.40	37.04
V <sub>2</sub>	0.35	0.18	1.26	3.30	4.79	7.19	11.98	12.41	20.11	22.15	58.61	32.09
SEd	0.028	0.031	0.050	0.126	0.379	0.168	0.421	0.484	1.727	0.582	1.311	0.864
CD (P=0.05)	0.068	NS	0.122	0.309	0.927	0.411	1.030	1.185	NS	1.424	3.207	2.113
D <sub>1</sub>	0.23	0.15	1.15	3.78	4.48	7.27	12.51	11.60	20.55	24.38	56.18	34.45
D <sub>2</sub>	0.27	0.12	0.84	3.49	3.05	6.30	9.94	10.68	17.64	17.25	43.83	32.68
SEd	0.028	0.030	0.050	0.126	0.379	0.168	0.421	0.484	1.727	0.582	1.311	0.864
CD (P=0.05)	NS	NS	0.121	NS	0.927	0.411	1.030	NS	NS	1.424	3.207	NS
F <sub>1</sub>	0.13	0.10	0.46	3.55	1.81	4.48	7.58	10.40	12.30	16.82	32.23	30.36
F <sub>2</sub>	0.25	0.14	0.97	3.65	3.73	6.44	10.43	10.98	19.61	19.27	50.09	33.79
F <sub>3</sub>	0.33	0.18	1.62	3.91	5.75	8.96	13.28	11.46	29.38	25.21	69.69	32.54
SEd	0.022	0.070	0.078	0.156	0.400	0.332	0.489	0.598	2.355	0.621	4.410	0.675
CD (P=0.05)	0.047	NS	0.166	0.331	0.848	0.703	1.037	NS	4.993	1.316	9.348	1.430
V x D												
SEd	0.039	0.054	0.070	0.179	0.536	0.238	0.726	0.685	2.443	0.752	1.854	1.221
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
V at F												
SEd	0.038	0.083	0.103	0.184	0.598	0.418	0.785	0.843	3.222	0.924	5.258	1.163
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
F at V												
SEd	0.032	0.095	0.111	0.164	0.566	0.469	0.755	0.846	3.331	0.907	6.236	0.954
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
D at F												
SEd	0.038	0.083	0.103	0.184	0.598	0.418	0.785	0.843	3.222	0.924	5.258	1.163
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
F at D												
SEd	0.032	0.095	0.111	0.164	0.566	0.469	0.755	0.846	3.331	0.907	6.236	0.954
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

I crop: 1999 NEM

II crop: 2000 NEM

NS = Not significant

Table 37. Effect of varieties, times of sowing and nutrient levels on N uptake (kg ha<sup>-1</sup>) of sorghum at flowering and maturity stages

Treatments	Flowering stage						Maturity stage							
	56 DAS		63 DAS		70 DAS		77 DAS		84 DAS		91 DAS		At harvest	
	I crop	II crop	I crop	II crop	I crop	II crop	I crop	II crop	I crop	II crop	I crop	II crop	I crop	II crop
V <sub>1</sub>	54.4	50.7	81.9	57.1	84.4	59.0	89.6	67.2	96.6	73.8	115.0	75.4	131.9	76.5
V <sub>2</sub>	67.9	56.3	85.5	63.7	103.9	66.0	105.1	69.9	116.3	76.5	129.2	78.5	146.2	79.3
SEd	3.77	1.17	1.94	0.72	3.80	1.25	3.98	0.69	3.75	1.24	5.55	0.66	3.90	1.99
CD (P=0.05)	9.22	2.86	NS	1.77	9.30	3.07	9.74	1.68	9.18	NS	13.59	1.62	9.54	NS
D <sub>1</sub>	65.8	57.7	88.1	64.1	94.5	68.3	99.2	69.4	108.4	76.5	135.6	77.8	149.9	79.0
D <sub>2</sub>	60.5	46.3	74.5	59.1	90.9	62.1	97.4	64.2	101.2	66.8	124.1	72.8	132.2	74.2
SEd	3.77	1.17	1.94	0.72	3.80	1.25	3.98	0.69	3.75	1.24	5.55	0.66	3.90	1.99
CD (P=0.05)	NS	2.86	4.75	1.77	NS	3.07	NS	1.68	NS	3.05	NS	1.62	9.54	NS
F <sub>1</sub>	45.0	40.2	60.2	44.7	69.0	52.9	73.5	57.2	78.8	60.6	102.1	63.5	114.6	69.7
F <sub>2</sub>	60.5	55.2	82.3	63.0	97.8	70.1	94.3	75.0	110.4	77.2	130.5	80.4	138.6	81.6
F <sub>3</sub>	84.2	59.5	104.7	61.2	115.8	68.2	119.3	69.6	128.2	72.3	156.6	75.6	166.0	76.2
SEd	4.64	2.52	4.42	1.68	5.63	3.07	5.94	2.40	4.73	3.14	6.67	0.50	5.82	2.94
CD (P=0.05)	9.84	5.34	9.37	3.56	11.94	6.52	12.59	5.09	10.03	6.65	14.14	1.06	12.35	6.22
V x D														
SEd	5.33	1.65	2.74	1.02	5.38	1.77	5.63	0.97	5.31	1.76	7.85	0.94	5.51	2.82
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
V at F														
SEd	6.55	3.14	5.46	2.07	7.53	3.76	7.93	2.86	6.63	3.83	9.49	0.88	7.77	3.93
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
F at V														
SEd	6.56	3.56	6.25	2.38	7.97	4.35	8.40	3.40	6.69	4.44	9.43	0.71	8.24	4.15
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
D at F														
SEd	6.55	3.14	5.46	2.07	7.53	3.76	7.93	2.86	6.63	3.83	9.49	0.88	7.77	3.93
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
F at D														
SEd	6.56	3.56	6.25	2.38	7.97	4.35	8.40	3.40	6.69	4.44	9.43	0.71	8.24	4.15
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

NS = Not significant

I crop: 1999 NEM

II crop: 2000 NEM

Table 38. Effect of varieties, times of sowing and nutrient levels on P uptake ( $\text{kg ha}^{-1}$ ) of sorghum at vegetative stage

Treatments	14 DAS		21 DAS		28 DAS		35 DAS		42 DAS		49 DAS	
	I crop	II crop	I crop	II crop	I crop	II crop	I crop	II crop	I crop	II crop	I crop	II crop
$V_1$	0.032	0.0206	0.12	0.51	0.39	0.97	1.52	1.48	2.68	2.51	6.81	4.78
$V_2$	0.045	0.0222	0.26	0.61	0.59	1.11	1.75	1.91	3.64	2.74	8.90	5.89
SEd	<b>0.0040</b>	<b>0.0014</b>	<b>0.009</b>	<b>0.019</b>	<b>0.059</b>	<b>0.027</b>	<b>0.068</b>	<b>0.076</b>	<b>0.265</b>	<b>0.053</b>	<b>0.211</b>	<b>0.137</b>
CD (P=0.05)	<b>0.0098</b>	NS	<b>0.022</b>	<b>0.046</b>	<b>0.145</b>	<b>0.065</b>	<b>0.167</b>	<b>0.185</b>	NS	<b>0.130</b>	<b>0.516</b>	<b>0.334</b>
$D_1$	0.0344	0.0233	0.22	0.58	0.57	1.10	1.62	1.72	2.71	2.75	8.43	5.47
$D_2$	0.0433	0.0194	0.14	0.54	0.44	0.98	1.14	1.67	3.56	2.49	7.88	5.19
SEd	<b>0.0040</b>	<b>0.0014</b>	<b>0.009</b>	<b>0.019</b>	<b>0.059</b>	<b>0.027</b>	<b>0.068</b>	<b>0.076</b>	<b>0.265</b>	<b>0.053</b>	<b>0.211</b>	<b>0.137</b>
CD (P=0.05)	NS	<b>0.0034</b>	<b>0.022</b>	NS	NS	<b>0.065</b>	<b>0.167</b>	<b>0.185</b>	NS	<b>0.130</b>	<b>0.516</b>	NS
$F_1$	0.0292	0.0180	0.07	0.55	0.28	0.73	0.78	1.64	1.65	1.94	5.33	5.17
$F_2$	0.0367	0.0219	0.21	0.56	0.61	1.06	1.38	1.72	3.04	2.78	8.03	5.39
$F_3$	0.0508	0.0254	0.28	0.57	0.85	1.33	1.59	1.73	4.44	3.15	10.98	5.48
SEd	<b>0.0037</b>	<b>0.0017</b>	<b>0.013</b>	<b>0.017</b>	<b>0.062</b>	<b>0.052</b>	<b>0.086</b>	<b>0.093</b>	<b>0.375</b>	<b>0.125</b>	<b>0.710</b>	<b>0.107</b>
CD (P=0.05)	<b>0.0079</b>	<b>0.0037</b>	<b>0.027</b>	NS	<b>0.131</b>	<b>0.109</b>	<b>0.183</b>	NS	<b>0.795</b>	<b>0.265</b>	<b>1.506</b>	<b>0.227</b>
V x D												
SEd	<b>0.0057</b>	<b>0.0020</b>	<b>0.013</b>	<b>0.026</b>	<b>0.084</b>	<b>0.037</b>	<b>0.099</b>	<b>0.107</b>	<b>0.374</b>	<b>0.075</b>	<b>0.298</b>	<b>0.193</b>
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
V at F												
SEd	<b>0.0059</b>	<b>0.0024</b>	<b>0.017</b>	<b>0.027</b>	<b>0.093</b>	<b>0.065</b>	<b>0.101</b>	<b>0.131</b>	<b>0.507</b>	<b>0.154</b>	<b>0.847</b>	<b>0.184</b>
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
F at V												
SEd	<b>0.0053</b>	<b>0.0025</b>	<b>0.018</b>	<b>0.024</b>	<b>0.088</b>	<b>0.073</b>	<b>0.9935</b>	<b>0.132</b>	<b>0.530</b>	<b>0.177</b>	<b>1.005</b>	<b>0.151</b>
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
D at F												
SEd	<b>0.0059</b>	<b>0.0024</b>	<b>0.017</b>	<b>0.027</b>	<b>0.093</b>	<b>0.065</b>	<b>0.101</b>	<b>0.131</b>	<b>0.507</b>	<b>0.154</b>	<b>0.847</b>	<b>0.184</b>
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
F at D												
SEd	<b>0.0053</b>	<b>0.0025</b>	<b>0.018</b>	<b>0.024</b>	<b>0.088</b>	<b>0.073</b>	<b>0.993</b>	<b>0.132</b>	<b>0.530</b>	<b>0.177</b>	<b>1.005</b>	<b>0.151</b>
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

I crop: 1999 NEM

II crop: 2000 NEM

NS = Not significant

Table 39. Effect of varieties, times of sowing and nutrient levels on P uptake ( $\text{kg ha}^{-1}$ ) of sorghum at flowering and maturity stages

Treatments	Flowering stage						Maturity stage								
	56 DAS		63 DAS		70 DAS		77 DAS		84 DAS		91 DAS		At harvest		
	I crop	II crop	I crop	II crop	I crop	II crop	I crop	II crop	I crop	II crop	I crop	II crop	I crop	II crop	
$V_1$	7.89	7.79	11.84	8.78	12.98	9.50	14.13	10.50	11.48	15.83	11.48	17.07	11.80	21.21	12.53
$V_2$	11.30	8.51	13.41	10.73	15.79	11.14	18.01	12.40	12.95	19.42	12.95	22.64	13.60	25.46	13.43
SEd	0.663	0.181	0.303	0.111	0.623	0.201	0.646	0.114	0.210	0.625	0.210	0.870	0.111	0.712	0.335
CD (P=0.05)	1.622	0.442	NS	0.271	1.525	0.492	1.580	0.278	0.514	1.529	0.514	2.128	0.273	1.741	0.821
$D_1$	10.29	8.87	13.81	9.95	15.78	11.00	17.19	11.50	12.08	18.16	12.08	21.20	12.87	26.85	13.40
$D_2$	9.01	7.43	11.59	9.56	13.79	9.63	15.95	11.40	11.36	16.48	11.36	18.90	12.23	22.92	12.56
SEd	0.663	0.181	0.303	0.111	0.623	0.202	0.646	0.114	0.210	0.625	0.210	0.870	0.111	0.712	0.335
CD (P=0.05)	NS	0.442	0.742	0.271	NS	0.492	NS	NS	0.514	NS	0.514	NS	0.273	1.741	0.821
$F_1$	6.89	6.50	9.09	7.47	10.08	8.53	10.64	9.60	10.25	11.76	10.25	14.38	10.60	18.79	12.19
$F_2$	9.20	8.80	11.92	9.97	15.28	11.35	16.76	11.70	12.61	18.50	12.61	21.52	12.97	23.76	14.37
$F_3$	13.55	9.16	15.15	9.82	18.69	11.07	20.31	11.50	11.80	22.26	11.80	24.66	12.60	29.95	13.97
SEd	0.715	0.388	0.688	0.258	0.927	0.494	0.916	0.396	0.532	0.786	0.532	1.051	0.081	1.026	0.497
CD (P=0.05)	1.517	0.822	1.457	0.547	1.964	1.048	1.943	NS	1.127	1.667	1.127	2.229	0.172	2.175	1.054
$V \times D$															
SEd	0.938	0.256	0.429	0.157	0.881	0.284	0.913	0.161	0.297	0.884	0.297	1.230	0.158	1.006	0.474
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
$V$ at $F$															
SEd	1.059	0.483	0.850	0.318	1.238	0.605	1.240	0.471	0.649	1.102	0.649	1.493	0.146	1.382	0.665
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
$F$ at $V$															
SEd	1.012	0.549	0.972	0.365	1.310	0.699	1.296	0.560	0.752	1.112	0.752	1.487	0.115	1.451	0.703
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
$D$ at $F$															
SEd	1.059	0.483	0.850	0.318	1.238	0.605	1.240	0.471	0.649	1.102	0.649	1.493	0.146	1.382	0.665
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
$F$ at $D$															
SEd	1.012	0.549	0.972	0.365	1.310	0.699	1.296	0.560	0.752	1.112	0.752	1.487	0.115	1.451	0.703
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

NS = Not significant

II crop: 2000 NEM

I crop: 1999 NEM

crops, except at 42 and 63 DAS of first crop (1999-2000) and 14 DAS of second crop (2000-2001), where the result was not significant.

With regard to dates of sowing,  $D_1$  registered its superiority over  $D_2$  in P uptake at all the crop growth stages during both 1999-2000 and 2000-2001 except at 14, 28, 42, 56, 70, 77, 84 and 91 DAS of first crop and also at 21, 49 and 77 DAS of second crop where the result was not significant.

In general, the level  $F_3$  (60: 30: 0 kg of N:  $P_2O_5$ :  $K_2O$  ha<sup>-1</sup>) did influence P uptake significantly over other levels studied at all the stages studied in the first crop and also at 28 and 42 DAS of second crop. While  $F_2$  (40: 20: 0 kg of N:  $P_2O_5$ :  $K_2O$  ha<sup>-1</sup>) and  $F_3$  levels were at par in recording higher P uptake at 14, 49, 56, 63, 70, 84 DAS and at harvest in the second crop.

All the interactions were not significant in both the crops.

#### 4.1.7.3 Potassium uptake

The mean data on K uptake by sorghum at various stages of crop growth are presented in Tables 40 and 41.

Through out the different stages of both the crops,  $V_2$  (CSV 15) was significantly superior to  $V_1$  in registering higher K uptake except at 42, 63, 70 and 77 DAS of first crop (1999-2000), 56, 63, 70 and 77 DAS of second crop (2000-2001), where in the result was not significant.

Wherever the result was significant, in both the crops,  $D_1$  sowing was found superior for this parameter except at 63 DAS for the first crop, where  $D_1$  and  $D_2$  were at par.

In respect of nutrient levels evaluated, the result was in favour of  $F_3$  (60: 30: 0 kg of N:  $P_2O_5$ :  $K_2O$  ha<sup>-1</sup>) level up to harvest of first crop and also up to 49 DAS of second crop and there after for second crop, the nutrient level  $F_2$  (40: 20: 0 kg of N:  $P_2O_5$ :  $K_2O$  ha<sup>-1</sup>) was at par with  $F_3$  level in recording higher K uptake.

Interactions were absent.

Table 40. Effect of varieties, times of sowing and nutrient levels on K uptake ( $\text{kg ha}^{-1}$ ) of sorghum at vegetative stage

Treatments	14 DAS		21 DAS		28 DAS		35 DAS		42 DAS		49 DAS	
	I crop	II crop	I crop	II crop	I crop	II crop	I crop	II crop	I crop	II crop	I crop	II crop
$V_1$	0.40	0.26	1.45	7.89	4.61	11.09	11.06	20.12	26.54	23.68	60.52	38.77
$V_2$	0.66	0.29	2.40	6.04	6.90	13.71	14.96	16.59	33.47	25.08	74.81	45.94
SEd	0.055	0.006	0.097	0.251	0.677	0.300	1.218	0.798	2.506	0.505	1.730	1.164
CD (P=0.05)	0.136	0.014	0.238	0.615	1.656	0.734	2.980	1.952	NS	1.237	4.234	2.848
$D_1$	0.42	0.29	2.26	7.51	6.52	12.57	15.08	18.12	28.19	25.21	73.24	44.58
$D_2$	0.45	0.25	1.67	6.43	5.29	10.23	10.68	17.40	32.86	23.59	61.09	42.02
SEd	0.055	0.006	0.097	0.251	0.677	0.300	1.218	0.798	2.506	0.505	1.730	1.164
CD (P=0.05)	NS	0.014	0.238	NS	NS	0.734	2.980	NS	NS	1.237	4.234	NS
$F_1$	0.30	0.23	0.90	7.06	3.08	8.33	8.98	17.28	14.92	18.35	40.64	42.11
$F_2$	0.51	0.28	1.78	7.14	5.91	13.16	12.58	18.08	32.71	24.70	68.14	43.48
$F_3$	0.75	0.31	2.92	7.35	8.98	16.22	16.14	18.22	44.12	30.89	95.21	46.72
SEd	0.044	0.013	0.156	0.299	0.704	0.588	1.427	0.985	3.558	1.183	5.872	0.881
CD (P=0.05)	0.094	0.028	0.331	NS	1.493	1.247	3.025	NS	7.543	2.509	12.448	1.868
$V \times D$												
SEd	0.078	0.008	0.137	0.356	0.957	0.424	1.726	1.128	3.543	0.715	2.447	1.646
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
$V$ at $F$												
SEd	0.075	0.017	0.205	0.365	1.058	0.742	1.924	1.389	4.812	1.457	6.998	1.546
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
$F$ at $V$												
SEd	0.063	0.019	0.221	0.324	0.996	0.832	1.853	1.392	5.032	1.674	8.304	1.246
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
$D$ at $F$												
SEd	0.075	0.017	0.209	0.365	1.058	0.742	1.924	1.389	4.812	1.457	6.998	1.546
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
$F$ at $D$												
SEd	0.063	0.019	0.221	0.324	0.996	0.832	1.853	1.392	5.032	1.674	8.304	1.246
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

I crop: 1999 NEM

II crop: 2000 NEM

NS = Not significant

Table 41. Effect of varieties, times of sowing and nutrient levels on K uptake ( $\text{kg ha}^{-1}$ ) of sorghum at flowering and maturity stages

Treatments	Flowering stage						Maturity stage							
	56 DAS		63 DAS		70 DAS		77 DAS		84 DAS		91 DAS		At harvest	
	I crop	II crop	I crop	II crop	I crop	II crop	I crop	II crop	I crop	II crop	I crop	II crop	I crop	II crop
V <sub>1</sub>	67.46	57.07	79.06	59.96	84.11	62.66	87.11	66.82	89.06	68.49	90.39	70.18	117.78	72.45
V <sub>2</sub>	82.83	55.46	90.33	60.11	92.58	64.62	95.13	69.01	99.44	72.18	106.42	74.85	126.15	76.43
SEd	4.863	1.381	2.103	1.562	3.869	1.212	3.58	1.516	3.67	1.146	4.25	1.231	3.36	1.881
CD (P=0.05)	11.899	NS	NS	NS	NS	NS	NS	NS	8.990	2.804	10.41	3.012	8.22	4.602
D <sub>1</sub>	76.84	63.28	89.72	66.09	92.11	68.08	96.40	70.64	99.44	72.33	103.15	75.65	128.00	76.15
D <sub>2</sub>	74.56	57.14	85.97	59.21	86.83	62.66	88.81	63.98	90.72	68.72	96.03	71.29	111.11	72.12
SEd	4.863	1.381	2.103	1.562	3.869	1.212	3.58	1.516	3.67	1.146	4.25	1.231	3.36	1.881
CD (P=0.05)	NS	3.380	5.146	3.822	NS	2.966	NS	3.710	NS	2.804	NS	3.012	8.22	4.602
F <sub>1</sub>	52.17	49.97	63.58	51.19	65.33	55.93	68.11	59.06	70.79	65.10	75.83	66.08	95.42	68.54
F <sub>2</sub>	76.44	67.68	89.17	68.08	94.11	70.78	97.00	73.18	100.17	74.22	108.97	75.24	120.08	76.38
F <sub>3</sub>	100.83	66.48	107.33	67.50	115.50	69.80	118.51	71.22	120.08	72.50	124.42	73.52	133.08	74.82
SEd	5.444	2.982	4.854	3.121	5.805	2.975	5.14	3.218	4.48	2.893	5.16	2.742	4.91	2.771
CD (P=0.05)	11.541	6.321	10.289	6.616	12.306	6.307	10.90	6.821	9.49	6.132	10.94	5.813	10.41	5.873
VXD														
SEd	6.877	1.953	2.974	1.827	5.471	1.714	5.06	2.413	5.19	1.621	6.02	2.384	4.75	2.660
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	11.63	NS
V at F														
SEd	7.947	3.710	5.986	4.281	7.739	3.643	6.93	4.082	6.34	3.531	7.32	3.586	6.59	3.711
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
F at V														
SEd	7.699	4.217	6.864	4.022	8.210	4.207	7.27	3.966	6.33	4.091	7.29	3.441	6.94	3.918
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
D at F														
SEd	7.947	3.710	5.986	4.281	7.739	3.643	6.93	4.082	6.34	3.531	7.32	3.586	6.59	3.711
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
F at D														
SEd	7.699	4.217	4.864	4.022	8.210	4.207	7.27	3.966	6.33	4.091	7.29	3.441	6.94	3.918
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

I crop: 1999 NEM

II crop: 2000 NEM

NS = Not significant

#### 4.1.8 Post harvest soil available NPK status

The mean data on soil available N, P and K recorded at post harvest stage are presented in Table 42.

The perusal of data revealed that varieties, times of sowing and nutrient levels did not differ significantly for available soil N, P and K at post harvest stage in both the crops (1999-2000 and 2000-2001).

The treatment interactions were also not significant.

#### 4.1.9 Economic analysis (not statistically analysed)

The B: C ratio computed for various treatments are presented in Tables 43 and 44 and also in Fig. 8.

Considering the B: C ratio, it was higher (2.68) when V<sub>1</sub> (CO 26) entry was sown at D<sub>1</sub> under F<sub>3</sub> nutrient level (60: 30: 0 kg of N: P<sub>2</sub>O<sub>5</sub>: K<sub>2</sub>O ha<sup>-1</sup>) and still higher performance was observed for V<sub>2</sub> entry (3.17) in the first crop. While in the second crop, it was D<sub>2</sub> sowing with a nutrient level of 40: 20: 0 kg of N: P<sub>2</sub>O<sub>5</sub>: K<sub>2</sub>O ha<sup>-1</sup> (F<sub>2</sub>) for the variety CO 26 (1.27) and it was D<sub>1</sub> sowing with 40: 20: 0 kg of N: P<sub>2</sub>O<sub>5</sub>: K<sub>2</sub>O ha<sup>-1</sup> (F<sub>2</sub>) for the variety CSV 15 (1.43), which had recorded higher B: C ratio.

### 4.2 Part II Evaluation of DSSAT V.3.5 CERES-Sorghum model

#### 4.2.1 Computation of genetic coefficients for varieties

The Genetic coefficient calculator programme (Gencalc programme) of the CERES-Sorghum model embedded in DSSAT V.3.5 was used to calculate the genetic coefficients for the varieties evaluated (CO 26 and CSV 15). The data obtained from the plots (Table 45) specific to this purpose were used for creating an experimental file (SGX file), average file (SGA file) and time file (SGT file). The soil, weather and management conditions used in the model were same as that of the conditions that prevailed during the field experimentation. By using the above said files, the Gencalc programme was run and the genetic coefficients for CO 26 and CSV 15 were obtained (Table 46).

Table 42. Effect of varieties, times of sowing and nutrient levels on post harvest available soil NPK ( $\text{kg ha}^{-1}$ ) status

Treatments	I crop			II crop		
	N	P	K	N	P	K
V <sub>1</sub>	112.0	11.5	358.0	120.0	11.3	384.0
V <sub>2</sub>	107.0	11.0	353.0	117.0	10.8	380.0
SEd	<b>2.90</b>	<b>0.87</b>	<b>6.54</b>	<b>3.47</b>	<b>0.56</b>	<b>6.23</b>
CD (P=0.05)	NS	NS	NS	NS	NS	NS
D <sub>1</sub>	106.0	10.8	352.0	118.0	11.2	381.0
D <sub>2</sub>	109.0	11.4	354.0	120.0	11.3	385.0
SEd	<b>2.90</b>	<b>0.87</b>	<b>6.54</b>	<b>3.47</b>	<b>0.56</b>	<b>6.23</b>
CD (P=0.05)	NS	NS	NS	NS	NS	NS
F <sub>1</sub>	110.0	11.6	361.0	122.0	11.4	389.0
F <sub>2</sub>	108.0	11.5	352.0	116.0	11.0	376.0
F <sub>3</sub>	105.0	10.8	348.0	119.0	11.3	380.0
SEd	<b>7.47</b>	<b>1.04</b>	<b>9.43</b>	<b>3.41</b>	<b>0.45</b>	<b>9.74</b>
CD (P=0.05)	NS	NS	NS	NS	NS	NS
V x D						
SEd	<b>4.11</b>	<b>1.23</b>	<b>9.25</b>	<b>4.90</b>	<b>0.80</b>	<b>8.81</b>
CD (P=0.05)	NS	NS	NS	NS	NS	NS
V at F						
SEd	<b>9.10</b>	<b>1.48</b>	<b>12.70</b>	<b>5.25</b>	<b>0.68</b>	<b>12.84</b>
CD (P=0.05)	NS	NS	NS	NS	NS	NS
F at V						
SEd	<b>10.56</b>	<b>1.47</b>	<b>13.33</b>	<b>4.83</b>	<b>0.47</b>	<b>13.78</b>
CD (P=0.05)	NS	NS	NS	NS	NS	NS
D at F						
SEd	<b>9.10</b>	<b>1.48</b>	<b>12.70</b>	<b>5.25</b>	<b>0.68</b>	<b>12.84</b>
CD (P=0.05)	NS	NS	NS	NS	NS	NS
F at D						
SEd	<b>10.56</b>	<b>1.47</b>	<b>13.33</b>	<b>4.83</b>	<b>0.47</b>	<b>13.78</b>
CD (P=0.05)	NS	NS	NS	NS	NS	NS

I crop: 1999 NEM

II crop: 2000 NEM

NS = Not significant

Table 43. Economics of sorghum cultivation under dryland conditions during 1999-2000  
(not statistically analysed)

Particulars	Nutrient level	V <sub>1</sub>		V <sub>2</sub>	
		D <sub>1</sub>	D <sub>2</sub>	D <sub>1</sub>	D <sub>2</sub>
Total cost of cultivation (Rs ha <sup>-1</sup> )	F <sub>1</sub>	7218	7218	7218	7218
	F <sub>2</sub>	7999	7999	7999	7999
	F <sub>3</sub>	8389	8389	8389	8389
Gross income (Rs ha <sup>-1</sup> )	F <sub>1</sub>	13553	9503	20138	18274
	F <sub>2</sub>	18028	11922	23456	24077
	F <sub>3</sub>	22468	16224	26593	25741
Net income (Rs ha <sup>-1</sup> )	F <sub>1</sub>	6335	2285	12920	11056
	F <sub>2</sub>	10029	3924	15458	16079
	F <sub>3</sub>	14079	7835	18204	17352
B: C Ratio	F <sub>1</sub>	1.88	1.32	2.79	2.53
	F <sub>2</sub>	2.25	1.49	2.93	3.01
	F <sub>3</sub>	2.68	1.93	3.17	3.07

Cost of sorghum grain : Rs. 6.00 kg<sup>-1</sup>

Cost of sorghum straw : Rs. 500 t<sup>-1</sup>

Cost of urea : Rs. 4.60 kg<sup>-1</sup>

Cost of single super phosphate : Rs. 3.05 kg<sup>-1</sup>

Table 44. Economics of sorghum cultivation under dryland conditions during 2000-2001  
(not statistically analysed)

Particulars	Nutrient level	V <sub>1</sub>		V <sub>2</sub>	
		D <sub>1</sub>	D <sub>2</sub>	D <sub>1</sub>	D <sub>2</sub>
Total cost of cultivation (Rs ha <sup>-1</sup> )	F <sub>1</sub>	5171	5171	5171	5171
	F <sub>2</sub>	5952	5952	5952	5952
	F <sub>3</sub>	6342	6342	6342	6342
Gross income (Rs ha <sup>-1</sup> )	F <sub>1</sub>	5255	5508	5876	5373
	F <sub>2</sub>	6999	7570	8497	7768
	F <sub>3</sub>	6760	6727	8310	7303
Net income (Rs ha <sup>-1</sup> )	F <sub>1</sub>	84	337	705	202
	F <sub>2</sub>	1048	1619	2545	1816
	F <sub>3</sub>	419	385	1968	961
B: C Ratio	F <sub>1</sub>	1.02	1.07	1.14	1.04
	F <sub>2</sub>	1.18	1.27	1.43	1.31
	F <sub>3</sub>	1.07	1.06	1.31	1.15

Cost of sorghum grain : Rs. 6.00 kg<sup>-1</sup>  
 Cost of sorghum straw : Rs. 500 t<sup>-1</sup>  
 Cost of urea : Rs. 4.60 kg<sup>-1</sup>  
 Cost of single super phosphate : Rs. 3.05 kg<sup>-1</sup>

Table 45. Minimum Data Set (MDS) for genetic coefficient calculation of sorghum varieties (CSV 15 and CO 26)

Particulars	CSV 15	CO 26
HWAM	5753	4028
HWUM	0.026	0.026
H#AM	40065	30915
H#UM	2671	2061
LAIX	4.93	5.51
CWAM	21365	19550
BWAH	15487	15570
ADAT	99344	99345
MDAT	00018	00018

Where,

- HWAM : Yield at maturity ( $\text{kg ha}^{-1}$ )  
 HWUM : Single grain weight at maturity (g)  
 H#AM : Number of grains  $\text{m}^{-2}$   
 H#UM : Number of grains earhead $^{-1}$   
 LAIX : Leaf area index (maximum)  
 CWAM : Tops weight at maturity ( $\text{kg ha}^{-1}$ )  
 BWAH : Byproduct harvest (straw yield) in  $\text{kg ha}^{-1}$   
 ADAT : Anthesis date  
 MDAT : Physiological maturity date

Table 46. Genetic coefficients for CSV 15 and CO 26

Coefficient	CSV 15	CO 26
VAR #	TN 001	TN 002
VAR-NAME	CSV 15	CO 26
ECO #	IB 001	IB 001
P <sub>1</sub>	410.00	410.00
P <sub>2</sub> O	15.60	14.60
P <sub>2</sub> R	45.00	45.00
P <sub>5</sub>	550.00	550.00
G <sub>1</sub>	10.00	10.00
G <sub>2</sub>	20.00	12.36
PHINT	49.00	49.00

VAR# : Identification code or number for a specific cultivar.

VAR-NAME : Name of cultivar.

ECO# : Ecotype code for this cultivar, points to the Ecotype in the ECO file (currently not used).

P<sub>1</sub> : Thermal time from seedling emergence to the end of the juvenile phase (expressed in degree days above a base temperature of 8°C) during which the plant is not responsive to changes in photo period.

P<sub>2</sub>O : Critical photo period or the longest day length (in hours) at which development occurs at a maximum rate. At values higher than P<sub>2</sub>O, the rate of development is reduced.

P<sub>2</sub>R : Extent to which phasic development leading to panicle initiation (expressed in degree days) is delayed for each hour increase in photo period above P<sub>2</sub>O.

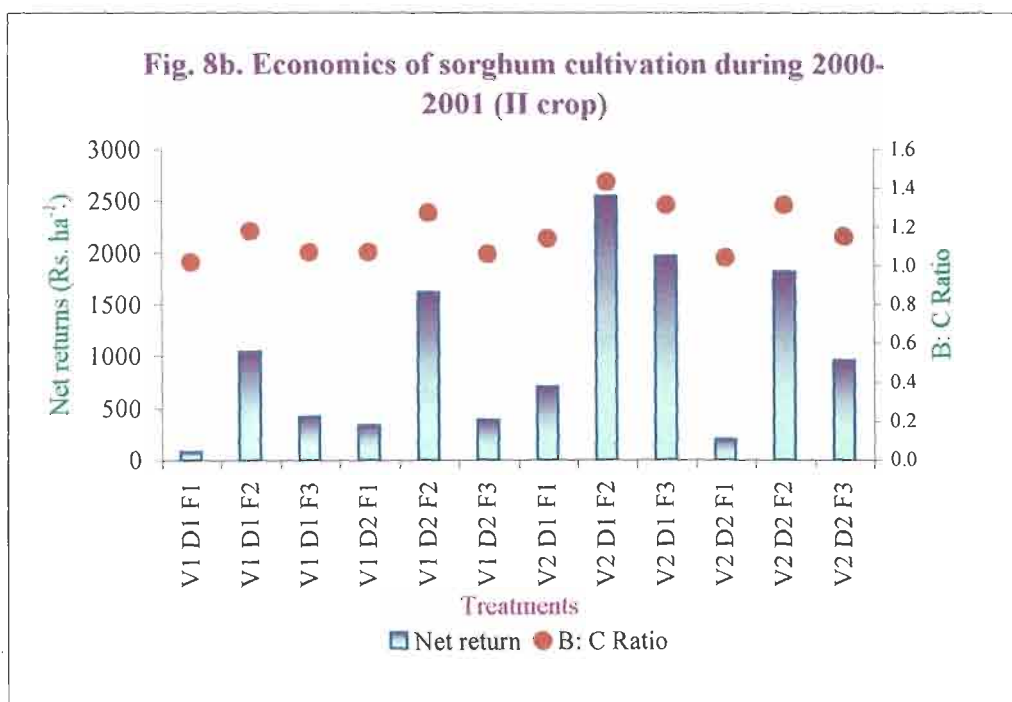
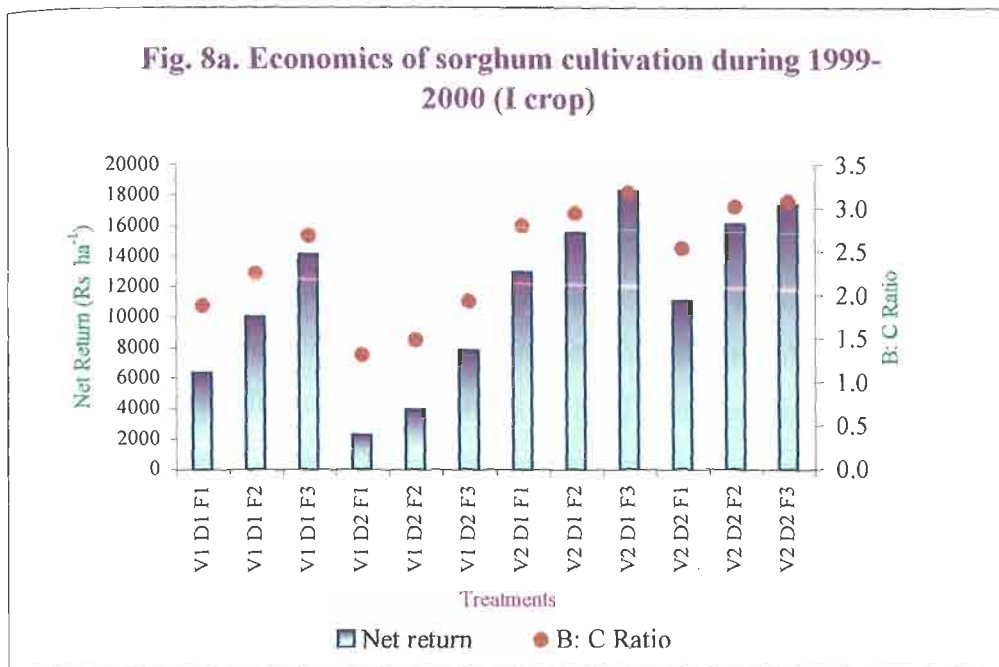
P<sub>5</sub> : Thermal time (degree days above a base temperature of 8°C) from beginning of grain filling (3-4 days after flowering) to physiological maturity.

G<sub>1</sub> : Scaler for relative leaf size.

G<sub>2</sub> : Scaler for partitioning of assimilates to the panicle (head).

PHINT : Phylochron interval; the interval in thermal time (degree days) between successive leaf tip appearances.

**Fig. 8. Economics of sorghum cultivation**



#### **4.2.2 Creation of experiment file, average file and time file in DSSAT V.3.5 CERES-Sorghum model**

The data obtained from the field experiments conducted during 1999-2000 and 2000-2001 were used for creating corresponding experimental file (TNCB9901.SGX and TNCB 0001.SGX), average file (TNCB 9901. SGA and TNCB 0001.SGA) and time file (TNCB 9901. SGT and TNCB0001.SGT) in order to evaluate CERES-Sorghum model. While creating the experimental file, the same soil, weather and management conditions were used as that of the conditions prevailed in the field during the period of experimentation. By using all these input files, the model was run and simulated values on grain yield, biomass yield at harvest, date of occurrence of phenological events like panicle initiation, anthesis and physiological maturity and yield components like number of grains earhead<sup>-1</sup> and individual kernel (seed) weight of sorghum were generated. These simulated values were compared with the corresponding actual observed values in the field during 1999-2000 and 2000-2001 for evaluation purpose. The Root Mean Square Error (RMSE) between simulated and observed values was worked out for various treatment combinations. The percentage of RMSE with the observed values was also worked out. The results are detailed here under.

##### **4.2.2.1 Simulated Vs Observed date of panicle initiation**

The data on time of panicle initiation (both observed and simulated) are presented in Table 47.

The results indicated that CERES-Sorghum model predicted the date of panicle initiation closely to that of the observed values during 1999-2000 and the RMSE was 3.2 and the percentage of RMSE with observed values was around 10 per cent for all the treatment combinations.

For 2000-2001 the RMSE was 5.7 and the percentage of RMSE with observed values was about 19 per cent for all the treatments irrespective of varieties, dates of sowing and nutrient levels.

Table 47. Observed and CERES-Sorghum model predicted Panicle Initiation (PI) date for sorghum cultivars under different times of sowing and nutrient levels

Treatments	I crop (1999 NEM)			II crop (2000 NEM)		
	Predicted PI date (DAS)	Observed PI date (DAS)	% of RMSE with observed values	Predicted PI date (DAS)	Observed PI date (DAS)	% of RMSE with observed values
V <sub>1</sub> D <sub>1</sub> F <sub>1</sub>	33	33	9.6	37	32	17.8
V <sub>1</sub> D <sub>1</sub> F <sub>2</sub>	33	32	9.9	37	32	17.8
V <sub>1</sub> D <sub>1</sub> F <sub>3</sub>	33	32	9.9	37	31	18.4
V <sub>1</sub> D <sub>2</sub> F <sub>1</sub>	34	32	9.9	37	32	17.8
V <sub>1</sub> D <sub>2</sub> F <sub>2</sub>	34	31	10.2	37	31	18.4
V <sub>1</sub> D <sub>2</sub> F <sub>3</sub>	34	31	10.2	37	31	18.4
V <sub>2</sub> D <sub>1</sub> F <sub>1</sub>	33	32	9.9	37	31	18.4
V <sub>2</sub> D <sub>1</sub> F <sub>2</sub>	33	30	10.5	37	29	19.6
V <sub>2</sub> D <sub>1</sub> F <sub>3</sub>	33	29	10.9	37	29	19.6
V <sub>2</sub> D <sub>2</sub> F <sub>1</sub>	34	31	10.2	33	30	19.0
V <sub>2</sub> D <sub>2</sub> F <sub>2</sub>	34	29	10.9	33	29	19.6
V <sub>2</sub> D <sub>2</sub> F <sub>3</sub>	34	28	11.3	33	29	19.6
<b>Mean</b>	<b>34</b>	<b>31</b>	<b>10.3</b>	<b>36</b>	<b>31</b>	<b>18.8</b>
<b>RMSE*</b>	<b>3.2</b>	-	-	<b>5.7</b>	-	-

$$*\text{Root mean Square Error} = \sqrt{\frac{1}{t} \sum (f_i - o_i)^2}$$

Where,

t = sample size

f<sub>i</sub> = predicted values

o<sub>i</sub> = observed values

#### **4.2.2.2 Simulated Vs observed date of anthesis**

The date of anthesis (simulated Vs observed values) for 1999-2000 and 2000-2001 are presented in Table 48.

During 1999-2000, the model predicted the date of anthesis very closer to that of observed one and the RMSE was 5.0 and the percentage of RMSE with observed values were with in the range of 10 per cent for all the treatments.

During 2000-2001 also, the model prediction was closer to the observed values and the RMSE was 4.3 and the percentage of RMSE with observed values were with in the range of 10 per cent.

#### **4.2.2.3 Simulated Vs observed date of physiological maturity**

The data on simulated and observed dates of physiological maturity are presented in Table 49.

During 1999-2000, the model predicted the date of physiological maturity reasonably well for all the treatments and the RMSE was 5.8 and the percentage of RMSE with the observed values were with in the range of 10 per cent.

The predicted and observed values on the date of physiological maturity during 2000-2001 was also nearer to each other and the RMSE was 9.6 and the percentage of RMSE with the observed values were in the range of 10 per cent.

#### **4.2.2.4 Simulated Vs observed biomass yield at harvest**

The data on predicted and observed biomass yield at harvest are presented in Table 50.

The data presented in Table 50 revealed that during 1999-2000 (first crop), and 2000-2001 (second crop), the model under estimated the total biomass production and the difference between the observed and simulated values were quite high which in turn reflected on the RMSE and this was 4606 for 1999-2000 and 2131 for 2000-2001, respectively. During 1999-2000, the percentage of RMSE with the observed value was ranged from 31.9 to 55.4 with a mean value of 44.5 for all the treatments, while in 2000-2001, it ranged from 29.1 to 46.9 with a mean value of 35.3.

Table 48. Observed and CERES-Sorghum model predicted anthesis date for sorghum cultivars under different times of sowing and nutrient levels

Treatments	I crop (1999 NEM)			II crop (2000 NEM)		
	Predicted anthesis date (DAS)	Observed anthesis date (DAS)	% of RMSE with observed values	Predicted anthesis date (DAS)	Observed anthesis date (DAS)	% of RMSE with observed values
V <sub>1</sub> D <sub>1</sub> F <sub>1</sub>	70	80	6.2	72	75	5.8
V <sub>1</sub> D <sub>1</sub> F <sub>2</sub>	70	77	6.5	72	73	5.9
V <sub>1</sub> D <sub>1</sub> F <sub>3</sub>	70	76	6.5	72	73	5.9
V <sub>1</sub> D <sub>2</sub> F <sub>1</sub>	71	78	6.4	68	75	5.8
V <sub>1</sub> D <sub>2</sub> F <sub>2</sub>	71	75	6.6	68	73	5.9
V <sub>1</sub> D <sub>2</sub> F <sub>3</sub>	71	75	6.6	68	72	6.0
V <sub>2</sub> D <sub>1</sub> F <sub>1</sub>	70	75	6.6	72	69	6.3
V <sub>2</sub> D <sub>1</sub> F <sub>2</sub>	70	72	6.9	72	68	6.4
V <sub>2</sub> D <sub>1</sub> F <sub>3</sub>	70	71	7.0	72	67	6.5
V <sub>2</sub> D <sub>2</sub> F <sub>1</sub>	71	72	6.9	68	73	5.9
V <sub>2</sub> D <sub>2</sub> F <sub>2</sub>	71	71	7	68	73	5.9
V <sub>2</sub> D <sub>2</sub> F <sub>3</sub>	71	71	7	68	73	5.9
Mean	71	74	6.7	70	72	6.0
RMSE	5.0	-	-	4.3	-	-

Table 49. Observed and CERES-Sorghum model predicted Physiological Maturity (PM) date for sorghum cultivars under different times of sowing and nutrient levels

Treatments	I crop (1999 NEM)			II crop (2000 NEM)		
	Predicted PM date (DAS)	Observed PM date (DAS)	% of RMSE with observed values	Predicted PM date (DAS)	Observed PM date (DAS)	% of RMSE with observed values
V <sub>1</sub> D <sub>1</sub> F <sub>1</sub>	108	115	5.0	109	122	7.9
V <sub>1</sub> D <sub>1</sub> F <sub>2</sub>	108	115	5.0	109	122	7.9
V <sub>1</sub> D <sub>1</sub> F <sub>3</sub>	108	115	5.0	109	122	7.9
V <sub>1</sub> D <sub>2</sub> F <sub>1</sub>	109	116	5.0	105	112	8.6
V <sub>1</sub> D <sub>2</sub> F <sub>2</sub>	109	116	5.0	105	112	8.6
V <sub>1</sub> D <sub>2</sub> F <sub>3</sub>	109	116	5.0	105	112	8.6
V <sub>2</sub> D <sub>1</sub> F <sub>1</sub>	111	115	5.0	112	122	7.9
V <sub>2</sub> D <sub>1</sub> F <sub>2</sub>	107	115	5.0	112	122	7.9
V <sub>2</sub> D <sub>1</sub> F <sub>3</sub>	111	115	5.0	112	122	7.9
V <sub>2</sub> D <sub>2</sub> F <sub>1</sub>	112	110	5.3	108	115	8.3
V <sub>2</sub> D <sub>2</sub> F <sub>2</sub>	112	110	5.3	108	115	8.3
V <sub>2</sub> D <sub>2</sub> F <sub>3</sub>	112	110	5.3	108	115	8.3
<b>Mean</b>	<b>110</b>	<b>114</b>	<b>5.1</b>	<b>109</b>	<b>118</b>	<b>8.2</b>
<b>RMSE</b>	<b>5.8</b>	-	-	9.6	-	-

Table 50. Observed and CERES-Sorghum model predicted biomass yield ( $\text{kg ha}^{-1}$ ) of sorghum cultivars under different times of sowing and nutrient levels

Treatments	I crop (1999 NEM)			II crop (2000 NEM)		
	Predicted biomass yield ( $\text{kg ha}^{-1}$ )	Observed biomass yield ( $\text{kg ha}^{-1}$ )	% of RMSE with observed values	Predicted biomass yield ( $\text{kg ha}^{-1}$ )	Observed biomass yield ( $\text{kg ha}^{-1}$ )	% of RMSE with observed values
V <sub>1</sub> D <sub>1</sub> F <sub>1</sub>	2511	8536	54.0	2385	5055	42.2
V <sub>1</sub> D <sub>1</sub> F <sub>2</sub>	7464	10864	42.4	4306	6782	31.4
V <sub>1</sub> D <sub>1</sub> F <sub>3</sub>	9072	14448	31.9	4320	6504	32.8
V <sub>1</sub> D <sub>2</sub> F <sub>1</sub>	2403	7401	62.2	2616	4546	46.9
V <sub>1</sub> D <sub>2</sub> F <sub>2</sub>	6678	8321	55.4	4909	6520	32.7
V <sub>1</sub> D <sub>2</sub> F <sub>3</sub>	7951	10987	41.6	4949	6384	33.4
V <sub>2</sub> D <sub>1</sub> F <sub>1</sub>	2971	9687	47.5	2576	5497	38.8
V <sub>2</sub> D <sub>1</sub> F <sub>2</sub>	8641	11989	38.4	4719	7321	29.1
V <sub>2</sub> D <sub>1</sub> F <sub>3</sub>	9852	13789	33.4	4804	7126	29.9
V <sub>2</sub> D <sub>2</sub> F <sub>1</sub>	2847	8839	52.1	2804	5098	41.8
V <sub>2</sub> D <sub>2</sub> F <sub>2</sub>	7802	11885	38.8	5587	6740	31.6
V <sub>2</sub> D <sub>2</sub> F <sub>3</sub>	8812	12875	35.8	5689	6586	32.4
<b>Mean</b>	<b>6417</b>	<b>10802</b>	<b>44.5</b>	<b>4139</b>	<b>6180</b>	<b>35.3</b>
<b>RMSE</b>	<b>4606</b>	-	-	<b>2131</b>	-	-

#### **4.2.2.5 Simulated Vs observed number of grains per earhead**

The data on number of grains earhead<sup>-1</sup> (both simulated and observed) are presented in Table 51.

During 1999-2000, except F<sub>1</sub> in all other treatments, the predicted value was very close to the observed one irrespective of varieties and dates of sowing. The RMSE was 351.4 and in general the percentage of RMSE with the observed values ranged from 28.1 to 50.9 per cent with a mean value of 35.9 per cent for all the treatments.

During 2000-2001, the difference between the predicted and observed values was higher and the RMSE was 170.6 and the percentage of RMSE with observed value was ranged from 36.3 to 66.9 per cent with a mean value of 51.4 per cent for all treatment combinations.

#### **4.2.2.6 Simulated Vs observed single grain weight of sorghum**

The data on predicted and observed kernel weight of sorghum are presented in Table 52.

In general, there were deviations between the observed and predicted single grain weight during both the years and the RMSE was 0.0087 for 1999-2000 and 0.0054 for 2000-2001, respectively. The percentage of RMSE with the observed values for all the treatments was around 33 per cent for 1999-2000 and 23 per cent for 2000-2001, respectively.

#### **4.2.2.7 Simulated Vs Observed sorghum grain yield**

The data on observed and simulated grain yield of dryland sorghum are presented in Table 53.

The perusal of results revealed that during 1999-2000, the model prediction (simulated yield) was very closer to the actual observed yield in the field for the treatments involving the nutrient levels of F<sub>2</sub> and F<sub>3</sub> irrespective of varieties and dates of sowing where as in case of treatments involving F<sub>1</sub>, the difference between the simulated and actual observed values were comparatively higher due to under

Table 51. Observed and CERES-Sorghum model predicted grains per earhead of sorghum cultivars under different times of sowing and nutrient levels.

Treatments	I crop (1999 NEM)			II crop (2000 NEM)		
	Predicted grain numbers earhead <sup>-1</sup>	Observed grain numbers earhead <sup>-1</sup>	% of RMSE with observed values	Predicted grain numbers earhead <sup>-1</sup>	Observed grain numbers earhead <sup>-1</sup>	% of RMSE with observed values
V <sub>1</sub> D <sub>1</sub> F <sub>1</sub>	325	815	43.1	245	255	66.9
V <sub>1</sub> D <sub>1</sub> F <sub>2</sub>	986	1102	31.9	527	368	46.4
V <sub>1</sub> D <sub>1</sub> F <sub>3</sub>	1264	1186	29.6	530	351	48.6
V <sub>1</sub> D <sub>2</sub> F <sub>1</sub>	320	689	50.9	275	225	75.8
V <sub>1</sub> D <sub>2</sub> F <sub>2</sub>	888	767	45.8	514	298	57.2
V <sub>1</sub> D <sub>2</sub> F <sub>3</sub>	1153	878	40.0	522	329	51.8
V <sub>2</sub> D <sub>1</sub> F <sub>1</sub>	346	1068	32.9	322	352	48.5
V <sub>2</sub> D <sub>1</sub> F <sub>2</sub>	1127	1190	29.5	611	470	36.3
V <sub>2</sub> D <sub>1</sub> F <sub>3</sub>	1264	1250	28.1	628	420	40.6
V <sub>2</sub> D <sub>2</sub> F <sub>1</sub>	323	1008	34.8	338	290	58.8
V <sub>2</sub> D <sub>2</sub> F <sub>2</sub>	1017	1053	33.3	652	415	41.1
V <sub>2</sub> D <sub>2</sub> F <sub>3</sub>	1153	1150	30.5	673	385	44.3
<b>Mean</b>	<b>847</b>	<b>1013</b>	<b>35.9</b>	<b>486</b>	<b>347</b>	<b>51.4</b>
<b>RMSE</b>	<b>351.4</b>	<b>-</b>	<b>-</b>	<b>170.6</b>	<b>-</b>	<b>-</b>

Table 52. Observed and CERES-Sorghum model predicted single grain weight (g) of sorghum cultivars under different times of sowing and nutrient levels.

Treatments	I crop (1999 NEM)			II crop (2000 NEM)		
	Predicted single grain weight (g)	Observed single grain weight (g)	% of RMSE with observed values	Predicted single grain weight (g)	Observed single grain weight (g)	% of RMSE with observed values
V <sub>1</sub> D <sub>1</sub> F <sub>1</sub>	0.015	0.027	32.22	0.015	0.023	23.5
V <sub>1</sub> D <sub>1</sub> F <sub>2</sub>	0.015	0.026	33.46	0.028	0.023	23.5
V <sub>1</sub> D <sub>1</sub> F <sub>3</sub>	0.017	0.027	32.2	0.028	0.024	22.5
V <sub>1</sub> D <sub>2</sub> F <sub>1</sub>	0.015	0.027	32.2	0.015	0.024	22.5
V <sub>1</sub> D <sub>2</sub> F <sub>2</sub>	0.015	0.026	33.5	0.028	0.023	23.5
V <sub>1</sub> D <sub>2</sub> F <sub>3</sub>	0.016	0.025	34.8	0.028	0.022	24.5
V <sub>2</sub> D <sub>1</sub> F <sub>1</sub>	0.023	0.025	34.8	0.018	0.022	24.5
V <sub>2</sub> D <sub>1</sub> F <sub>2</sub>	0.020	0.025	34.8	0.028	0.023	23.5
V <sub>2</sub> D <sub>1</sub> F <sub>3</sub>	0.021	0.027	32.2	0.028	0.024	22.5
V <sub>2</sub> D <sub>2</sub> F <sub>1</sub>	0.023	0.025	34.8	0.020	0.023	23.5
V <sub>2</sub> D <sub>2</sub> F <sub>2</sub>	0.020	0.027	32.2	0.028	0.024	22.5
V <sub>2</sub> D <sub>2</sub> F <sub>3</sub>	0.020	0.027	32.2	0.028	0.024	22.5
<b>Mean</b>	<b>0.018</b>	<b>0.026</b>	<b>33.3</b>	<b>0.024</b>	<b>0.023</b>	<b>23.3</b>
<b>RMSE</b>	<b>0.0087</b>	-	-	<b>0.0054</b>	-	-

Table 53. Observed and CERES-Sorghum model predicted grain yield ( $\text{kg ha}^{-1}$ ) of sorghum cultivars under different times of sowing and nutrient levels.

Treatments	I crop (1999 NEM)			II crop (2000 NEM)		
	Predicted grain yield ( $\text{kg ha}^{-1}$ )	Observed grain yield ( $\text{kg ha}^{-1}$ )	% of RMSE with observed values	Predicted grain yield ( $\text{kg ha}^{-1}$ )	Observed grain yield ( $\text{kg ha}^{-1}$ )	% of RMSE with observed values
V <sub>1</sub> D <sub>1</sub> F <sub>1</sub>	683	1662	39.0	514	493	253.8
V <sub>1</sub> D <sub>1</sub> F <sub>2</sub>	2071	2333	27.8	2066	737	169.7
V <sub>1</sub> D <sub>1</sub> F <sub>3</sub>	3020	2817	23.0	2076	699	179.0
V <sub>1</sub> D <sub>2</sub> F <sub>1</sub>	672	1116	58.1	577	451	277.4
V <sub>1</sub> D <sub>2</sub> F <sub>2</sub>	1864	1417	45.8	2014	699	179.0
V <sub>1</sub> D <sub>2</sub> F <sub>3</sub>	2529	2114	30.7	2046	603	207.5
V <sub>2</sub> D <sub>1</sub> F <sub>1</sub>	1092	2490	26.0	832	559	223.8
V <sub>2</sub> D <sub>1</sub> F <sub>2</sub>	3072	3169	20.5	2397	903	138.5
V <sub>2</sub> D <sub>1</sub> F <sub>3</sub>	3644	3675	17.6	2463	879	142.3
V <sub>2</sub> D <sub>2</sub> F <sub>1</sub>	1059	2181	29.7	933	508	246.3
V <sub>2</sub> D <sub>2</sub> F <sub>2</sub>	2789	3090	21.0	2557	845	148.1
V <sub>2</sub> D <sub>2</sub> F <sub>3</sub>	3218	3524	18.4	2638	804	155.6
Mean	2143	2466	29.8	1759	682	193.5
RMSE	648.0	-	-	1251.0	-	-

prediction of yield by the model. The RMSE was 648.0 for 1999-2000 and the percentage of RMSE with observed values ranged from 17.6 for  $V_2D_1F_3$  to 58.1 for  $V_1D_2F_1$  with a mean value of 29.8 for all the treatments.

During 2000-2001, the difference between the simulated yield and observed yield was very high for all the treatments irrespective of varieties, dates of sowing and nutrient levels. The RMSE was 1251.0 and the percentage of RMSE with observed values was ranged from 138.5 to 277.4 per cent with a mean value of 193.5 per cent for all the treatment combinations.

#### 4.2.3 Sensitivity analysis

The sensitivity analysis option available in DSSAT V.3.5 CERES-Sorghum model allowed to evaluate alternate management strategies or to make tactical or strategic decisions by modifying the default values in the cultivar, weather, soil, initial conditions, planting, harvest, water and irrigation, nitrogen, residue, pest and diseases and field conditions.

For carrying out the sensitivity analysis, the experiment TNCB 9901.SGX and TNCB 0001.SGX were taken and changes were made with respect to date of sowing and nitrogen levels and the yields were simulated.

During 1999-2000 (first crop), four dates of sowing (26<sup>th</sup> September, 1<sup>st</sup> October, 6<sup>th</sup> October and 11<sup>th</sup> October) along with different N levels ranging from 0 kg ha<sup>-1</sup> to 500 kg ha<sup>-1</sup> were taken into account for both the varieties (CO 26 and CSV 15) to carry out sensitivity analysis and the simulated grain yields are presented in Tables 54 and 55. In the second crop (2000-2001) also, four different dates of sowing (19<sup>th</sup> September, 24<sup>th</sup> September, 29<sup>th</sup> September and 4<sup>th</sup> October) along with different N levels ranging from 0 kg ha<sup>-1</sup> to 500 kg ha<sup>-1</sup> were taken into account for both the varieties (CO 26 and CSV 15) to carry out sensitivity analysis and the simulated grain yields are presented in Tables 56 and 57.

The results on simulated grain yield indicated that sorghum varieties differed their response to N application under different times of sowing.

Table 54. Simulated grain yield of CSV 15 during 1999-2000 by sensitivity analysis

Nitrogen level (kg ha <sup>-1</sup> )	Simulated grain yield (kg ha <sup>-1</sup> )			
	D <sub>1</sub>	D <sub>2</sub>	D <sub>3</sub>	D <sub>4</sub>
0	1092	1059	1062	1097
20	2336	2147	1951	2022
40	3072	2789	2433	2490
60	3644	3218	2947	2918
80	4357	3591	3313	3284
100	4949	4144	4064	3399
120	5579	4526	4310	3466
140	5918	4628	4308	3451
160	6019	4696	4250	3415
180	6088	4752	4307	3406
200	6096	4799	4318	3404
220	6131	4836	4358	3406
240	6164	4878	4361	3408
260	6193	4911	4355	3411
280	6226	4938	4320	3421
300	6253	4963	4362	3422
350	6322	5015	4365	3426
400	6334	5030	4369	3422
450	6337	5043	4363	3433
500	6340	5045	4327	3434
Economic optimum level of N (kg ha <sup>-1</sup> )	180	160	120	120

Where,

D<sub>1</sub> = sowing on 26<sup>th</sup> September, 1999

D<sub>2</sub> = sowing on 1<sup>st</sup> October, 1999

D<sub>3</sub> = sowing on 6<sup>th</sup> October, 1999

D<sub>4</sub> = sowing on 11<sup>th</sup> October, 1999

Table 55. Simulated grain yield of CO 26 during 1999-2000 by sensitivity analysis

N level (kg ha <sup>-1</sup> )	Simulated grain yield (kg ha <sup>-1</sup> )			
	D <sub>1</sub>	D <sub>2</sub>	D <sub>3</sub>	D <sub>4</sub>
0	683	672	672	690
20	1443	1327	1206	1249
40	2071	1864	1864	1936
60	3020	2529	2465	2371
80	3739	3005	3021	2532
100	4431	3348	3262	2536
120	4665	3593	3365	2568
140	4786	3761	3355	2574
160	4829	3779	3318	2547
180	4856	3835	3378	2541
200	4845	3857	3388	2530
220	4871	3874	3419	2530
240	4849	3886	3422	2530
260	4922	3899	3416	2531
280	4951	3902	3390	2539
300	4977	3904	3422	2540
350	5006	3899	3424	2543
400	5006	3902	3427	2537
450	5008	3913	3421	2545
500	5009	3915	3396	2546
Economic optimum level of N (kg ha <sup>-1</sup> )	140	140	120	80

Where,

D<sub>1</sub> = sowing on 26<sup>th</sup> September, 1999

D<sub>2</sub> = sowing on 1<sup>st</sup> October, 1999

D<sub>3</sub> = sowing on 6<sup>th</sup> October, 1999

D<sub>4</sub> = sowing on 11<sup>th</sup> October, 1999

Table 56. Simulated grain yield of CSV 15 during 2000-2001 by sensitivity analysis

N level (kg ha <sup>-1</sup> )	Simulated grain yield (kg ha <sup>-1</sup> )			
	D <sub>1</sub>	D <sub>2</sub>	D <sub>3</sub>	D <sub>4</sub>
0	832	873	933	934
20	1986	2085	2224	1885
40	2397	2399	2557	2352
60	2463	2514	2638	2171
80	2484	2586	2663	2155
100	2499	2624	2697	2147
120	2498	2658	2704	2146
140	2498	2662	2708	2145
160	2497	2662	2726	2145
180	2497	2661	2746	2144
200	2497	2660	2746	2144
220	2497	2658	2746	2144
240	2496	2658	2746	2143
260	2496	2658	2745	2143
280	2496	2657	2745	2142
300	2496	2657	2745	2142
350	2496	2657	2745	2131
400	2496	2656	2744	2131
450	2495	2656	2744	2130
500	2495	2656	2741	2130
Economic optimum level of N (kg ha <sup>-1</sup> )	40	80	60	40

Where,

D<sub>1</sub> = sowing on 19<sup>th</sup> September, 2000

D<sub>2</sub> = sowing on 24<sup>th</sup> September, 2000

D<sub>3</sub> = sowing on 29<sup>th</sup> September, 2000

D<sub>4</sub> = sowing on 4<sup>th</sup> October, 2000

Table 57. Simulated grain yield of CO 26 during 2000-2001 by sensitivity analysis

N level (kg ha <sup>-1</sup> )	Simulated grain yield (kg ha <sup>-1</sup> )			
	D <sub>1</sub>	D <sub>2</sub>	D <sub>3</sub>	D <sub>4</sub>
0	514	540	577	577
20	1964	1849	1801	1471
40	2066	2074	2014	1741
60	2076	2114	2046	1515
80	2075	2118	2059	1498
100	2074	2116	2073	1490
120	2073	2115	2076	1490
140	2073	2114	2076	1489
160	2072	2114	2076	1489
180	2072	2113	2072	1488
200	2072	2113	2072	1488
220	2072	2112	2072	1488
240	2071	2112	2071	1488
260	2071	2111	2071	1487
280	2071	2111	2071	1487
300	2071	2111	2071	1487
350	2071	2110	2070	1476
400	2070	2110	2070	1475
450	2070	2110	2070	1475
500	2070	2110	2069	1475
Economic optimum level of N (kg ha <sup>-1</sup> )	40	40	40	40

Where,

D<sub>1</sub> = sowing on 19<sup>th</sup> September, 2000

D<sub>2</sub> = sowing on 24<sup>th</sup> September, 2000

D<sub>3</sub> = sowing on 29<sup>th</sup> September, 2000

D<sub>4</sub> = sowing on 4<sup>th</sup> October, 2000

In the case of CSV 15, the sorghum grain yield was increased with increased level of N application up to 500 kg N ha<sup>-1</sup> when sowing was done on 26<sup>th</sup> September and at 1<sup>st</sup> October during 1999-2000. Whereas in the same cropping season, the maximum grain yield was obtained under 400 kg N ha<sup>-1</sup> and 120 kg N ha<sup>-1</sup>, respectively for the sowing done on 6<sup>th</sup> October and 11<sup>th</sup> October. This indicated relatively lesser response to applied N for the late two sowings. The computed economic optimum level was 180 kg N ha<sup>-1</sup> for 26<sup>th</sup> September sowing and 160 kg N ha<sup>-1</sup> for 1<sup>st</sup> October sowing and 120 kg N ha<sup>-1</sup> for 6<sup>th</sup> October and 11<sup>th</sup> October sowing.

In the case of CO 26, the sorghum grain yield was increased with increased level of N application even up to 500 kg N ha<sup>-1</sup> when sowing was done on 26<sup>th</sup> September or at 1<sup>st</sup> October during 1999-2000. Whereas in the same cropping season, the maximum grain yield was obtained under 400 kg N ha<sup>-1</sup> and 140 kg N ha<sup>-1</sup>, respectively for the sowing done on 6<sup>th</sup> October and 11<sup>th</sup> October, respectively. The computed economic optimum level was 140 kg N ha<sup>-1</sup> for 26<sup>th</sup> September and 1<sup>st</sup> October sowing, 120 kg N ha<sup>-1</sup> for 6<sup>th</sup> October sowing and 80 kg N ha<sup>-1</sup> for 11<sup>th</sup> October sowing.

During 2000-2001, for the variety CSV 15, sown on 19<sup>th</sup> September, 24<sup>th</sup> September, 29<sup>th</sup> September and 4<sup>th</sup> October, the maximum grain yield was obtained when N was applied @ 100 kg ha<sup>-1</sup>, 140 kg ha<sup>-1</sup>, 180 kg ha<sup>-1</sup> and 40 kg ha<sup>-1</sup>, respectively. This further revealed that under low rainfall situation delayed sown crop required more N as compared to earlier sowing except the last sowing (D<sub>4</sub>). The economic optimum level was 40 kg N ha<sup>-1</sup> when sowing was done on 19<sup>th</sup> September or at 4<sup>th</sup> October and 80 kg ha<sup>-1</sup> for 24<sup>th</sup> September sowing and 60 kg N ha<sup>-1</sup> when sowing was done on 29<sup>th</sup> September.

Similarly in 2000-2001, for the variety CO 26, sown on 19<sup>th</sup> September, 24<sup>th</sup> September, 29<sup>th</sup> September and 4<sup>th</sup> October, the maximum grain yield was obtained when N was applied @ 60 kg ha<sup>-1</sup>, 80 kg ha<sup>-1</sup>, 120 kg ha<sup>-1</sup> and 40 kg ha<sup>-1</sup>, respectively. The economic optimum level of grain yield was obtained when N was applied @ 40 kg ha<sup>-1</sup>, irrespective of the sowing dates evaluated.

It can be concluded that in the present investigation, DSSAT V.3.5 CERES-Sorghum model predicted the phenology quite well in both the years. However, the

growth parameter (biomass yield) was not properly accounted by the model. Errors in yield parameters were also high in both the years. The predicted grain yield was very close to the actual observed yield under field condition during the first crop (good rainfall year) and during the second crop (deficit rainfall year), the model over predicted the yield. Thus the model can be used very well for yield prediction in good rainfall years but the model needed further modification with larger data sets for farm decision making by using the options available in DSSAT V.3.5 CERES-Sorghum model under deficit rainfall situation.

## **DISCUSSION**

---

---

## CHAPTER V

### DISCUSSION

The results of the field experiments conducted at Tamil Nadu Agricultural University Farm, Coimbatore during Northeast monsoon seasons of 1999 and 2000 to evaluate the performance of different sorghum (*Sorghum bicolor* (L) Moench.) varieties under different sowing times and levels of Nitrogen and Phosphorus and also to evaluate DSSAT V.3.5 CERES-Sorghum model for key management practices like choice of varieties, times of sowing and nutrient levels under dryland *Vertisols* are discussed in this chapter.

#### 5.1 Part I Main experiment

##### 5.1.1 Influence of weather prevailed during experimentation on the productivity of test crop sorghum (Table 58)

Weather elements play an important role in crop production under dryland condition. As per the World Meteorological Organisation (WMO), the productivity loss in annual crop production is around 40 per cent due to vagaries of weather in tropical countries.

Solar radiation is an important factor responsible for increased photosynthetic activity of a plant. The mean solar radiation prevailed during the vegetative (0-49 DAS), flowering (50-77 DAS) and maturity (78-Harvest) stages under D<sub>1</sub> sowing was 14.8, 15.1 and 15.1 MJ m<sup>-2</sup> day<sup>-1</sup> for the first crop (1999-2000) and 14.6, 14.6 and 17.5 MJ m<sup>-2</sup> day<sup>-1</sup> for the second crop (2000-2001). There was higher radiation at the maturity stage of second year as compared to first year. In respect of D<sub>2</sub> sowing it was 14.9, 16.1 and 16.3 MJ m<sup>-2</sup> day<sup>-1</sup> for the first crop in the respective stages and 14.7, 16.8 and 16.6 MJ m<sup>-2</sup> day<sup>-1</sup> for the second crop, respectively. As compared to first sowing (D<sub>1</sub>), the second sowing (D<sub>2</sub>) had higher solar radiation in general at reproductive and maturity stages of both the crops (1999-2000 and 2000-2001). Thus, solar radiation was not a constraint during the cropping period of both the crops, since the solar radiation was more than 12.6 MJ m<sup>-2</sup> day<sup>-1</sup> (equivalent of 300 cal cm<sup>-2</sup> day<sup>-1</sup>) through out the crop growth period.

Table 58. Weather parameters prevailed at different stages of crop growth during 1999-2000 (I crop) and 2000- 2001 (II crop)

Particulars		Maximum temperature (°C)	Minimum temperature (°C)	Mean solar radiation (MJ m <sup>-2</sup> day <sup>-1</sup> )	Total rainfall (mm)	Number of rainy days
1999-2000 (I crop)						
Vegetative stage	D <sub>1</sub>	30.4	21.4	14.8	367.6	21
	D <sub>2</sub>	29.7	21.0	14.9	331.0	17
Flowering stage	D <sub>1</sub>	29.7	20.9	15.1	41.6	3
	D <sub>2</sub>	28.1	19.7	16.1	45.6	4
Maturity stage	D <sub>1</sub>	29.1	20.5	15.1	18.4	3
	D <sub>2</sub>	28.7	19.0	16.3	14.4	2
2000-2001 (II crop)						
Vegetative stage	D <sub>1</sub>	30.6	21.4	14.6	207.7	11
	D <sub>2</sub>	30.6	21.2	14.7	47.6	6
Flowering stage	D <sub>1</sub>	29.0	19.8	14.6	63.5	5
	D <sub>2</sub>	28.7	18.2	16.8	62.9	5
Maturity stage	D <sub>1</sub>	29.2	18.5	17.5	12.8	2
	D <sub>2</sub>	29.4	19.2	16.6	12.8	2

The mean maximum and minimum temperatures prevailed during the vegetative, flowering and maturity stages under D<sub>1</sub> sowing were 30.4 and 21.4°C, 29.7 and 20.9°C and 29.1 and 20.5°C for the first crop (1999-2000) and 30.6 and 21.4°C, 29.0 and 19.8°C and 29.2 and 18.5°C for the second crop (2000-2001). There was decreased minimum temperature in the second crop especially under reproductive and maturity stages as compared to first crop. In respect of D<sub>2</sub> sowing, it was 29.7 and 21.0°C, 28.1 and 19.7°C and 28.7 and 19.0°C for the first crop and 30.6 and 21.2°C, 28.7 and 18.2°C and 29.4 and 19.2°C for the second crop, respectively. Quinby *et al.* (1958) considered that the minimum, maximum and optimum temperature levels for the entire sorghum crop growth period were 15, 38 and 27-30°C, respectively. In both the crops, the temperatures did not exceed these cardinal values and were highly favourable for crop growth through out the crop growth period.

The prevailed bright sunshine hours and relative humidity were also favourable to sorghum crop growth during the cropping season of both the years (1999-2000 and 2000-2001) as per the data furnished in Tables 1 and 2.

Rainfall received during the cropping period is of paramount importance under dryland condition because soil moisture is the only key source, which meets the evapotranspiration (ET) requirement of dryland crops (Suraj Bhan *et al.*, 1995).

During 1999-2000 (first crop), the rainfall received was 427.6 mm and distributed in 27 rainy days for D<sub>1</sub> sowing and 391 mm distributed in 23 rainy days for D<sub>2</sub> sowing. The distribution was 367.6 mm (21 rainy days), 41.6 mm (3 rainy days) and 18.4 mm (3 rainy days) for D<sub>1</sub> sowing and it was 331.0 mm (17 rainy days), 45.6 mm (4 rainy days) and 14.4 mm (2 rainy days) for D<sub>2</sub> sowing in respect of vegetative, flowering and maturity stages, respectively of first crop.

The 94 years average rainfall for the Northeast Monsoon (NEM) season is 324.8 mm. Hence, the rainfall received during the NEM season of 1999 under D<sub>1</sub> sowing (427.6 mm) and D<sub>2</sub> sowing (391.0 mm) were well above the average by 31.65 and 20.38 per cent, respectively and both could be classified under normal rainfall category as per India Meteorological Department (IMD) classification (Normal = mean  $\pm$  1 $\sigma$  *i.e.*, 182 to 466 mm).

In 2000-2001, a quantum of 284 mm (18 rainy days) and 123.3 mm (13 rainy days) of rainfall were recorded under D<sub>1</sub> and D<sub>2</sub> sowings, respectively and the rainfall received at vegetative, flowering and maturity stages were 207.7 mm (11 rainy days), 63.5 mm (5 rainy days) and 12.8 mm (2 rainy days) for D<sub>1</sub> sowing and 47.6 mm (6 rainy days), 62.9 mm (5 rainy days) and 12.8 mm (2 rainy days) under D<sub>2</sub> sowing.

By considering the 94 years average NEM season rainfall of 324.8 mm, the rainfall received during the NEM season of 2000 under D<sub>1</sub> sowing (284 mm) and under D<sub>2</sub> sowing (123.3 mm) were below the average by 12.56 and 62.04 per cent, respectively. However the rainfall received under D<sub>1</sub> sowing could be classified under normal rainfall category of IMD classification (182 mm to 466 mm), whereas, the rainfall received under D<sub>2</sub> sowing (123.3 mm) came under deficit rainfall category (< 182 mm).

With in the first crop of 1999, D<sub>1</sub> sowing (sowing before the onset of monsoon rainfall) received 9.36 per cent higher rainfall over D<sub>2</sub> sowing (sowing after the receipt of monsoon rainfall). Similarly during the second crop of 2000 also, D<sub>1</sub> sowing received 130.3 per cent higher rainfall than D<sub>2</sub> sowing. Similar to that of total cumulative rainfall, in both the years (1999-2000 and 2000-2001), D<sub>1</sub> sowing registered more effective rainfall (218.78 mm and 198.8 mm for 1999-2000 and 2000-2001, respectively) over D<sub>2</sub> sowing (173.1 mm and 96.46 mm for 1999-2000 and 2000-2001, respectively) irrespective of the quantum of rainfall received during the crop growth period.

Capturing the benefits of the initial monsoon rainfall through manipulation of sowing time (sowing before the onset of monsoon rain) would be of immense use in extending the moisture availability period for crop growth, especially under dryland condition. Balasubramanian *et al.* (1996) reported that the Length of Growing Period (LGP) was 97 days for *Vertisol* condition of Coimbatore. Hence, the D<sub>1</sub> sown crop had extended moisture availability period than D<sub>2</sub> sown crop and this provided a moisture risk free period for D<sub>1</sub> sowing than D<sub>2</sub> in both the years (1999-2000 and 2000-2001).

Between the first crop of 1999 and second crop of 2000, there were lot of differences in the quantum of rainfall received as well as its distribution. During the

first crop of 1999, the rainfall received by the crop was 427.6 mm in 27 rainy days under  $D_1$  sowing and 391 mm in 23 rainy days under  $D_2$  sowing. In both  $D_1$  and  $D_2$  sowings of the first crop (1999-2000), the rainfall was well distributed through out the entire crop growth period especially at vegetative and flowering stages, which kept the crop under moisture stress free condition. But in respect of 2000-2001 cropping period, the rainfall received by the crop was 284 mm in 18 rainy days and 123.3 mm in 13 rainy days under  $D_1$  and  $D_2$  sowings, respectively. When compared to the first crop, the rainfall distribution in the second crop was highly varying both in terms of quantity and distribution.

The better crop growth and higher yield recorded during first crop over the second crop could be directly ascribed to the adequate availability of rainfall. Except this variation in rainfall, other weather parameters (maximum temperature, minimum temperature, relative humidity, solar radiation and bright sunshine hours) were cardinal to sorghum crop in both the years as reported elsewhere in this chapter. Similarly, significant influence of distribution of rainfall in determining the dryland sorghum yield rather than total rainfall was earlier reported by Rao and Vijayalakshmi (1986). Estimation of soil moisture content (Tables 34a and 35a) at weekly interval during Northeast monsoon season (NEM) of 1999 had also revealed that adequate soil moisture was available for the first crop raised as compared to NEM season of 2000. This in turn might have resulted in higher grain and straw yields in the first crop. Backer and Norman (1975) reported that inadequate rainfall during the crop growth period might limit the crop production as a result of soil moisture deficit and this had happened in the second crop of the present investigation.

The fact also could be supported from the results of returning period worked out by using 94 years NEM season rainfall (Appendix VI). The results indicated that the chances for getting the average NEM rainfall of 324.8 mm was 4/9 (four years out of nine years). Similarly, to get the rainfall of NEM of 1999 and 2000 (427.6 and 284 mm) in future, the chance would be 4/ 18 and 1/2 (four years out of eighteen years and once in two years), respectively.

### 5.1.2 Soil water balance studies

Available soil moisture for crops requirement in dryland depends on the amount and distribution of rainfall, water retention characteristics of the soil and crop characteristics such as duration and rooting depth, *etc.*. Since the influence of rainfall was the over riding factor in determining the final crop yield than other factors, a knowledge on plant-soil-water relation and its effect on sorghum crop under dryland condition is very critical and this was done by employing daily water balance model of Gupta *et al.* (1972). The water budget simulation provided a variety of output variables, those related to the crop response to variable sowing dates and to different cultivars under dryland condition. The evaluation of variable water balance components during the cropping period provided a clear cut picture on how the duration of the crop was adopted to available soil moisture under drylands and also how the soil and crop management had influenced the components of the water balance.

#### 5.1.2.1 Cumulative rainfall

During 1999-2000 (above average rainfall year), the onset of the rainfall was on 39<sup>th</sup> (27-09-1999) Meteorological Standard Week (MSW) and its cessation was on 47<sup>th</sup> MSW (24-11-1999) with a duration of nine weeks. The treatments involving times of sowing received different quantities of cumulative rainfall during cropping period and the D<sub>1</sub> sowing captured 9 per cent higher cumulative rainfall than D<sub>2</sub> sowing (Table 30). During 2000-2001 (below average rainfall year), the onset of monsoon was on 38<sup>th</sup> MSW (23-09-2000) and its cessation was on 48<sup>th</sup> MSW (01-12-2000). The rainy season accounted for 11 weeks with the intermittent occurrence of dry spells. There was a wide variation between D<sub>1</sub> and D<sub>2</sub> sowings in terms of cumulative rainfall received during the crop growth period and D<sub>1</sub> sowing received 130.3 per cent higher cumulative rainfall over D<sub>2</sub> sowing (Table 32).

During both the years, D<sub>1</sub> sown crop effectively utilized the initial rains (36.6 mm and 160.7 mm) which offered good start to the sorghum crop as compared to D<sub>2</sub> sown crop. Similar findings were given by Somasundaram (2000) in maize, who reported that pre monsoon sowing (sowing at 37<sup>th</sup> and 38<sup>th</sup> MSW) effectively utilized

the initial rains (27.6 mm), which gave good start for the maize crop as compared to post monsoon sowing (sowing at 39<sup>th</sup> MSW).

#### 5.1.2.2 Water requirement Vs water use (Tables 30, 31, 32 and 33)

In drylands, water requirement to satisfy the evapotranspiration (AET) of crops is of paramount importance.

Regarding varieties evaluated during 1999-2000 (above average rainfall year), the water requirement was same for V<sub>1</sub> and V<sub>2</sub> when sowing was done under D<sub>1</sub>. When sowing was delayed to D<sub>2</sub>, the water requirement was higher for CO 26 (V<sub>1</sub>) than CSV 15 (V<sub>2</sub>). This was due to the early maturity nature of CSV 15. During 2000-2001 (below average rainfall year), water requirement showed a decreasing trend as sowing date was delayed from D<sub>1</sub> to D<sub>2</sub> for both the varieties. This variation was due to the difference in duration between the varieties under varying rainfall condition of the second year study.

Regarding sowing date, irrespective of the varieties, D<sub>1</sub> sown crop required slightly higher amount of water (286.79 mm) than D<sub>2</sub> sown crop (284.79 mm) during 1999-2000, while it was still higher amount of water (345.72 mm) than D<sub>2</sub> sown crop (327.89 mm) during 2000-2001 and this variation between years was due to high evaporation (E<sub>p</sub>) demand that occurred in the second crop (2000-2001) than 1999-2000 cropping season as a result of intermittent longer dry spells.

The water used or the actual amount of water utilized for evapotranspiration had direct effect on Dry Matter Production (DMP) since the relation between crop ET and DMP was linear. Regarding water use, irrespective of sowing dates both the varieties were not satisfied fully.

During 1999-2000 (above average rainfall year), both the varieties had only 76.30 per cent of the total water requirement (218.94 mm out of 286.79 mm) under D<sub>1</sub> sowing and under D<sub>2</sub> sowing, the variety V<sub>1</sub> received only 70.18 per cent of the water requirement (207.7 mm out of 295.96 mm) and the variety V<sub>2</sub> received only 75.91 per cent of the water requirement (207.7 mm out of 273.61 mm). This was due to the soil moisture deficit that observed at later part of the maturity stage (Appendix V).

During 2000-2001 (below average rainfall year), irrespective of the varieties, D<sub>1</sub> sowing got only 59.86 per cent of the water requirement (206.95 mm out of 345.72 mm), while it was 59.91 per cent for D<sub>2</sub> sowing (196.46 mm out of 327.89 mm). This was due to the soil moisture deficit that occurred at flowering and maturity stages of the crop because of prolonged dry spell that prevailed during the cropping period.

From the above facts, it is clear that the quantum of water used by D<sub>1</sub> sown crop for evapotranspiration was higher than the water used by D<sub>2</sub> sown crop in both the years. This ultimately resulted in higher DMP in D<sub>1</sub> sown crop than D<sub>2</sub> sown crop since the relationship between crop ET and DMP was linear (Somasundaram, 2000).

Similarly, between the first and second crop, the first crop satisfied more than 70 per cent of the crop water requirement where as the second crop got satisfaction only up to 60 per cent of the crop water requirement irrespective of the varieties and times of sowing evaluated. This was the reason why the first crop performed better than the second crop.

### **5.1.2.3 Effective rainfall**

Effective rainfall is a portion of the rainfall available for the consumptive use of the crop. It included both the rain water used by the crop as ET and the previously stored soil moisture. When the rainfall of high intensity occurred in dry lands, only a part was stored in the soil in relation to field capacity, which was considered as effective, and the remaining water left as runoff.

Irrespective of sowing dates, both the varieties (CO 26 and CSV 15) recorded the same amount as effective rainfall in both the crops (1999-2000 and 2000-2001) as depicted in Tables 30 and 32. This was because harvesting was done in the same day for both the varieties in both the years, except in D<sub>2</sub> sowing of first year in which CSV 15 was harvested on 18-1-2000, while CO 26 was harvested on 24-1-2000. Since, there was no rainfall after the harvest of CSV 15 (18-1-2000), there was no variation in the quantum of effective rainfall received by both the varieties. As reported earlier soil type and previous soil moisture were responsible, whether the rain event was effective or not.

Irrespective of both the varieties, D<sub>1</sub> sown crop had recorded 26.39 and 106.1 per cent higher effective rainfall over D<sub>2</sub> sown crop during 1999-2000 and 2000-2001, respectively. This was due to the utilization of initial rains. This effect had been reflected on the grain yield obtained.

#### 5.1.2.4 Surplus water

The average water holding capacity of the soil in the experimental field was 100 mm/ m depth. The rainfall received after the soil profile saturation was considered as ineffective and accounted for surplus water. In the first year (1999-2000), around 50 per cent of rainfall was registered as surplus water irrespective of sowing dates (Table 30) and in the second year (2000-2001) (Table 32), around 25 per cent of rainfall had become surplus water irrespective of sowing dates. During 1999-2000, the trend for surplus water was in reverse to that of the effective rainfall. It was increased as sowing delayed. This was in conformity with the findings of Chowdhury and Das (1993). However, during 2000-2001, D<sub>1</sub> recorded higher water loss through runoff as compared to D<sub>2</sub> sowing and this might be due to the lower amount of rainfall received under D<sub>2</sub> sowing (only 43.42 per cent of the rainfall received by D<sub>1</sub> sowing) and the highest rainfall received in a single day hardly exceeded 24 mm (Appendix IV).

The present discussion indicated that considerable opportunity existed to shift the runoff water towards effective rainfall by adopting suitable *in situ* moisture conservation practices though not fully at least partly.

#### 5.1.2.5 Soil moisture dynamics

Available soil moisture changes monitored by both water balance method (simulated) and gravimetric method (measured) were in good agreement with each other but with few exceptions. (Tables 34, 34a, 35 and 35a).

Trend was similar in both the methods for both the years of study. In general, decreased moisture content was observed under D<sub>2</sub> sowing in both simulated and measured data except at early part of the vegetative stage. This was because D<sub>1</sub> crop was sown before the onset of monsoon rains, whereas D<sub>2</sub> crop was sown after the receipt of soaking rains during 1999-2000 and 2000-2001.

A wide variation was observed with quantity of moisture observed. Water balance model (Gupta *et al.*, 1972) showed magnified values for all the stages computed. The reason might be the in built nature of the model with limited data and took only certain parameters for computation like rainfall and PET and the excess water was assumed as runoff. Other parameters accounting for addition or deletion of soil moisture in the sorghum root zone (deep internal drainage, seepage and percolation, capillary rise contributing water to the root zone, *etc.*) used by the improved models were not accounted.

Also it was observed that the variation in quantity of soil moisture computed between the model output and actual measured data got narrowed down as the crop reached to harvest from germination. In general, modification of the present model is recommended to suit the present needs. Similar results were given by Somasundaram (2000) for dryland maize.

### **5.1.3 Varietal performance of sorghum on the growth and yield parameters and yield**

During mid sixties, crop varietal introduction had brought green revolution under irrigated condition. This indicated the available opportunity to be used to increase the productivity. This would be true even for dryland situation, where in certain genotypes might have tolerance mechanisms against possible moisture stress which is common in the dryland situation. Under this context, evaluation of genotypes would bring second green revolution from drylands.

Varieties did not exert any significant difference in plant height through out the crop growth period (vegetative, flowering and maturity stages) in both the crops except at 14 DAS of first crop in which the variety CSV 15 (V<sub>2</sub>) had grown taller than CO 26 (V<sub>1</sub>). The reduced plant height in CO 26 was due to the excessive moisture condition that prevailed during early vegetative stage. This situation actually hampered the establishment of CO 26 seedlings as compared to CSV 15 seedlings. These events had happened especially under D<sub>2</sub> sowing. The ocular observations made by the author on root colour during the period of excessive soil moisture indicated discolouration of seminal roots in CO 26 as a result of deficit oxygen supply and this had ultimately reduced the growth whereas in CSV 15, the roots remained

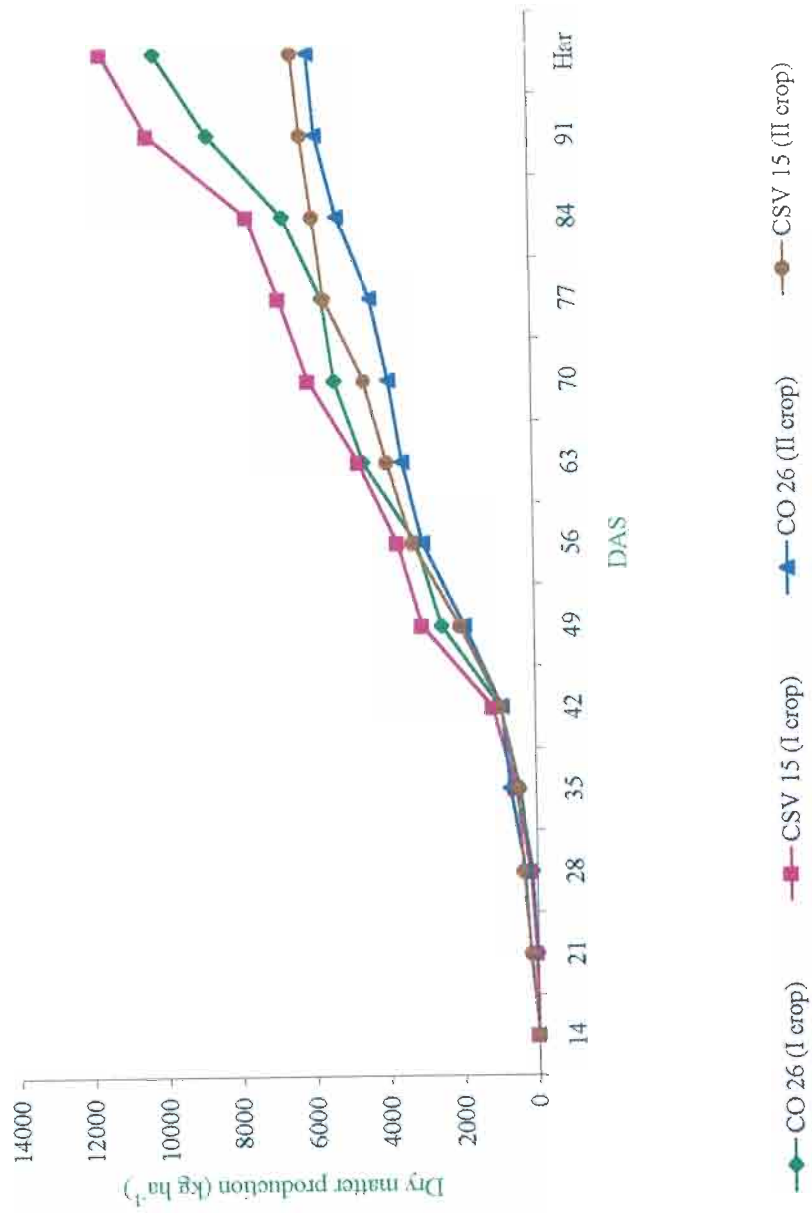
white in colour even under excessive moisture which indicated the tolerance of CSV 15 to water stagnation. The stunted growth of sorghum seedlings because of water stagnation was also reported earlier by Periyathambi (1980).

In respect of LAI, the variety CO 26 ( $V_1$ ) registered higher LAI at flowering and maturity stages except at 56 DAS (flowering stage) and at harvest (maturity stage) over CSV 15 ( $V_2$ ) during 1999-2000. The higher LAI of CO 26 might be due to the genetic character of the variety. This was also supported by Quinby *et al.* (1973) who opined that the leaf area of a crop was controlled by number of leaves, rate of expansion, eventual size of the leaves and senescence and these parameters were influenced by the genetic trait of a particular cultivar.

In general, the root volume was steadily increased and reached its peak at flowering stage and then started declining. Between varieties, the variety CSV 15 ( $V_2$ ) registered higher root volume and Root: Shoot ratio than CO 26 ( $V_1$ ) in most of the crop growth stages in both the crops (1999-2000 and 2000-2001). This was due to the genetic makeup of CSV 15 as reported in sorghum by Bhan *et al.* (1973); Jordan and Monk (1980) and Wright *et al.* (1983).

With regard to Dry Matter Production (DMP), the variety CSV 15 ( $V_2$ ) produced significantly higher DMP than CO 26 ( $V_1$ ) at all the vegetative, flowering and maturity stages of both the crops (Table 10 and 11 and Fig. 9) except at 35 and 42 DAS in vegetative stage and at 63 DAS in flowering stage of first crop (1999-2000) and 21 DAS in vegetative stage of second crop (2000-2001). The DMP is a function of numerous interactions between environment and genetic factors. The optimum LAI coupled with well developed root system enabled the variety CSV 15 to produce more dry matter than CO 26. Though CO 26 had higher LAI at later stages of crop growth during 1999-2000, the crop was not supported by its root system as indicated elsewhere because roots played an indispensable role, particularly in relation to the transfer of substances between root and shoot (Jesko, 1989). During 2000-2001 (second crop), the higher root volume and Root: Shoot ratio of  $V_2$  (CSV 15) helped to produce more DMP over  $V_1$  (CO 26). This might be because of the crop's ability to forage water and nutrients from deep soil layers through its well developed root system. In both the years (1999-2000 and 2000-2001), the variety CSV 15 also

**Fig. 9. Dry matter production ( $\text{kg ha}^{-1}$ ) of sorghum varieties CO 26 and CSV 15 during 1999 NEM and 2000 NEM**



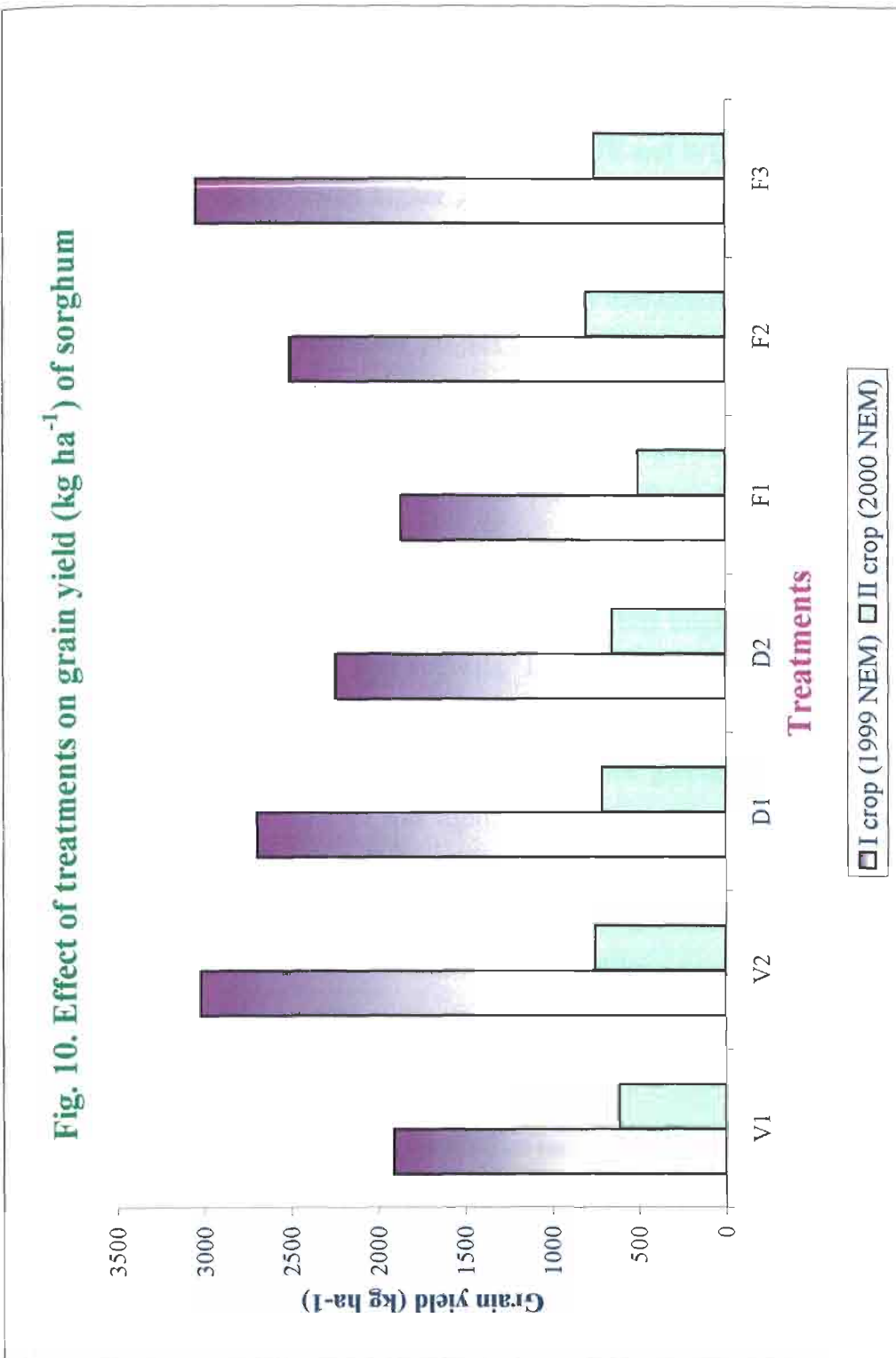
recorded higher NAR and CGR than CO 26, and these growth analysis characters also much contributed to higher DMP as recorded by CSV 15 (V<sub>2</sub>).

The varieties did not differ in terms of earhead length during 1999-2000 (above average rainfall year). This might be due to the efficient utilization of resources by both the varieties (CSV 15 and CO 26) evaluated. But during 2000-2001 (below average rainfall year), the variety CSV 15 (V<sub>2</sub>) produced lengthier panicles than CO 26 (V<sub>1</sub>). This might be due to the well developed root system of CSV 15 which enabled the crop to obtain more soil moisture from panicle initiation to flowering stage as compared to CO 26.

The variety CSV 15 (V<sub>2</sub>) had contained significantly higher number of grains earhead<sup>-1</sup> as compared to the variety CO 26 (V<sub>1</sub>) in both the years (1999-2000 and 2000-2001). The variation in this character between CSV 15 and CO 26 might be due to the difference in assimilate partitioning and assimilate redistribution capacity. Similar results were also reported earlier by Somasundaram (2000) in maize.

In respect of test weight, there was no difference between CSV 15 and CO 26 and this was because the size and weight of grains were essentially varietal characters which were not influenced by any of the treatments imposed in the present study. However, if soil moisture became limited especially after heading, development of grain size and weight were adversely affected and resulted in reduced test weight. This was the reason for the lower test weight of second crop (below average rainfall year) as compared to first crop (above average rainfall year). Similar result was also reported by Pushpanathan (1987).

Grain yield is a dependent variable on many independent variables like growth characters, yield components, *etc.* In a nutshell, grain yield is the product of growth occurred at different stages of crop growth. The variety CSV 15 out yielded CO 26 in both the years and the increase in grain yield was 58 and 22 per cent, respectively during 1999-2000 (above average rainfall year) and 2000-2001 (below average rainfall year) over CO 26 (Fig. 10). The straw yield also showed similar trend as that of grain yield though the difference was not significant during both the years. Higher grain and straw yields in CSV 15 over CO 26 was due to higher level of growth contributing characters *viz.*, dry matter production (Tables 10 and 11), Crop Growth



Rate (Table 16), Net Assimilation Rate (NAR) (Tables 19 and 20), root volume (Tables 21 and 22) and yield contributing characters *viz.*, earhead length (Table 25) and number of grains per panicle (Table 25) recorded in both the years. This also corroborated with the findings of Thombre *et al.* (1982) who concluded that panicle length, panicle girth, number of primaries and secondaries, panicle weight, number of grains panicle<sup>-1</sup> and 1000 seed weight did influence either directly or indirectly the per plant grain yield of a particular genotype. In addition to this, higher resource use efficiencies recorded by CSV 15 *viz.*, TRUE, ERUE and WUE (Table 29) than CO 26 also had contributed towards higher grain yield of CSV 15. This was because, the productivity under dryland depends on how best the available resources (water) was used effectively. Results of the advanced varietal trial conducted under All India Co-ordinated Sorghum Improvement Project in 31 locations across India during *Kharif* 1996 also revealed that CSV 15 recorded higher grain yield (3016 kg ha<sup>-1</sup>) than CO 26 (2896 kg ha<sup>-1</sup>) though not significant and produced significantly higher fodder yield (13 t ha<sup>-1</sup>) as compared to CO 26 (10.7 t ha<sup>-1</sup>) (Annual Report, 1997-98).

During 1999-2000 (above average rainfall year), the variety CSV 15 registered significantly higher harvest index than CO 26 and this might be due to considerable increase in DMP in CSV 15 after anthesis. Increase in the yield of economic product was usually a reflection of an increase in total DMP. Harvest index normally depends to a large extent on the photosynthetic activity of the greener parts of the plant after anthesis. The NAR of CSV 15 was significantly higher than CO 26 between 84 DAS and harvest which indicated the higher photosynthetic activity of CSV 15 (Table 20). This was observed by Yellamanda Reddy and Sankara Reddi (1995). In addition, the higher root volume of CSV 15 recorded at grain filling stage of the crop (Table 22) might have supplied adequate nutrients to the crop and this ought to have mobilized more photosynthates to the sink (grains) from the source.

Uptake of nutrient is the quantitative estimation of a particular nutrient and it is borne between DMP and per cent of nutrient concentration in a plant. Between varieties, CSV 15 (V<sub>2</sub>) registered higher nutrients uptake (N, P and K) in most of the crop growth stages in both the crops (1999-2000 and 2000-2001) over CO 26 (V<sub>1</sub>). This was due to the higher DMP recorded by CSV 15 than CO 26. The well developed root system seen with CSV 15 enabled the crop to absorb more nutrients

under optimum soil moisture availability. The positive relationship between DMP and nutrient uptake was also reported by Selvaraju (1990). The role of well developed root system for higher nutrient uptake was supported by Jesko (1989) who opined that roots played an indispensable role in relation to transfer of substances between root and shoot.

#### **5.1.4 Effect of times of sowing on the growth and yield parameters and yield of sorghum**

Agronomically altering the time of sowing is a no cost technology and always preferred by the farming community. Identification of optimum time of sowing not only brings the critical phenological phases of crops under favourable weather but also indirectly minimises the pest and disease incidences. Though informations are available, further probe in this line would improve crop productivity in dryland.

Times of sowing had not altered the plant height significantly through out the crop growth period in both the crops (1999-2000 and 2000-2001). Except rainfall, other parameters did not vary greatly between two dates of sowing evaluated in both the crops. This led to non significance results for plant height studied. Cell division and cell elongation were mainly manipulated by thermal regimes rather than moisture regimes as reported by many workers in sorghum.

The crop sown under D<sub>1</sub> date of sowing recorded higher LAI at 28 DAS (vegetative stage), 63 and 77 DAS (flowering stage) and 91 DAS and at harvest (maturity stage) of first crop (1999-2000), while in the second crop (2000-2001), crop sown under D<sub>2</sub> sowing registered higher LAI at 35 DAS (vegetative stage) and 70 and 77 DAS (flowering stage). The lower LAI at early vegetative stage (28 DAS) of first crop (1999-2000) under D<sub>2</sub> sowing was due to existence of excessive soil moisture condition from emergence onwards which actually reduced the root activity. From the data of Tables 34 and 34a, it was clear that D<sub>1</sub> sown crop enjoyed favourable soil moisture condition during the emergence and as well as at the early seedling establishment period and thereafter only it experienced excessive soil moisture situation. Whereas in the case of D<sub>2</sub> sown crop, right from the emergence onwards, the crop had experienced excessive soil moisture condition, which did not offer favourable condition for obtaining enhanced LAI. The higher LAI at 63 and 77 DAS

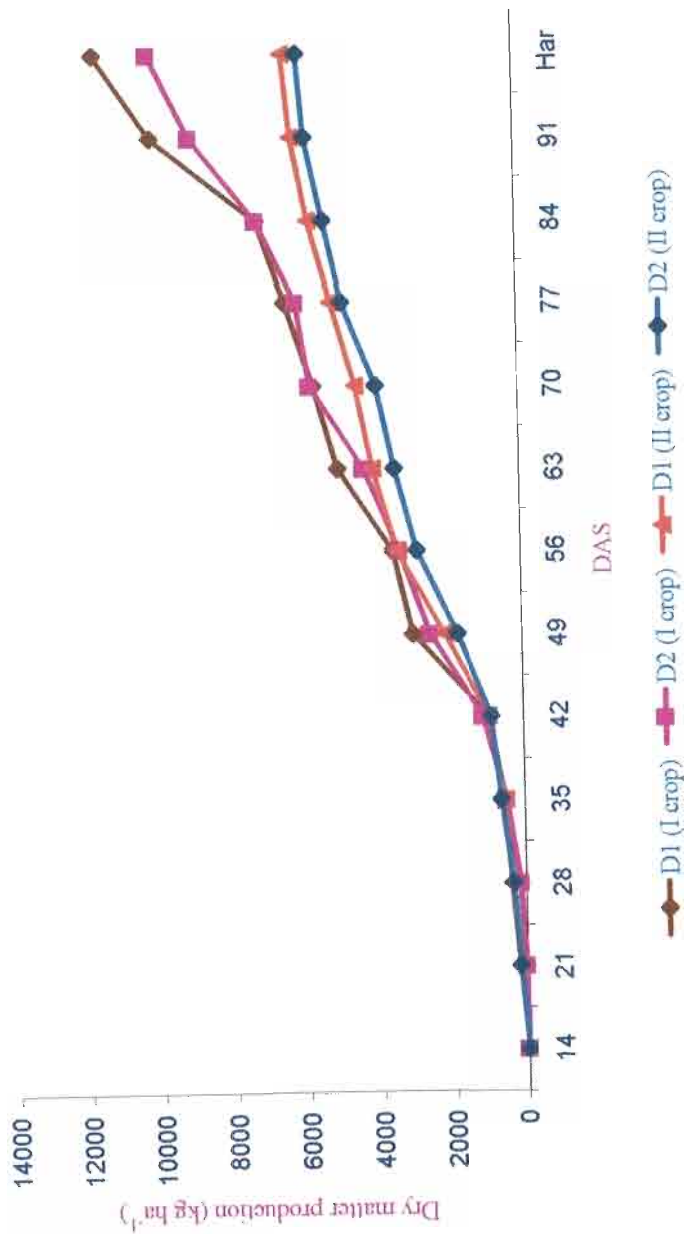
of the first crop under  $D_1$  sowing was due to enough soil moisture availability to the  $D_1$  sown crop as compared to the crop sown under  $D_2$  time of sowing (Tables 34 and 34a). The carry over effect of condition that prevailed at 77 DAS (flowering stage) might be the reason for the higher LAI of  $D_1$  sown crop at 91 DAS and at harvest also (maturity stage) in the first crop (1999-2000).

With regard to root volume, except at 14 DAS of first and second crops, in all other observations of vegetative stage,  $D_1$  sown crop did record significantly higher root volume than  $D_2$  sown crop, except at 42 DAS of first crop. This trend was continued at 63, 70 and 77 DAS of first crop and at harvest of the second crop. The higher root volume of  $D_1$  sown crop during 1999-2000 (above average rainfall year) was due to the favourable soil moisture condition that prevailed during the seedling establishment of  $D_1$  sown crop as compared to  $D_2$  sown crop as discussed elsewhere. During 2000-2001 (below average rainfall year), even though the rainfall amount was relatively lesser in this year, at vegetative stage,  $D_1$  sown crop recorded higher root volume than  $D_2$  sown crop and this was due to the optimum soil moisture availability whereas, at flowering and maturity stages, the crop experienced prolonged moisture stress which in turn reduced the root development and in turn reduced the root volume.

In respect of Root: Shoot ratio (R: S ratio),  $D_1$  sown crop was significantly superior over  $D_2$  sown crop in both the years (1999-2000 and 2000-2001) except at 42 DAS and at harvest of first crop and at 28 DAS of second crop where in  $D_2$  sown crop recorded significantly higher R: S ratio. The reason for increased R: S ratio recorded under  $D_1$  sowing in most of the crop growth stages could be understood from the present investigation, wherein there was higher root volume and DMP under  $D_1$  sown crop (Tables 21, 22, 10 and 11) as compared to  $D_2$  sown crop. The above fact was also supported by Pearsell (1927) who reported a linear relationship between shoot and root growth of sorghum during vegetative and mid reproductive stages.

In respect of DMP,  $D_1$  sown crop produced higher DMP than  $D_2$  sown crop in both the crops (1999-2000 and 2000-2001). Between first and second crop, first crop accumulated higher dry matter in most of the stages over second crop (Fig. 11). This was because of higher LAI of first crop as compared to the second crop. The formation and maintenance of active leaf area was essential for the continued

Fig. 11. Effect of times of sowing on dry matter production ( $\text{kg ha}^{-1}$ ) of sorghum during 1999 NEM and 2000 NEM



production of photosynthates to maintain carbon and energy flow to the developing plant tissues as reported by Jordan *et al.* (1983).

During 1999-2000, (above average rainfall year), D<sub>1</sub> sown crop produced significantly higher DMP than D<sub>2</sub> sown crop at most of the crop growth stages (21, 49, 63 and 91 DAS and at harvest). This was due to higher and optimum distribution of rainfall for the crops sown under D<sub>1</sub> date of sowing. At 63 DAS (flowering stage) of first crop, the LAI attained its zenith and this resulted in higher DMP. The higher DMP at maturity stage (91 DAS and at harvest) of D<sub>1</sub> sown crop was due to the chain action of the condition that prevailed from the vegetative and flowering stages and also due to the ability of the D<sub>1</sub> sown crop to maintain its leaf greenness.

During 2000-2001 (below average rainfall year), in all the stages D<sub>1</sub> sown crop produced higher DMP than D<sub>2</sub> sown crop. Though the LAI was higher in D<sub>2</sub> sown crop at 35, 70 and 77 DAS, the root volume was higher in D<sub>1</sub> sown crop in all the vegetative, flowering and maturity stages except at 14 DAS. This higher root volume coupled with higher soil moisture content allowed the D<sub>1</sub> sown crop to absorb more water and nutrients and hence produced higher DMP. At times of prolonged moisture stress, the lower LAI became a handy mechanism to the crop to minimise water loss. The smaller leaf area (lesser number of stomata) coupled with higher root volume allowed the process of photosynthesis even under water stress condition. Whereas, with higher leaf area under lower soil moisture situation, the D<sub>2</sub> sown crop as a result of lesser root spread (volume), had no choices other than to close all the stomata fully. Hence there was a problem of photosynthetic activity. This might have affected dry matter production (Yellamanda Reddy and Sankara Reddi, 1995).

In respect of CGR, RGR and NAR, times of sowing had no significant influence except at few stages in both the crops (1999-2000 and 2000-2001). This area requires further probing.

The times of sowing had no significant influence on earhead length in both the crops (1999-2000 and 2000-2001) probably due to non influence of these treatments on this parameter.

The crop sown under D<sub>1</sub> sowing recorded significantly higher number of grains earhead<sup>-1</sup> than crop sown under D<sub>2</sub> sowing during 1999-2000 (above average

rainfall year). This was because, in  $D_1$  sowing, there was no soil moisture stress observed up to 77 DAS, whereas it was only up to 70 DAS in  $D_2$  sowing (Tables 34, 34a, 35 and 35a). But such significance was absent during 2000-2001 (below average rainfall year). The existence of moisture stress condition during panicle development and grain filling stages would be the reason for such non significance results.

In general, the grain and straw yields were lesser during 2000-2001 (below average rainfall year) than that of 1999-2000 (above average rainfall year) irrespective of varieties, times of sowing and nutrient levels. This was due to inadequate and ill distributed rainfall noticed during the cropping period of 2000-2001 (second crop). During the first crop of 1999, the rainfall received by the crop was 427.6 mm in 27 rainy days under  $D_1$  sowing and 391 mm in 23 rainy days under  $D_2$  sowing. In both  $D_1$  and  $D_2$  sowings of the first crop (1999-2000), the rainfall was well distributed through out the entire crop growth period especially at vegetative and flowering stages, which kept the crop under moisture stress free condition. But in respect of 2000-2001 cropping period, the rainfall received by the crop was 284 mm in 18 rainy days and 123.3 mm in 13 rainy days under  $D_1$  and  $D_2$  sowings, respectively. Hence, when compared to the first crop, the rainfall distribution in the second crop was highly varying both in terms of quantity and distribution. This led to inadequate moisture supply to the crop right from the late vegetative stage to maturity stage (Tables 35 and 35a). The growth of plant was proportional to the amount of water present. Water was required for the manufacture of carbohydrates, to maintain hydration of protoplasm, and also as a vehicle for translocation of carbohydrates and nutrients. Internal moisture stress caused reduction in both cell division and cell elongation, and hence reflected on growth. Water stress occurred when the extractable water in the root zone was insufficient to meet the plant's transpirational demands (Tisdale *et al.*, 1997). From Tables 30 and 32, it was clear that the first crop (1999-2000) satisfied more than 70 per cent of the crop water requirement (AET), whereas the second crop was satisfied only up to 60 per cent of the crop water requirement (AET) irrespective of varieties and times of sowing. This resulted in reduction in leaf area index and root development, which ultimately affected the process of photosynthesis and finally reduced the total DMP. The reduced DMP led to poor yield components *viz.*, earhead length, number of grains per earhead and test

weight and this was the reason for the second crop's lower grain and straw yields as compared to first crop.

In respect of grain yield, D<sub>1</sub> sown crop had recorded significantly higher grain yield over D<sub>2</sub> sown crop (Fig. 10) during 1999-2000 (above average rainfall year) whereas the difference in yield was not significant during 2000-2001 (below average rainfall year).

During 1999-2000 (above average rainfall year), both grain and straw yields were higher to an extent of 20 and 13 per cent, respectively under D<sub>1</sub> sown crop over D<sub>2</sub>. With sowing before the onset of the monsoon, by nature the crop had been given an opportunity to utilize all the environmental resources effectively. This argument was supported by Periyathambi (1980) from his experimental results. The crop sown before the onset of monsoon had shown higher water use efficiency (Table 29). This led to improved LAI and DMP (Tables 13, 14, 10 and 11). This phenomenon could read through increased CGR, RGR and NAR in most of the vegetative, flowering and maturity stages of crop growth period. With increase in growth, due to right proportion of synthates movement from source to sink, the yield components were also positively influenced in the D<sub>1</sub> treatment (Table 25). As a result of this continued relay action, the yield under D<sub>1</sub> was greater than D<sub>2</sub>. As indicated elsewhere, the mean actual soil moisture also was not limited up to 77 DAS (late flowering stage) for D<sub>1</sub>, whereas it was only upto 70 DAS (mid flowering stage) for D<sub>2</sub> sown crop. As a result of extended favourable soil moisture environment, the N, P and K uptake were comparatively higher with D<sub>1</sub>. These factors put together made the yield higher for D<sub>1</sub> treatment. This finding was in agreement with the findings of Balasubramanian *et al.* (1993) who reported 33 and 8 per cent increase in grain and straw yields due to sowing before the onset of monsoon (during 38<sup>th</sup>-39<sup>th</sup> MSW) over sowing after the monsoon rain under Coimbatore condition.

During 2000-2001 (below average rainfall year), irrespective of treatments, the crop growth and yield were affected because of the prolonged moisture stress as experienced by the crop. Seetharama *et al.* (1982) reported that prolonged moisture stress directly affected the crop with reduced photosynthates, reduced mineral nutrient supply, reduced protein synthesis and malmetabolism, which all might have affected

leaf area development, stem elongation, panicle growth and partitioning of dry matter to different plant parts.

Bonnett (1979) reported that moisture stress occurring at panicle initiation to flowering stage affected the normal development of panicle and hence affected the development of the florets and size of the vegetative shoot (source). Moisture stress at grain filling stage affected the normal process of fertilization, seed setting and the size of the grains. As a whole, moisture stress occurred at critical stages of crop of sorghum and ultimately affected the yield of sorghum.

During 2000-2001 also, D<sub>1</sub> sown crop performed better than D<sub>2</sub> and D<sub>1</sub> recorded 9 and 4 per cent higher grain and straw yields over D<sub>2</sub>. This was due to lesser moisture stress experienced by D<sub>1</sub> sown crop than D<sub>2</sub> sown crop. This result is in accordance with the findings of Das *et al.* (1993) who reported that sorghum yield was inversely proportional to the stress period and the larger the stress duration, the lower was the grain yield.

The non significance of harvest index between D<sub>1</sub> and D<sub>2</sub> in both the crops (1999-2000 and 2000-2001) might be due to the uniform percentage of partition of photosynthates irrespective of biomass produced.

In general, the trend in nutrient (N, P and K) uptake was similar to that of DMP between sowing times studied. In both the years of study (1999-2000 and 2000-2001), D<sub>1</sub> sowing registered its superiority for higher nutrient uptake over D<sub>2</sub> sowing significantly in most of the crop growth stages evaluated. The increased nutrient uptake under D<sub>1</sub> sown crop was mainly due to increased DMP recorded (Somasundaram, 2000). The better root growth coupled with extended moisture availability under D<sub>1</sub> sowing might have also helped for higher nutrient uptake, especially N and P uptake (Tisdale *et al.*, 1997). The increased uptake of N and P under D<sub>1</sub> sowing might have also helped to extract more K from the soil (Roy and Wright, 1974 and Devarani, 1996).

### 5.1.5 Effect of nutrient levels on the growth and yield parameters and yield of sorghum

It was established that nutrient application did improve the yield up to 40 per cent under the influence of optimum irrigation. However such quantitative information does not precisely established for crops raised under dryland condition.

In the present investigation, nutrient application positively influenced the sorghum plant height during 1999-2000 (above average rainfall year) and application of 60: 30: 0 kg N: P<sub>2</sub>O<sub>5</sub>: K<sub>2</sub>O ha<sup>-1</sup> had produced taller plants over control (no nutrient application) at vegetative and flowering stages. At early vegetative stage of first crop (14, 21, 28 and 35 DAS), F<sub>3</sub> and F<sub>2</sub> levels of nutrient application were at par and produced taller plants than F<sub>1</sub> level. At late vegetative stage (42 and 49 DAS) and at early flowering stage (56 DAS), F<sub>3</sub> level of nutrient application produced tallest plants over F<sub>2</sub> and F<sub>1</sub> levels of nutrient application. At 63 and 70 DAS of flowering stage, F<sub>3</sub> and F<sub>2</sub> levels were at par and produced taller plants than F<sub>1</sub> level. The increased plant height with NP fertilization was because of increase in cell division (Levitt, 1972). In general, elongation of the stem internodes began shortly after panicle initiation and increased rapidly and the rate of elongation was at its peak at the flag leaf stage in sorghum. Since, this peak elongation fell between 42 and 56 DAS, the availability of optimum soil moisture coupled with higher level of available nutrients under F<sub>3</sub> level had pronounced effect on the plant height increment. There was an increase in nutrient uptake with availability of more extractable water as reported by Tisdale *et al.* (1997).

But during 2000-2001 (below average rainfall year), the plant height was not altered by nutrient application. There was lesser uptake due to moisture shortage (Tables 35 and 35a). The lack of adequate soil moisture in the root zone retarded nutrient availability to the crop by impairing the mass flow and diffusion processes through which N and P were mainly taken up by the crop as reported by Tisdale *et al.* (1997). When N was not available sufficiently for the plants at its peak vegetative stage, the plant got shortened (Ratikanta Maiti, 1996).

In respect of LAI, F<sub>3</sub> (60: 30: 0 kg N: P<sub>2</sub>O<sub>5</sub>: K<sub>2</sub>O ha<sup>-1</sup>) registered higher LAI than F<sub>2</sub> (40: 20: 0 kg N: P<sub>2</sub>O<sub>5</sub>: K<sub>2</sub>O ha<sup>-1</sup>) and F<sub>1</sub> (control) in the first crop (Plates 2 and

Plate 2. View of the D<sub>1</sub> sown CSV 15 sorghum under F<sub>1</sub> level at vegetative stage



F<sub>1</sub>- No nutrient application

Plate 3. View of the D<sub>1</sub> sown CSV 15 sorghum under F<sub>3</sub> level at vegetative stage



F<sub>3</sub>- 60: 30: 0 kg N: P<sub>2</sub>O<sub>5</sub>: K<sub>2</sub>O ha<sup>-1</sup>

3) and the difference was significant at 28 and 42 DAS, while  $F_3$  was at par with  $F_2$  at 35 and 49 DAS of vegetative stage and 56 DAS of flowering stage. Leaf growth could be related to increment in plant height. This was in agreement with the findings of Devarani (1996). But during 2000-2001 (below average rainfall year), the nutrient application did not alter the LAI and this was due to reduced plant height recorded. The combined effect of nitrogen and moisture stress reduced the leaf area development as reported by Seetharama *et al.* (1982). Inhibition of leaf growth in sorghum by water stress also observed by Stout *et al.* (1978).

Adequate fertilization encouraged not only greater top (shoot) growth but also vigorous and extensive root system (Plates 4, 5, 6 and 7). This stimulation was mainly due to build up of N and P nutrients in the cells that hastened division and elongation of root cells. During 1999-2000 (above average rainfall year), higher level of nutrient ( $F_3$ ) application (60: 30: 0 kg N:  $P_2O_5$ :  $K_2O$  ha<sup>-1</sup>) did record higher root volume at all the crop growth stages except at 14 DAS of vegetative stage. Warsi and Wright (1973) also reported increased root growth especially during early stages with increased N levels in sorghum. Suraj Bhan *et al.* (1995) also reported gradual increase in root development with the application of N up to 80 kg ha<sup>-1</sup>.

During 2000-2001 (below average rainfall year), at vegetative stage  $F_3$  level of nutrient application resulted in higher root volume while at flowering and maturity stages  $F_3$  and  $F_2$  levels were at par and produced significantly higher root volume than  $F_1$  (control) level of nutrient application. This was because at vegetative stage, the soil moisture was enough to meet crop demand and hence higher level of N and P application gave higher root volume as that of first crop. But at flowering and maturity stages because of inadequate soil moisture plants were not able to absorb enough nutrients to its demand from the top soil layer. But in case of  $F_1$  (no nutrient application), the root development was poor at vegetative stage itself and this condition continued as a chain action at the flowering and maturity stages as well and resulted in lower root volume as compared to  $F_3$  and  $F_2$  levels. This was in agreement with the findings of Smith and Myers (1978) who found that much of the N and P uptake in water stressed dryland sorghum took place from the sub soil layer during grain filling stage than surface soil layer.

Plate 6. Influence of nutrient levels on the root system of  $D_1$  sown CSV 15 sorghum

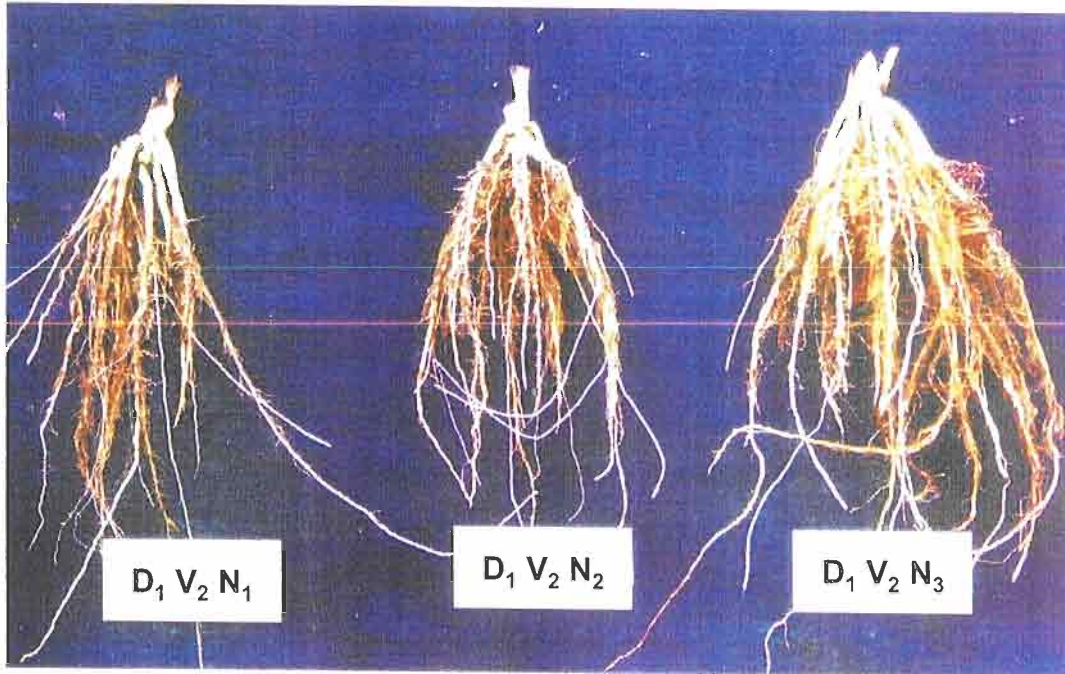
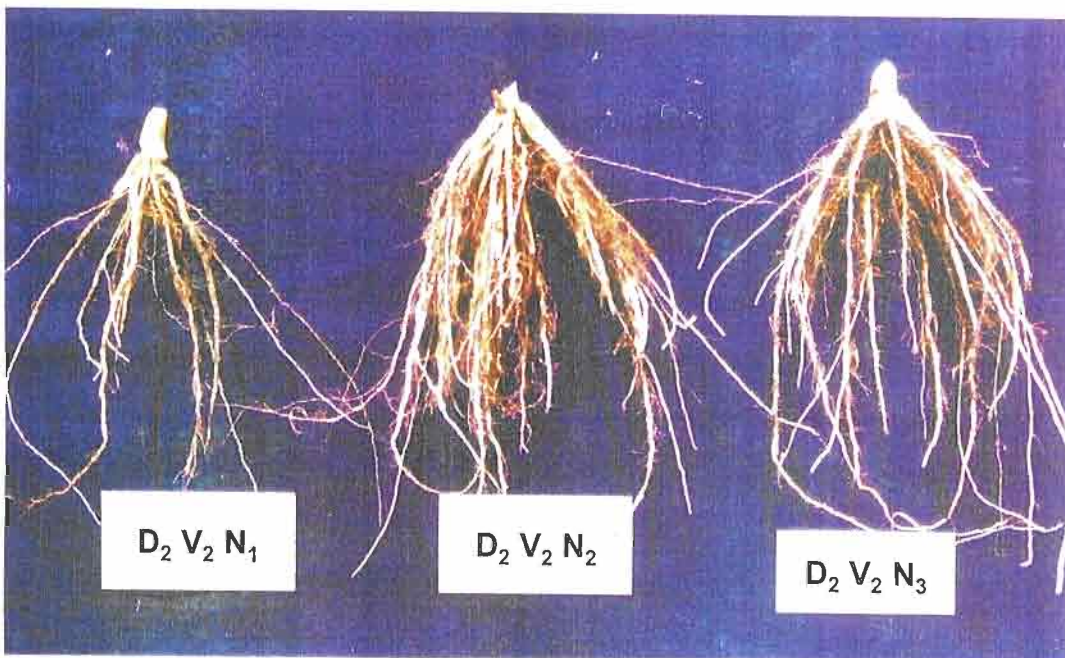


Plate 7. Influence of nutrient levels on the root system of  $D_2$  sown CSV 15 sorghum



As a result of increased root volume under higher nutrient level, Root: Shoot ratio was also higher in F<sub>3</sub> level in both the crops (1999-2000 and 2000-2001), except at 70 and 84 DAS of second crop in which F<sub>2</sub> registered higher Root: Shoot ratio than F<sub>3</sub> level.

In respect of Dry Matter Production (DMP), during 1999-2000 (above average rainfall year), higher level of nutrient application (F<sub>3</sub>) resulted in higher DMP as compared to F<sub>2</sub> and F<sub>1</sub> levels at all the stages of crop growth (Tables 10 and 11 and Fig. 12). This was due to the increased LAI under F<sub>3</sub> level, which intercepted more solar radiation and accumulated more DMP over F<sub>2</sub> and F<sub>1</sub> levels, since solar radiation was not a constraint as reported elsewhere during crop growth period. In addition to this, the higher resource use efficiencies *viz.*, TRUE, ERUE and WUE were also higher under F<sub>3</sub> level as compared to F<sub>2</sub> and F<sub>1</sub> levels. The increased resource use efficiencies under F<sub>3</sub> level of nutrient application gave an indication on the proper utilization of nutrients applied under stored soil moisture situation (Kanwar *et al.*, 1984).

In general, the F<sub>3</sub> level of nutrient application resulted in higher CGR and NAR during 1999-2000 (above average rainfall year) and this had increased physiological processes and thus higher DMP was obtained under F<sub>3</sub> level of nutrient application.

During 2000-2001 (below average rainfall year), F<sub>3</sub> level of nutrient application produced higher dry matter at vegetative stage and there after F<sub>2</sub> and F<sub>3</sub> levels were at par and produced higher DMP than F<sub>1</sub> level (Fig. 12). This indicated that F<sub>3</sub> level was not so efficient as observed in the first crop because of reduced soil moisture noted in the second crop. This means that at early vegetative stage, the soil moisture availability was highly favourable for crop growth and hence response was obtained for higher nutrient level. But at flowering and maturity stages, the crop had experienced severe moisture stress and the available soil moisture even fell below Permanent Wilting Point (PWP) and the crop was not able to take sufficient nutrients. The results were in agreement with the findings of Myers and Asher (1982) who reported lower response of sorghum crop to fertilizer application under lower rainfall amount. Rama Mohan Rao *et al.* (1995) reported that higher sorghum grain yield was obtained under 20 kg N ha<sup>-1</sup> over control (530 kg ha<sup>-1</sup>), but this result was at par with



the yield obtained under 40 and 60 kg N ha<sup>-1</sup>, during subnormal rainfall years (bad years) in medium black soils of Bellary. During 2000-2001 (below average rainfall year), the CGR, RGR and NAR under F<sub>2</sub> and F<sub>3</sub> levels were at par and higher than F<sub>1</sub> level.

In both the crops (1999-2000 and 2000-2001), higher level of nutrient application did improve panicle length. Jagtap and Pharande (1982) reported significant increase in panicle length under higher doses of N application in sorghum.

In respect of nutrient application, sorghum responded positively in terms of number of grains earhead<sup>-1</sup>. During 1999-2000 (above average rainfall year), higher level of nutrient application (F<sub>3</sub> level) gave higher number of grains earhead<sup>-1</sup> than F<sub>2</sub> and F<sub>1</sub> level. Increased panicle length as observed would give answer for this performance. Increase in DMP after anthesis was largely responsible for better grain filling (Yellamanda Reddy and Sankara Reddi, 1995).

During 2000-2001 (below average rainfall year), F<sub>2</sub> and F<sub>3</sub> levels of nutrient application produced higher number of grains earhead<sup>-1</sup> which were at par and significantly better than F<sub>1</sub> level. This was due to lack of response of sorghum crop to higher level of nutrient application (F<sub>3</sub>) during below average rainfall year. The result was in agreement with the findings of Rama Mohan Rao *et al.* (1995).

Investigation on the effect of different levels of nutrients on the grain yield and straw yield indicated a significant increase in the grain and straw yields at higher level of nutrient application during both the years.

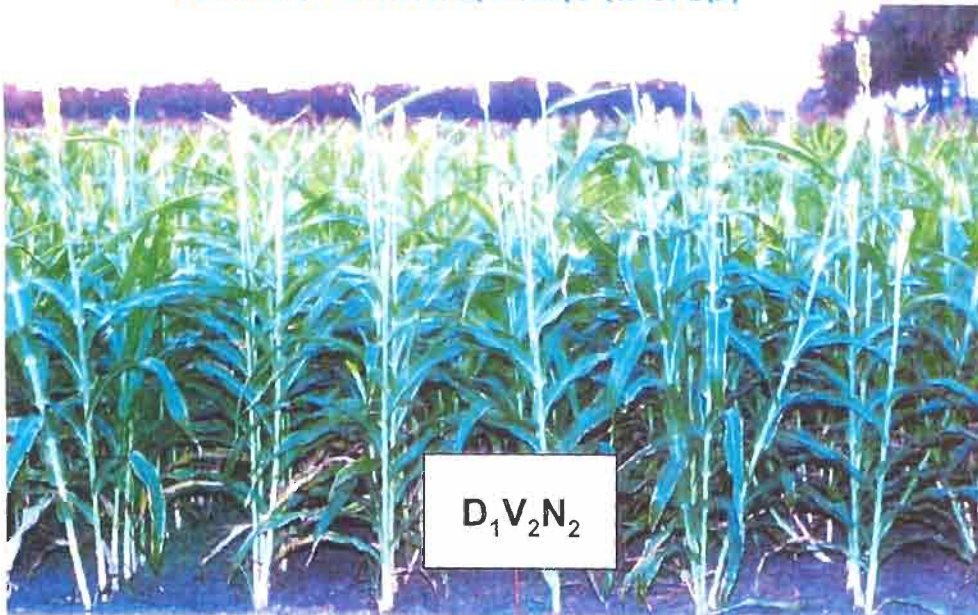
During 1999-2000 (above average rainfall year), the grain and straw yields increased significantly with increasing NP fertilization (Table 26 and 27 and Fig. 10). The nutrient level F<sub>3</sub> (60: 30: 0 kg N: P<sub>2</sub>O<sub>5</sub>: K<sub>2</sub>O ha<sup>-1</sup>) gave the highest grain yield (Plate 8) followed by F<sub>2</sub> (40: 20: 0 kg N: P<sub>2</sub>O<sub>5</sub>: K<sub>2</sub>O ha<sup>-1</sup>) and the increase was 63 and 34 per cent over F<sub>1</sub> (Control). F<sub>3</sub> also recorded the highest straw yield, though the difference was not significant. The higher yield of grain under higher nutrient level (F<sub>3</sub>) was due to higher growth and yield attributes obtained. F<sub>3</sub> recorded an average of 21, 8, 15 and 51, 13 25 per cent higher total DMP, panicle length and number of grains per panicle over F<sub>2</sub> and F<sub>1</sub>, respectively. Porwal and Pushpendra Singh (1992) also gave similar findings from their experimentation. F<sub>3</sub> also registered the highest

Plate 8. View of  $D_1$  sown CSV 15 sorghum under  $F_3$  level at flowering stage (I crop)



$F_3$ - 60: 30: 0 kg N:  $P_2O_5$ :  $K_2O$  ha<sup>-1</sup>

Plate 9. View of  $D_1$  sown CSV 15 sorghum under  $F_2$  level at flowering stage (II crop)



$F_2$ - 40: 20: 0 kg N:  $P_2O_5$ :  $K_2O$  ha<sup>-1</sup>

root volume and a positive relationship between root development and nutrient uptake in sorghum was already felt by Myers (1980).

Warsi and Wright (1973) reported that increasing N levels had increased the root growth. Hence application of higher level of N to sorghum ( $F_3$ ) resulted in higher root development which led to increased N, P and K uptake and ultimately increased the grain yield under the presence of favourable soil moisture condition.

During 2000-2001 (below normal rainfall year),  $F_2$  registered the highest grain yield ( $796 \text{ kg ha}^{-1}$ ; Plate 9) which was at par with  $F_3$  ( $746 \text{ kg ha}^{-1}$ ) and significantly higher than  $F_1$  ( $503 \text{ kg ha}^{-1}$ ). Higher grain yield at  $F_2$  was through obtaining higher values in the growth and yield components, especially number of grains per panicle. Similarly, highest straw yield was also recorded with  $F_2$ , though the difference was not significant. The insufficient soil moisture condition during the crop growth period had resulted reduction in grain and straw yields under increased nutrient levels beyond  $F_2$ . This was because soil moisture had a pronounced effect on the uptake of plant nutrients. Low levels of extractable water in the root zone retarded the nutrient availability to the plant by impairing the nutrient uptake processes *viz.*, diffusion, mass flow and root interception and though the rhizosphere was rich in available nutrients, the plant was not able to absorb it for want of moisture (Tisdale *et al.*, 1997). The results are in agreement with the findings of Rama Mohan Rao *et al.* (1995).

Myers and Asher (1982) also reported that during low rainfall years, the response to fertilizer application was less and for crops grown predominantly on stored soil moisture, progressive drying of soil from the surface downwards starved the upper part of the soil for mineral nutrients. Rainfall (soil moisture) played an important role on the uptake of nutrients and thereby the response of the crop to the applied higher level of nutrients was absent.

In both the crops (1999-2000 and 2000-2001), nutrient application brought changes in nutrient uptake by sorghum. But the weather factors especially rainfall (moisture) played an indispensable role in deciding the crops response to different levels of nutrient application. This was because soil moisture level had a pronounced effect on the uptake of plant nutrients. Low levels of extractable water in the root

zone retarded nutrient availability by impairing the nutrient uptake processes *viz.*, mass flow, diffusion and root interception. As a general rule, there was an increase in nutrient uptake when extractable water was high rather than low (Tisdale *et al.*, 1997).

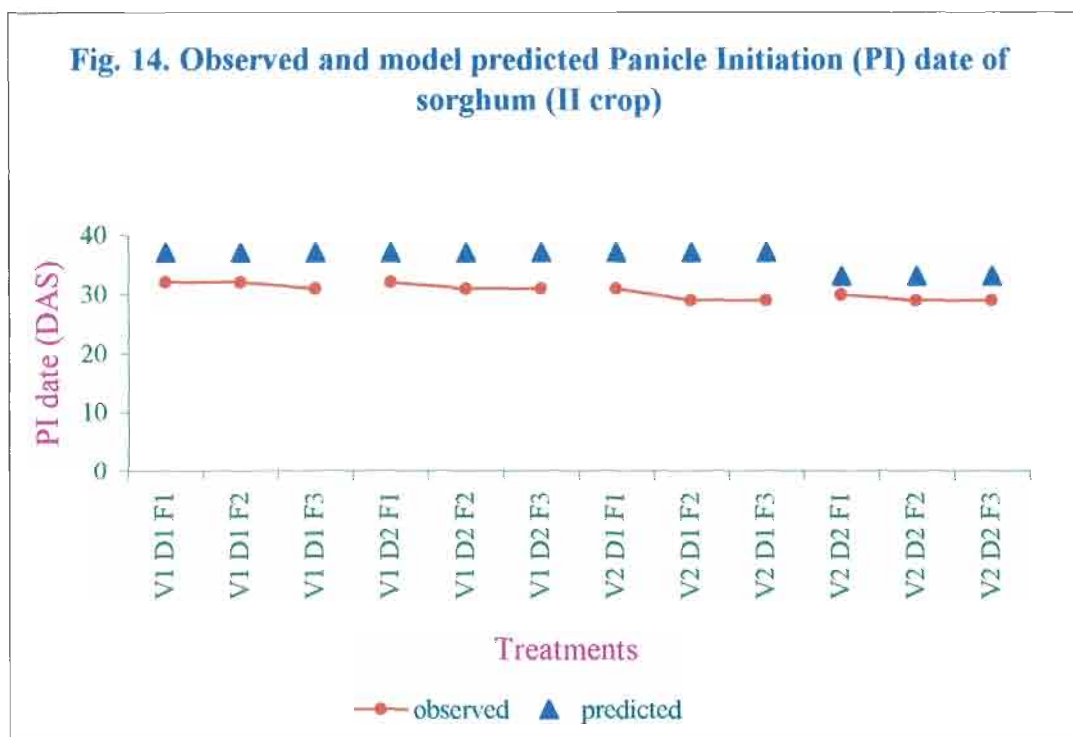
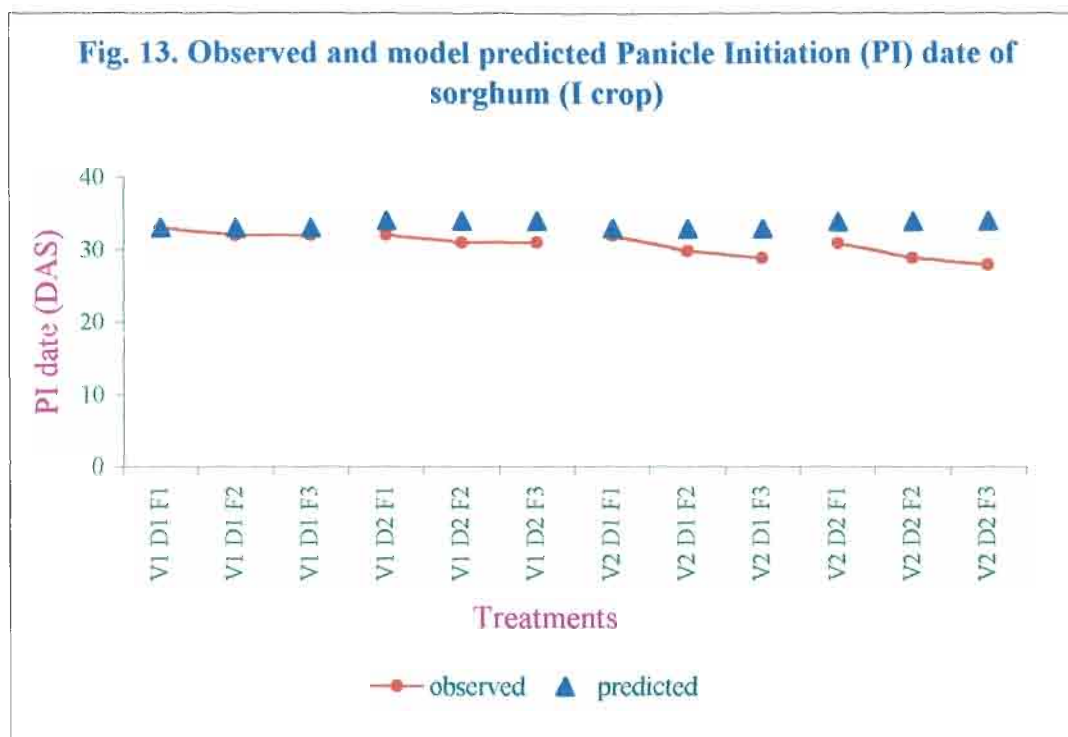
During 1999-2000 (above average rainfall year), F<sub>3</sub> level of nutrient application resulted in significantly higher nutrient (N, P and K) uptake in all the vegetative, flowering and maturity stages. This was due to the higher DMP recorded by F<sub>3</sub> level of nutrient application as a result of existence of favourable soil moisture regime. Response of sorghum to higher level of nutrient application during good rainfall year was also reported by Balasubramanian *et al.* (1993) and Rama Mohan Rao *et al.* (1995).

During 2000-2001 (below average rainfall year), higher uptake of nutrients (N, P and K) was recorded by F<sub>2</sub> and F<sub>3</sub> levels of nutrient application which were at par and significantly superior over F<sub>1</sub> level (control) indicating the interaction between soil moisture and nutrients uptake. This result recorded concurrently indicated that even under low rainfall situation, crop needed nutrients for its better productivity though not on higher side.

## **5.2 Part II Evaluation of DSSAT V.3.5 CERES-Sorghum model**

### **5.2.1 Phenological development**

The perusal of data presented in Table 47 revealed that the CERES-Sorghum model predicted the dates of panicle initiation closer to that of the observed dates of panicle initiation (Fig. 13) during 1999-2000 (above average rainfall year). The mean date of panicle initiation of all the treatments was 31 DAS, against the model prediction of 34 DAS. The RMSE was 3.2 and per cent of RMSE with observed values was around 10 per cent. Since the error was less than or approximately equal to 10 per cent, predictions of panicle initiation were considered genuine under Coimbatore condition (Varshneya, 1999). But in 2000-2001, (below average rainfall year), the model over estimated the dates of panicle initiation (Fig. 14). The predicted mean date of panicle initiation for various treatments was 36 DAS as against the observed mean panicle initiation date of 31 DAS. The RMSE was 5.69 and the per cent of RMSE with observed values was around 19 per cent for all the treatments.



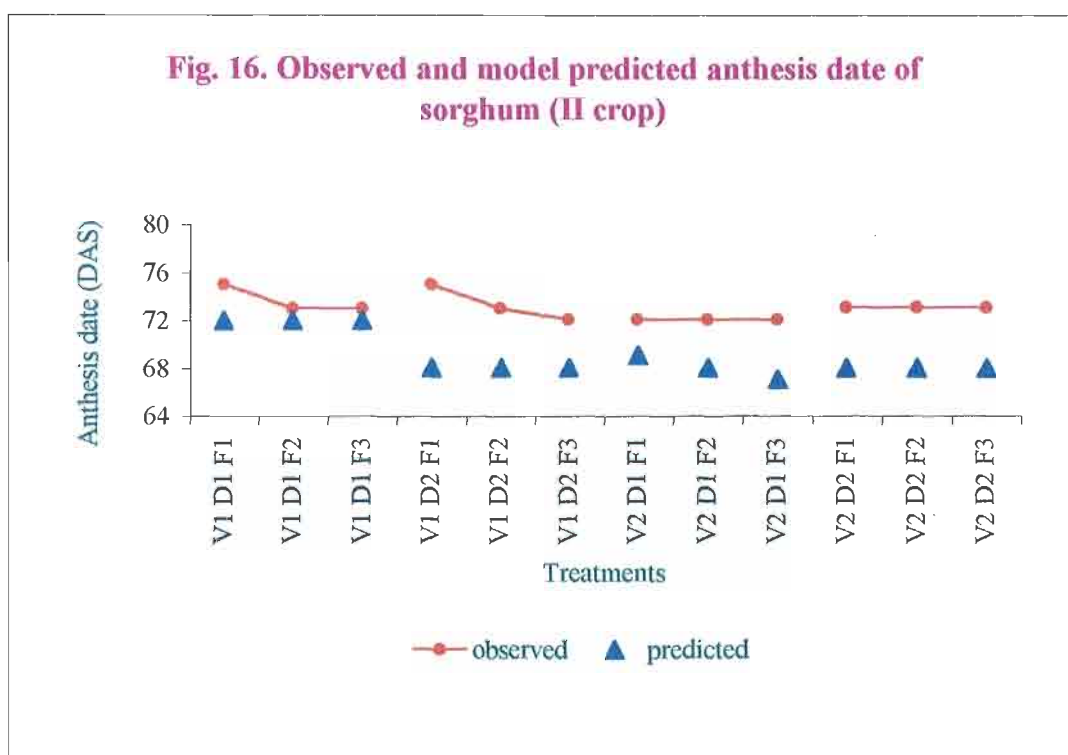
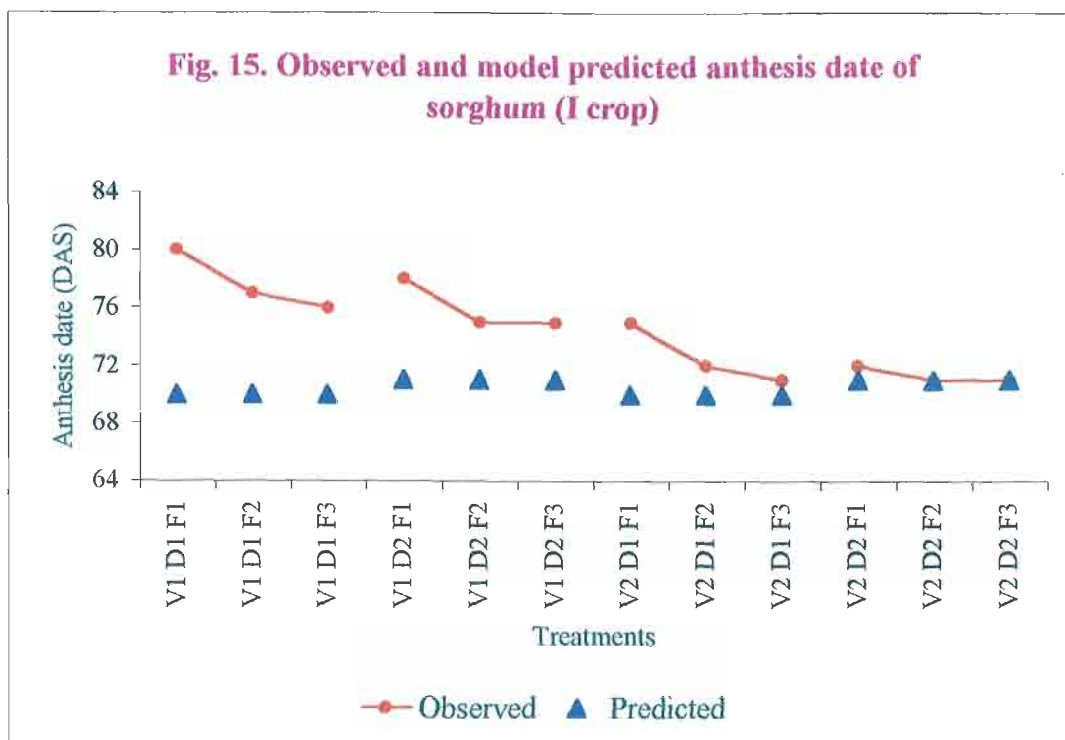
Varshneya *et al.* (1998) also reported similar results of closer predictions of date of panicle initiation by CERES-Sorghum model in Rahuri, Maharashtra.

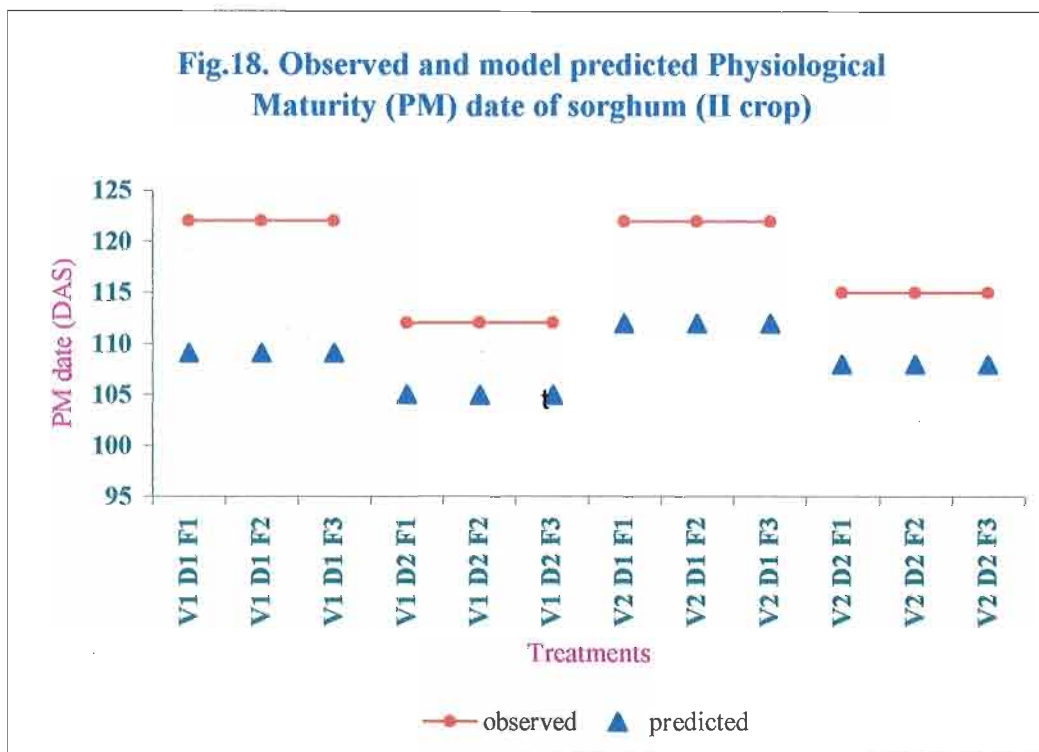
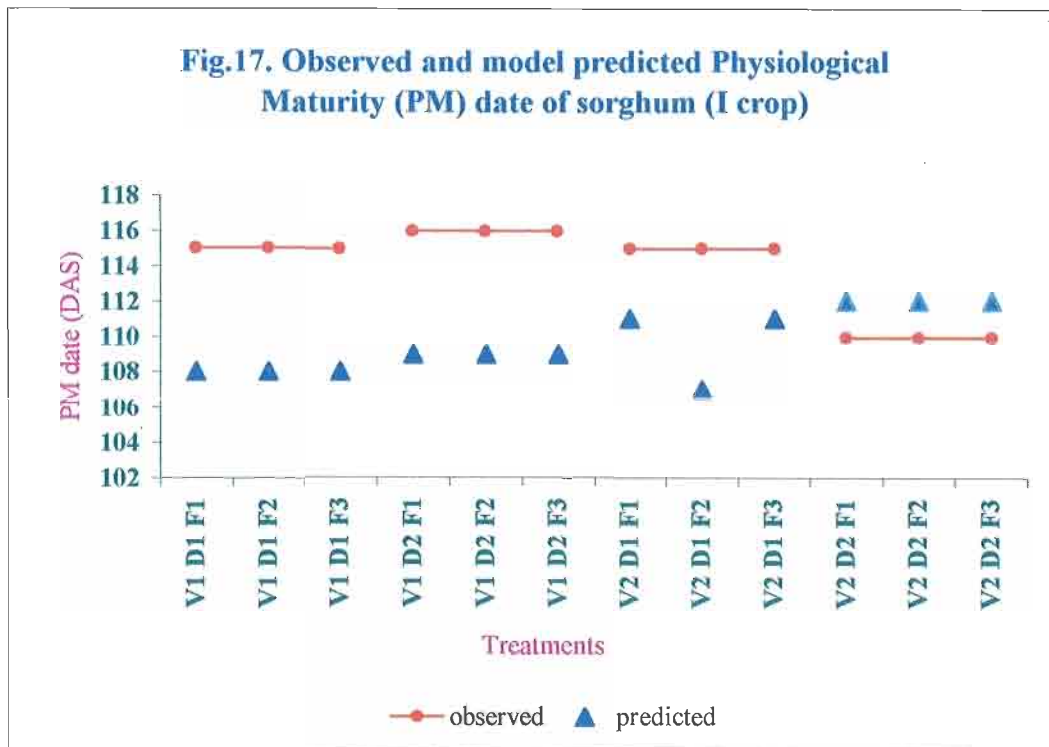
The anthesis time also well predicted in both the years (1999-2000 and 2000-2001). In 1999-2000 (above average rainfall year), the model estimated 71 DAS as the mean anthesis date, while the mean observed anthesis time was 74 DAS (Fig. 15). The RMSE value was 4.97. In 2000-2001 (below average rainfall year) also, the model predicted the anthesis date closer to that of the observed time (Fig. 16). The model estimated 70 DAS as the mean anthesis date, while the mean observed anthesis date was 72 DAS and the RMSE value was 4.34. In both the years, the per cent of RMSE with observed values was less than 10 per cent which indicated that the predictions were correct.

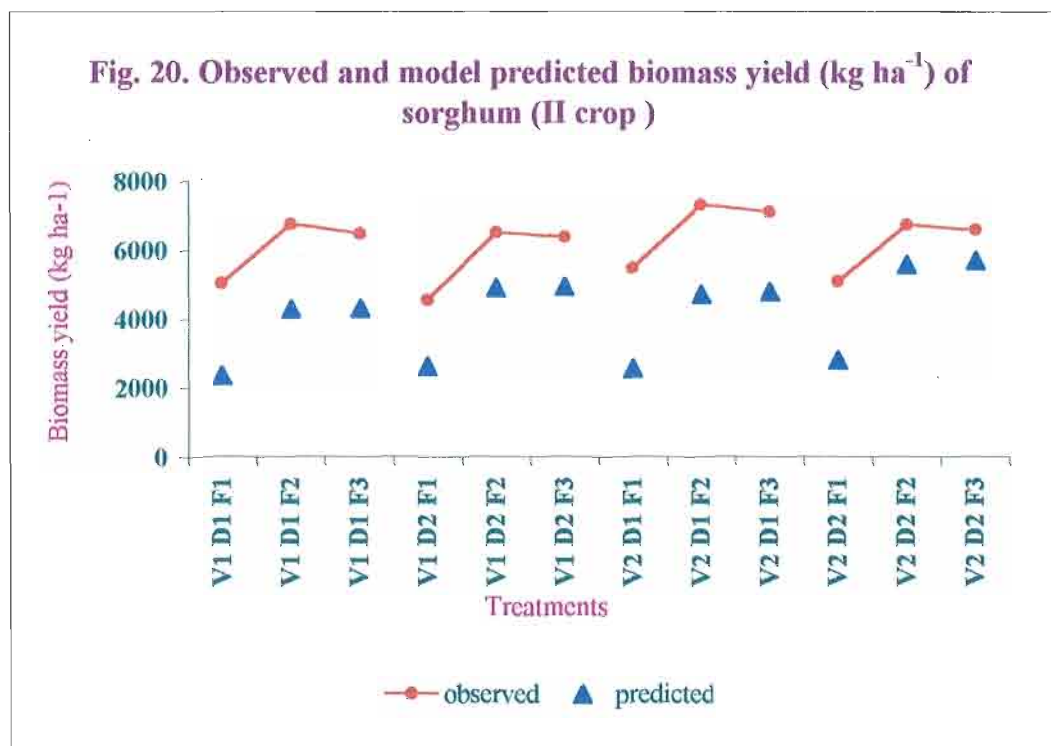
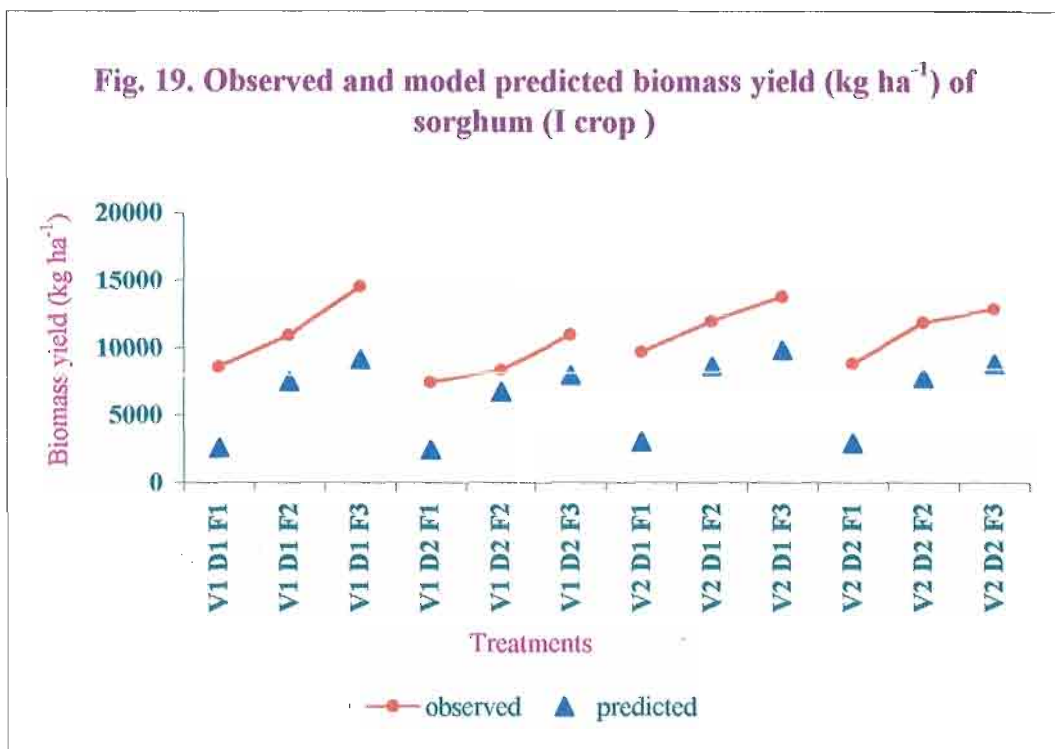
The physiological maturity was slightly under estimated by the model in both the years (1999-2000 and 2000-2001). In 1999-2000, the model predicted 110 DAS as the mean physiological maturity date as against the observed mean value of 114 DAS (Fig. 17). In 2000-2001, the model predicted 109 DAS as the physiological maturity stage as against the observed mean value of 118 DAS (Fig. 18). The CERES-Sorghum probably does not account for the soil moisture extraction from deeper soil layers, which the crop was extracting under moisture deficit conditions. Thus, it was very essential to record complete soil profile moisture measurements upto 2 m depth of soil as suggested by Varshneya *et al.* (1998). However in both the years, the per cent of RMSE with the observed values was within 10 per cent which indicated that the predictions were correct.

### 5.2.2 Biomass yield

In general, the model under estimated the biomass yield in both the years (1999-2000 and 2000-2001). In 1999-2000 (above average rainfall year), the mean observed biomass production was 10802 kg ha<sup>-1</sup>, while the model predicted 6417 kg ha<sup>-1</sup> (Fig. 19). The RMSE was 4606 and the per cent of RMSE with observed values was 32 and 62 per cent with a mean value of 44.5 per cent. The deviation of observed value with predicted value was lesser under higher level of nutrient application and as the nutrient level came down, the deviation got increased. In 2000-2001 (below average rainfall year) also, the model under predicted the biomass yield and the mean







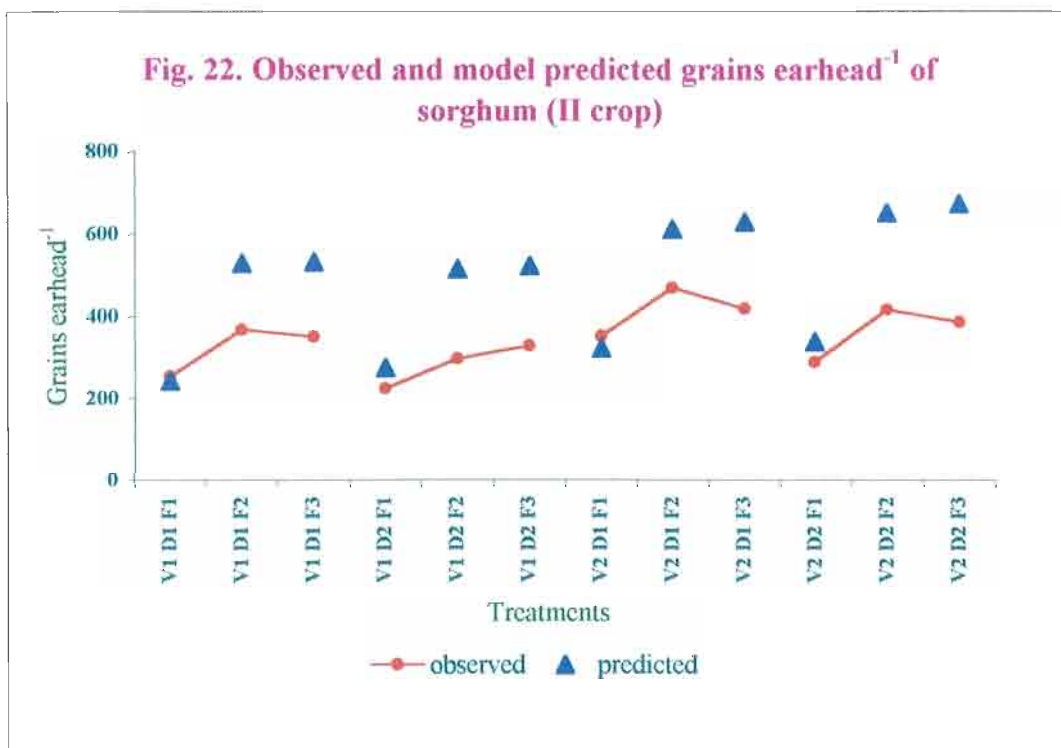
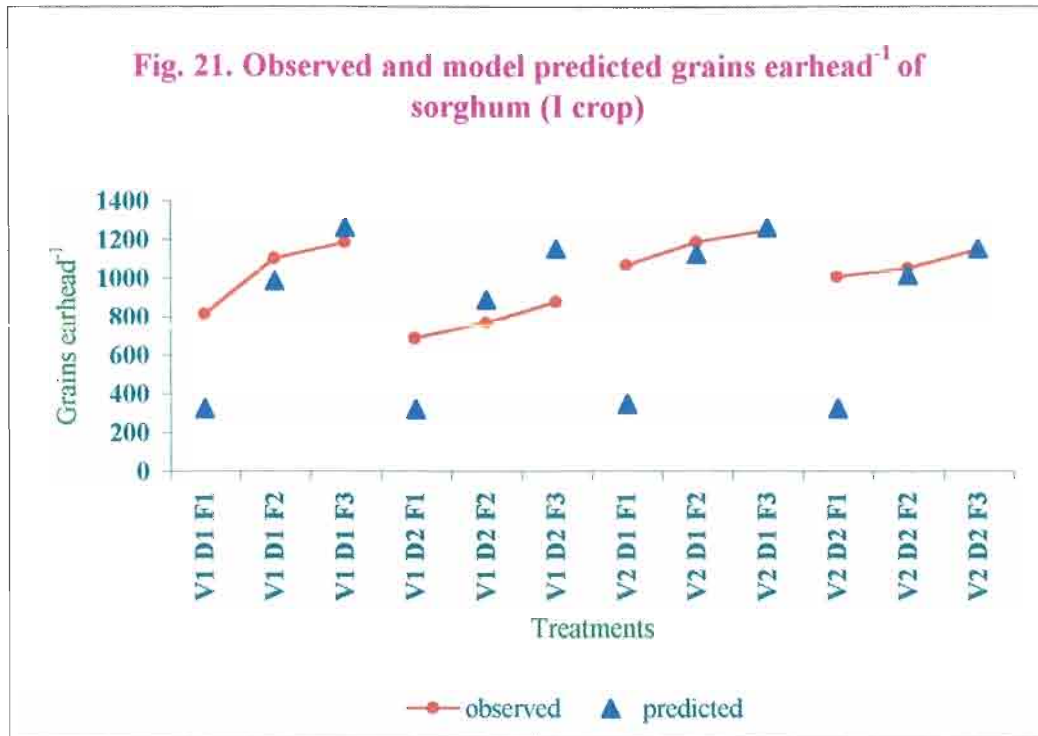
predicted biomass yield was 4139 kg ha<sup>-1</sup> for all the treatments while the observed biomass yield was 6180 kg ha<sup>-1</sup> (Fig. 20). The RMSE was 2131 and the per cent of RMSE with observed values ranged from 29 to 47 per cent with a mean value of 35 per cent. In 2000-2001 also the model highly under predicted the biomass yield under control (no fertilizer nutrient application). Thus the model needed refinement with reference to biomass yield prediction. Varshneya *et al.* (1998) also reported under prediction of biomass yield by CERES-Sorghum model in Rahuri, Maharashtra.

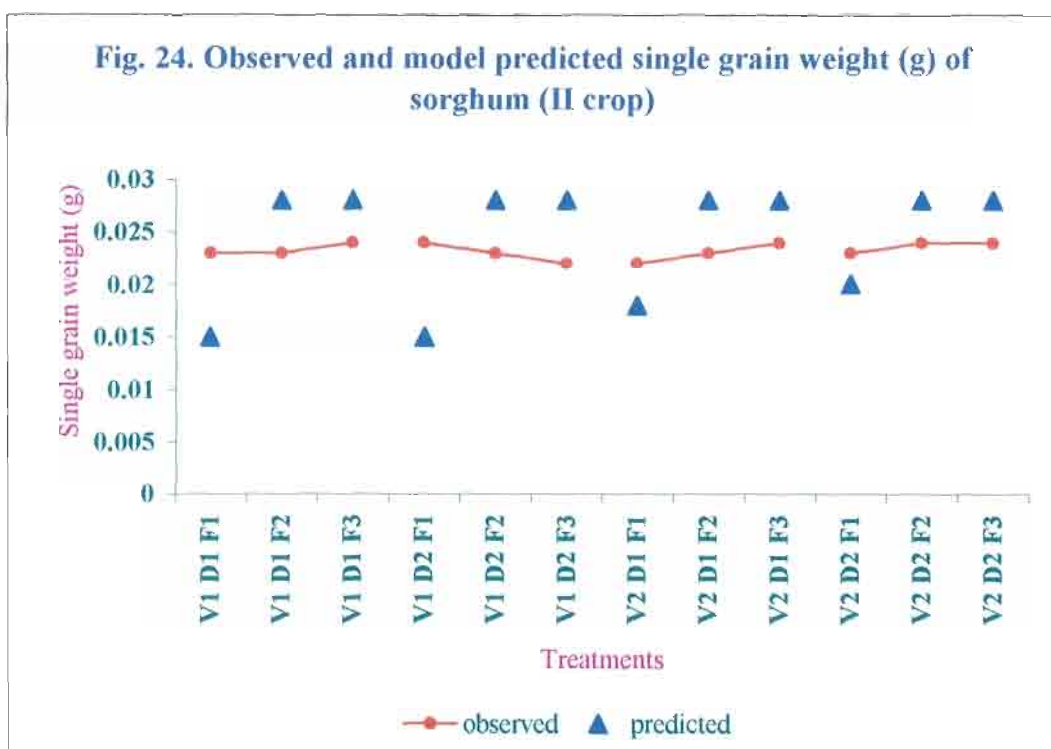
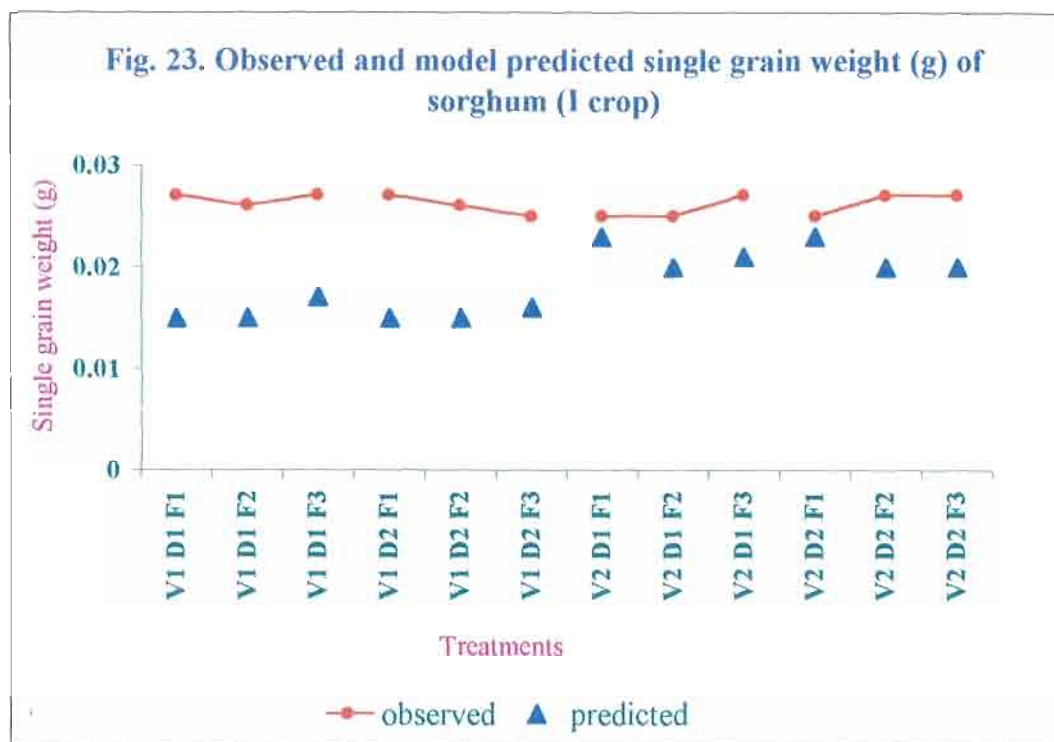
### 5.2.3 Number of grains per earhead

In 1999-2000 (above average rainfall year), the model closely predicted the number of grains earhead<sup>-1</sup> in nutrient applied treatments (F<sub>2</sub> and F<sub>3</sub> levels) and highly under estimated the number of grains earhead<sup>-1</sup> in control (no nutrient application) and was depicted in Fig. 21. The mean predicted number of grains earhead<sup>-1</sup> was 847 as against the mean observed value of 1013. The mean RMSE was 351 and the per cent of RMSE with observed values ranged from 30 to 45 per cent with a mean value of 32 per cent. In contrast, during 2000-2001 (below average rainfall year), the model closely predicted the number of grains earhead<sup>-1</sup> in the case of control (no nutrient application) and the model over estimated the number of grains earhead<sup>-1</sup> in nutrients applied (F<sub>2</sub> and F<sub>3</sub> levels) treatments (Fig. 22). The RMSE value was 171 and the per cent of RMSE with observed values ranged from 36 to 76 per cent with a mean value of 51 per cent.

### 5.2.4 Single grain weight

Kernel weight estimated by the model differed from the observed values in both the years (1999-2000 and 2000-2001). The predicted values were lesser than that of the observed values during 1999-2000 (Fig. 23) and higher than the observed values during 2000-2001 (Fig. 24). This was because, the model estimated kernel weight by dividing the grain weight panicle<sup>-1</sup> by the grain number panicle<sup>-1</sup>. The grain weight was estimated as panicle weight multiplied by thrashing percentage, whereas, total panicle weight depends on the rate of grain filling, panicle aging factor, panicle growth constant and soil moisture stress. In actual practice, earhead size varied under stress condition, but with emerged earhead irrespective of length, grain filling took place and kernel weight did not differ much, while in model panicle size





did not change, whereas total panicle weight changed under stress condition, hence, kernel weight was widely different. Hence the model needed modification for correct prediction of kernel weight as suggested by Varshneya *et al.* (1998).

### 5.2.5 Grain yield

The perusal of data revealed that during 1999-2000, the yield was closely predicted in nutrients applied treatments ( $F_2$  and  $F_3$  levels) and in control (no nutrient application), the yield was highly under estimated irrespective of varieties and times of sowing evaluated (Fig. 25). The mean observed yield was  $2466 \text{ kg ha}^{-1}$  while the model predicted  $2143 \text{ kg ha}^{-1}$  as mean grain yield. The RMSE was 648 and the per cent of RMSE with observed values ranged from 18 to 58 per cent with a mean value of 30 per cent.

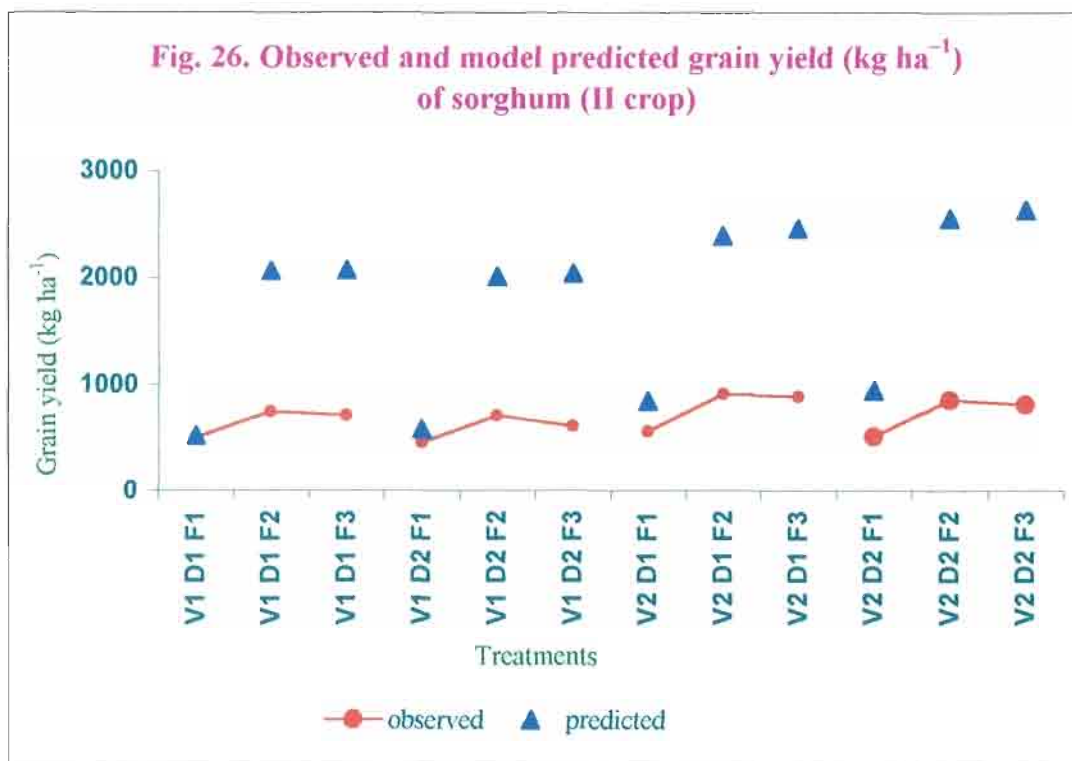
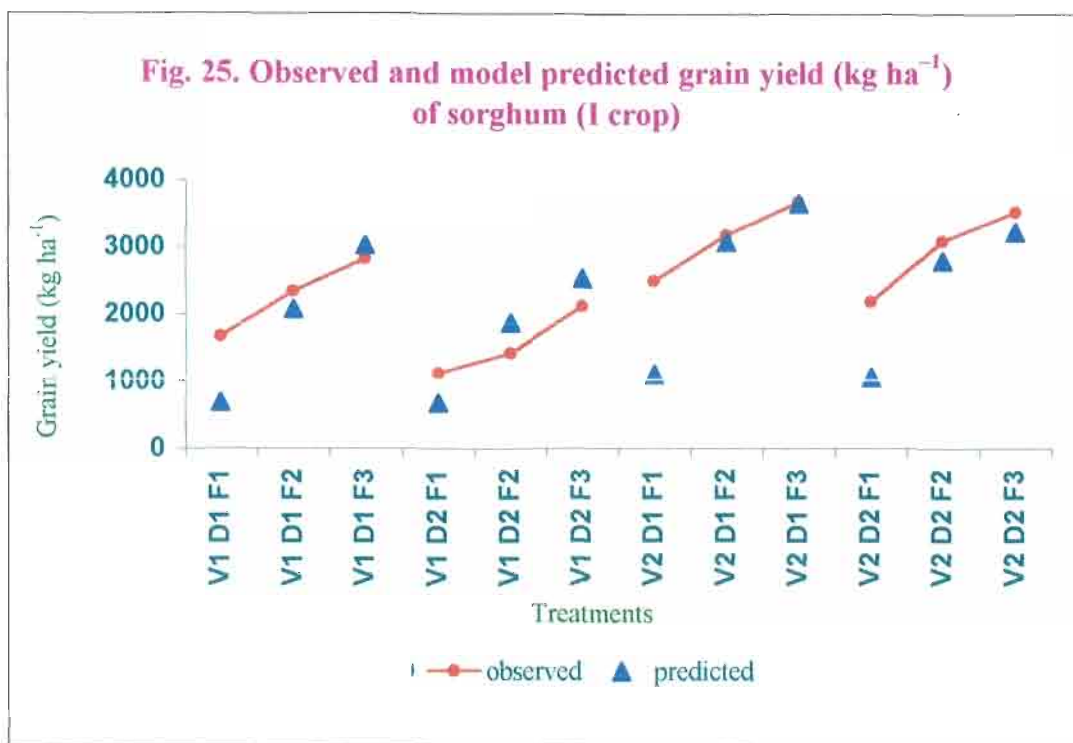
During 2000-2001 (below average rainfall year), the model slightly over estimated the yield of control (no nutrient application) treatment irrespective of varieties and times of sowing (Fig. 26). In respect of nutrient applied ( $F_2$  and  $F_3$  levels) treatments, the model highly over estimated the grain yield irrespective of varieties and times of sowing. The mean observed grain yield was  $682 \text{ kg ha}^{-1}$ , while the model predicted  $1759 \text{ kg ha}^{-1}$  as the mean grain yield. The RMSE value is 1251 and the per cent of RMSE with observed values ranged from 142 to 277 per cent with a mean value of 194 per cent which indicated the failure of the model in predicting the grain yield under moisture stress condition.

The model estimates yield by using the following equation (Ritchie and Algarswamy, 1989).

$$\text{GROPAN} = \text{RGFIL} * \text{PGC} * \text{PAF} * \text{SWDF}_2$$

Where,

- GROPAN = rate of growth of panicle
- PGFIL = the rate of grain filling which is a temperature dependent function, becomes 1 between  $20 - 25^\circ\text{C}$  of minimum temperature, while linearly decreases and becomes 0 at  $\leq 8^\circ\text{C}$  and  $\geq 40^\circ\text{C}$ .
- PGC = the panicle growth constant depends on the panicle size, a varietal character



- PAF = the panicle aging factor which depends upon the age of the panicle after flowering
- SWDF<sub>2</sub> = the soil moisture stress factor

During severe stress conditions, the panicle size was influenced by soil moisture deficit under field condition and the panicle size of a variety would be smaller or larger depending upon the moisture availability. But model did not adequately account for these variations in PGC factor. This resulted in over estimation of grain numbers earhead<sup>-1</sup> and kernel weight (Tables 51 and 52) and resulted in over estimation of yield as reported by Varshneya *et al.* (1998).

### 5.2.6 Sensitivity analysis

The sensitivity analysis option available in DSSAT V.3.5 CERES-Sorghum model allowed the user to evaluate the alternate management strategies or to make tactical or strategic decisions by modifying the default values in the original experiment. The results (simulated yield) of the sensitivity analysis done by modifying the default values of nutrient levels and dates of sowing in the original TNCB 9901.SGX and TNCB0001.SGX experimental files indicated that sorghum varieties differed in their response to N application under different times of sowing.

In the case of CSV 15 during 1999-2000 (above average rainfall year), the grain yield was increased with increased levels of N application (Fig. 27) up to 500 kg ha<sup>-1</sup> for 26<sup>th</sup> September sowing (D<sub>1</sub>) as well as for 1<sup>st</sup> October sowing (D<sub>2</sub>). But when sowing was delayed the response of sorghum to applied N was got reduced and the maximum grain yields obtained under 400 and 120 kg ha<sup>-1</sup> for 6<sup>th</sup> October (D<sub>3</sub>) and 11<sup>th</sup> October (D<sub>4</sub>) sowings. From the simulated yields, economically viable dose of N application was worked out by comparing the cost involved (fertilizer cost) and returns obtained (grain yield) between two consecutive levels of N application.

In the case of CSV 15 sown during 1999-2000 for various dates of sowing of N economically viable N dose was 180, 160, 120 and 120 kg ha<sup>-1</sup> for 26<sup>th</sup> September (D<sub>1</sub>), 1<sup>st</sup> October (D<sub>2</sub>), 6<sup>th</sup> October (D<sub>3</sub>) and 11<sup>th</sup> October (D<sub>4</sub>) sowings, respectively. Similarly for CO 26, the economically viable dose of N application was 140, 140, 120 and 80 kg ha<sup>-1</sup> for 26<sup>th</sup> September (D<sub>1</sub>), 1<sup>st</sup> October (D<sub>2</sub>), 6<sup>th</sup> October (D<sub>3</sub>) and 11<sup>th</sup> October (D<sub>4</sub>) sowings, respectively during 1999-2000 (Fig. 28).

Fig. 27. Simulated grain yield ( $\text{kg ha}^{-1}$ ) of CSV 15 during 1999-2000 (1 crop) by sensitivity analysis

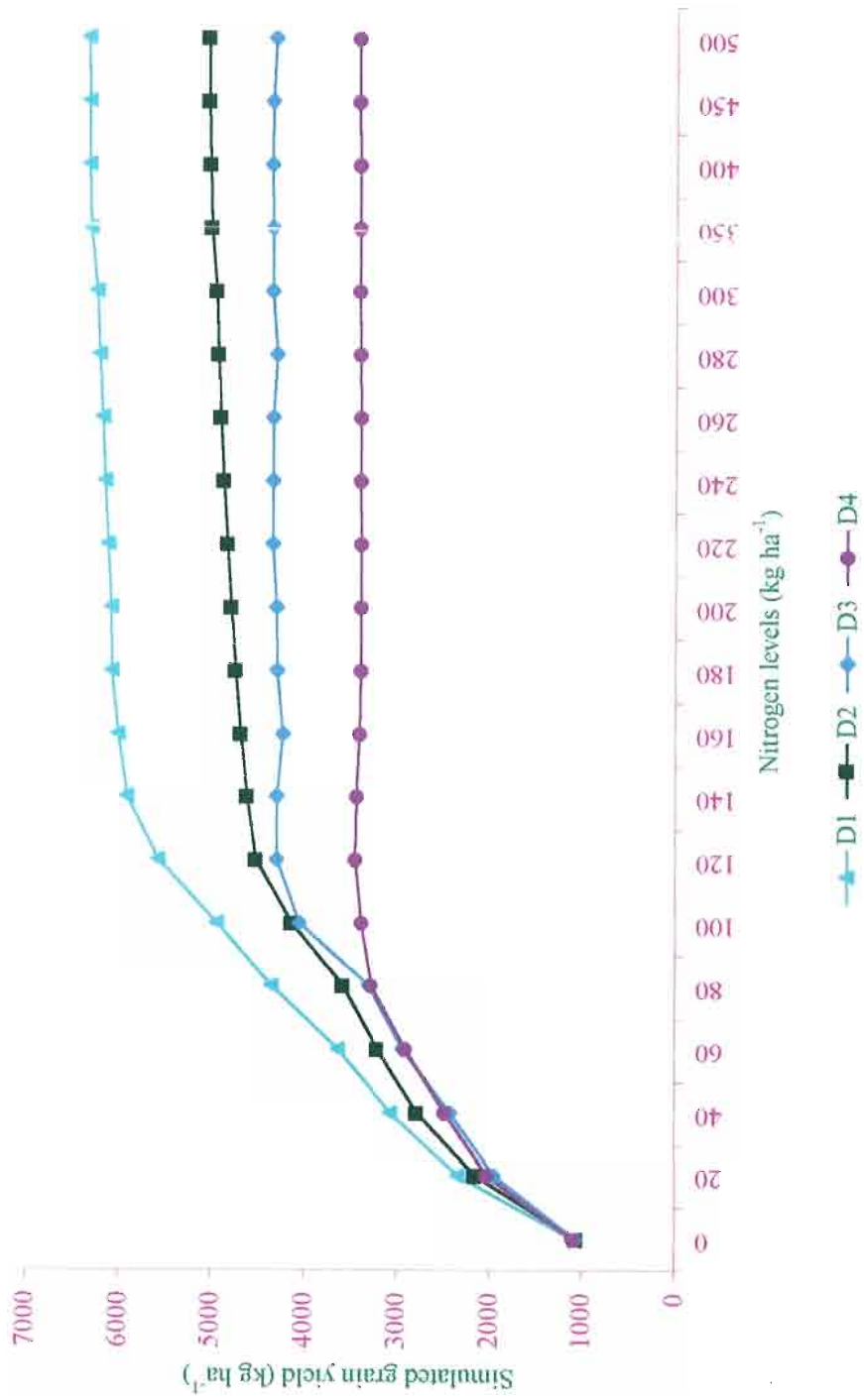
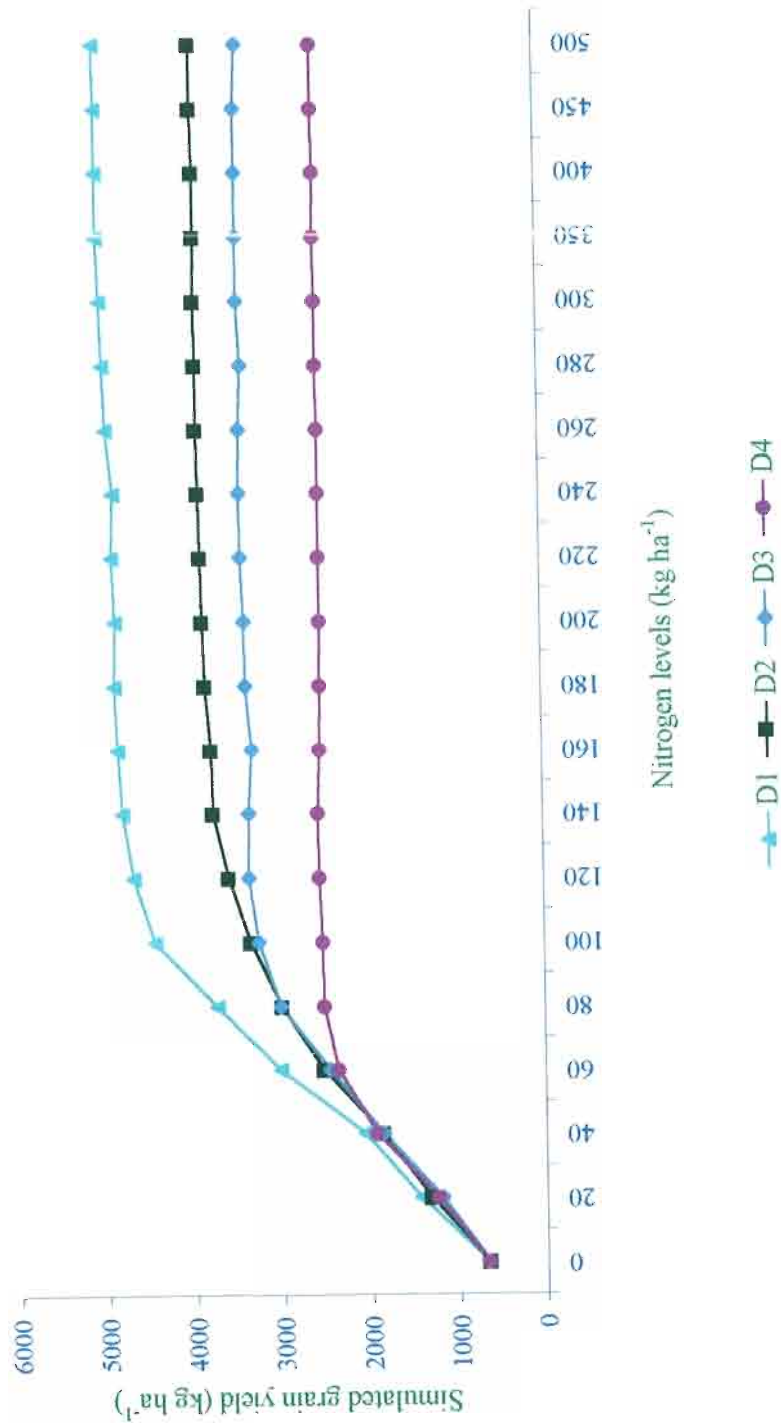


Fig. 28. Simulated grain yield ( $\text{kg ha}^{-1}$ ) of CO 26 during 1999-2000 (1 crop) by sensitivity analysis



During 2000-2001 (below average rainfall year), the variety CSV 15 produced maximum grain yield when the 19<sup>th</sup> September (D<sub>1</sub>), 24<sup>th</sup> September (D<sub>2</sub>), 29<sup>th</sup> September (D<sub>3</sub>) and 4<sup>th</sup> October (D<sub>4</sub>) sown crop were supplied with 100, 140, 180 and 40 kg N ha<sup>-1</sup> (Fig. 29). The economically viable dose of N application was 40, 80, 60 and 40 kg ha<sup>-1</sup> for the 19<sup>th</sup> September (D<sub>1</sub>), 24<sup>th</sup> September (D<sub>2</sub>), 29<sup>th</sup> September (D<sub>3</sub>) and 4<sup>th</sup> October (D<sub>4</sub>) sown crop. Similarly the variety CO 26 also produced maximum grain yield under 19<sup>th</sup> September (D<sub>1</sub>), 24<sup>th</sup> September (D<sub>2</sub>), 29<sup>th</sup> September (D<sub>3</sub>) and 4<sup>th</sup> October (D<sub>4</sub>) sowings when the crop was supplied with 60, 80, 120 and 40 kg N ha<sup>-1</sup>, respectively (Fig. 30). The economically viable dose of N was 40 kg ha<sup>-1</sup>, irrespective of the sowing dates used.

It is finally concluded that sensitivity analysis of DSSAT V.3.5 could be used for simulating sorghum yield for varying situations of rainfall, different dates of sowing and different levels of N, when seasonal climate forecast information are available so as to communicate to farmers to reduce risk under dryland situations.

Fig. 29. Simulated grain yield ( $\text{kg ha}^{-1}$ ) of CSV 15 during 2000-2001 (II crop) by sensitivity analysis

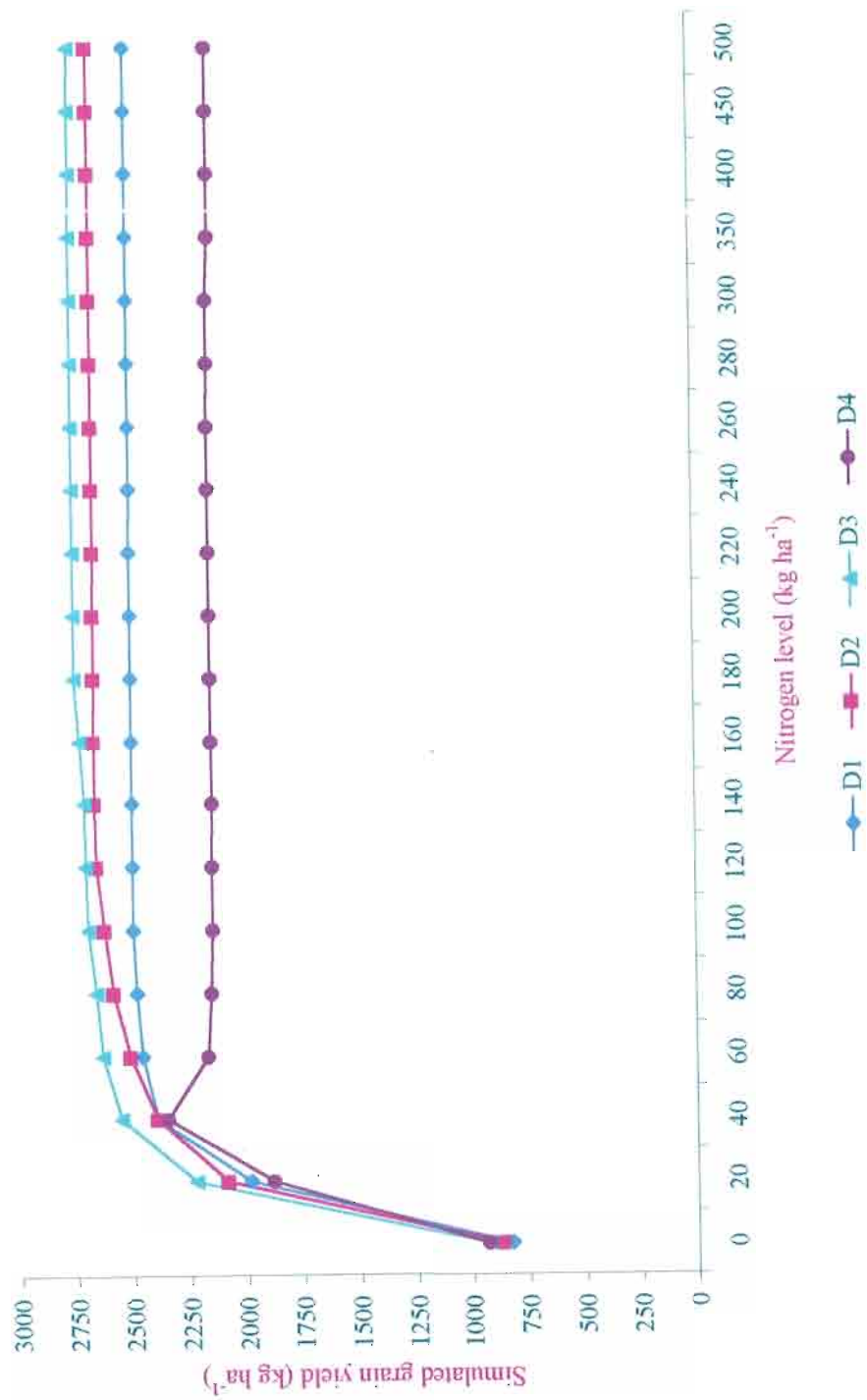
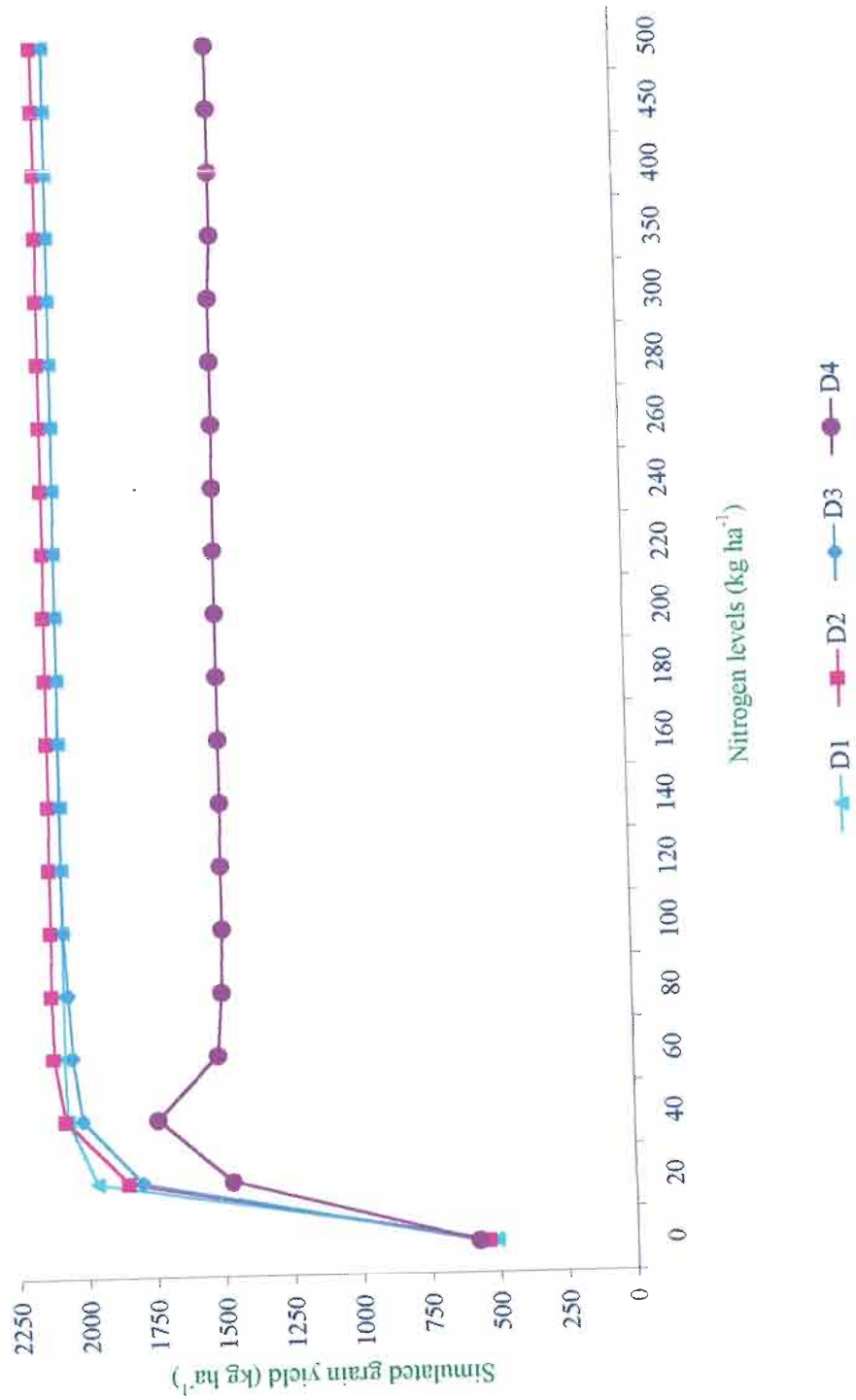


Fig. 30. Simulated grain yield ( $\text{kg ha}^{-1}$ ) of CO 26 during 2000-2001(II crop) by sensitivity analysis



## **SUMMARY AND CONCLUSION**

---

---

## CHAPTER VI

### SUMMARY AND CONCLUSION

Field experiments were conducted at Tamil Nadu Agricultural University Farm, Coimbatore during Northeast monsoon seasons of 1999 and 2000 for evaluating the performance of different sorghum (*Sorghum bicolor* (L.) Moench.) varieties under different sowing dates and levels of Nitrogen and Phosphorus under dryland condition. The study also aimed to evaluate DSSAT V.3.5 Decision Support System (CERES-Sorghum model) for key management practices like choice of varieties, times of sowing and nutrient levels.

The field experiments were laid out in sandy clay loam (*Vertic ustropept*) soils at Eastern Block of Tamil Nadu Agricultural University Farm. Split plot design was adopted and the treatments were replicated thrice in both the years. The treatments consisted of two sowing times (sowing before the receipt of monsoon rainfall (D<sub>1</sub>) and sowing after the receipt of monsoon rainfall (D<sub>2</sub>)) and two varieties (CO 26 (V<sub>1</sub>) and CSV 15 (V<sub>2</sub>)). These two factors were assigned to main plots. Three nutrient levels viz., No nutrient application (F<sub>1</sub>), 40: 20: 0 kg N: P<sub>2</sub>O<sub>5</sub>: K<sub>2</sub>O ha<sup>-1</sup> (F<sub>2</sub>) and 60: 30: 0 kg N: P<sub>2</sub>O<sub>5</sub>: K<sub>2</sub>O ha<sup>-1</sup> (F<sub>3</sub>) were allotted to subplots.

An uniform spacing of 45 x 15 cm was adopted and plant samples were harvested at 7 days interval from 14 DAS onwards for various growth component analysis. All the relevant observations were recorded as indicated in the chapter III.

The inferences and conclusions drawn from the experimental results are presented in this chapter.

- ❖ The 94 years (1907-2000) average rainfall of NEM season of Coimbatore is 324.8 mm and the rainfall received during 1999 NEM season (427.6 mm) was well above the long term average where as the rainfall received during 2000 NEM season (284 mm) was below the long term average rainfall. The returning period worked out by using 94 years NEM season rainfall indicated that the chances for getting the average NEM rainfall of 324.8 mm was 4/9 (four years out of nine years), while the repeatability of NEM of 1999 and 2000 (427.6 and 284 mm) would be 4/18 and 1/2, respectively.

Between the first crop of 1999 and second crop of 2000, there were differences in the quantum of rainfall received as well as its distribution. In the first crop, the rainfall was well distributed through out the entire crop growth period especially at vegetative and flowering stages, which kept the crop under moisture stress free condition. But in the second crop, the rainfall distribution was highly varying both in terms of quantity and distribution and the crop faced prolonged moisture stress from the flowering stage onwards till maturity.

- ❖ The water balance components *viz.*, cumulative rainfall, effective rainfall, water use, soil moisture change, deficit and surplus water were not differed between varieties in both the years. However, the mean water requirement (AET) was lesser for CSV 15 as compared to CO 26 during 1999-2000 (above average rainfall year).
- ❖ Water balance components worked out for different times of sowing in general showed a decreasing trend as the sowing was delayed in both the years. Sowing before the receipt of monsoon rainfall ( $D_1$ ) received more cumulative rainfall and effective rainfall in both the years (above and below average rainfall years) as compared to sowing after the receipt of monsoon rainfall ( $D_2$ ).
- ❖ Soil moisture dynamics observed by both water balance model (Gupta model) and actual measurement (Gravimetric method) showed the same trend for available soil moisture, but this magnitude varied.
- ❖ Varieties and times of sowing had not altered the plant height in both the crops (1999-2000 and 2000-2001), while higher level of nutrient application produced taller plants at vegetative and flowering stages of first crop (above average rainfall year) and such influence was not observed in the second crop (below average rainfall year).
- ❖ The variety CSV 15 and  $D_1$  sowing (sowing before the receipt of monsoon rainfall) produced significantly higher Dry Matter Production (DMP) at all the vegetative, flowering and maturity stages of both the years (1999-2000 and 2000-2001).

- ❖ Higher level of nutrient application ( $F_3$  level) resulted in significantly higher DMP at all stages of first crop (above average rainfall year) as well as at the vegetative stage of the second crop (below average rainfall year). At flowering and maturity stages of second crop,  $F_3$  and  $F_2$  levels of nutrient application were at par and produced significantly higher DMP.
- ❖ Variety CO 26 and  $D_1$  sowing (sowing before the receipt of monsoon rainfall) recorded higher Leaf Area Index (LAI) at flowering and maturity stages of first crop (above average rainfall year) while in the second crop,  $D_2$  sowing (sowing after the receipt of monsoon rainfall) resulted in higher LAI at flowering stage.
- ❖ Higher level of nutrients application (60: 30: 0 kg N:  $P_2O_5$ :  $K_2O$   $ha^{-1}$ ) registered higher LAI at vegetative stage of first crop (above average rainfall year) as well as at 56 DAS of first crop in which  $F_3$  level was at par with  $F_2$  level of nutrient application. In respect of second crop, nutrient application had no significant impact on LAI at any of the crop growth stage studied.
- ❖ Higher Crop Growth Rate (CGR) values were registered by CSV 15 at 14-28, 42-56 and 56-70 DAS of second crop (below average rainfall year). In respect of times of sowing,  $D_2$  sowing (sowing after the receipt of monsoon rainfall) registered higher CGR at 28-42 DAS of first crop while  $D_1$  sowing recorded superior CGR at 42-56 DAS of second crop.
- ❖ Higher level of nutrient application ( $F_3$  level) registered increased CGR at 14-28, 28-42 and 42-56 DAS of first crop (above average rainfall year), where as in the second crop (below average rainfall year),  $F_2$  level resulted in higher CGR at 56-70 and 70-84 DAS.
- ❖ Relative Growth Rate (RGR) was not differed significantly between varieties in both the crops except at 28-42 DAS of second crop (2000-2001) in which CO 26 recorded higher RGR. With reference to times of sowing, in both the crops, at early vegetative stage (28-42 DAS),  $D_2$  sowing recorded superior RGR, while at maturity stage (84 DAS-Harvest),  $D_1$  sowing registered higher RGR.

- ❖ Nutrient levels had no influence on the RGR of first crop, where as in the second crop, F<sub>2</sub> and F<sub>3</sub> levels were at par and produced significantly higher RGR at vegetative stage (14-28 and 28-42 DAS).
- ❖ The variety CSV 15 registered higher Net Assimilation Rate (NAR) between 28 and 42 DAS and between 84 DAS and harvest of first crop (1999-2000), while in the second crop, CO 26 recorded higher NAR between 84 DAS and harvest. The different times of sowing had no impact on NAR in both the crops except at 28-42 DAS of first crop in which D<sub>2</sub> sowing recorded higher NAR.
- ❖ The F<sub>3</sub> and F<sub>2</sub> levels of nutrient application were at par and registered higher NAR at vegetative stage (28-42 DAS) of first crop and at most of the crop growth stages of second crop (2000-2001) except at 56-70 DAS in which F<sub>2</sub> level resulted in superior NAR.
- ❖ Higher root volume and Root: Shoot ratio were recorded by CSV 15 in both the crops (1999-2000 and 2000-2001). In respect of times of sowing, D<sub>1</sub> sowing produced increased root volume and Root: Shoot ratio in most of the crop growth stages.
- ❖ With reference to the impact of nutrient application on root volume and Root: shoot ratio, F<sub>3</sub> level resulted in higher root volume and Root: Shoot ratio in all the growth stages of first crop (above average rainfall year). In the second crop (below average rainfall year), F<sub>3</sub> level of nutrient application recorded higher root volume at vegetative stage while at flowering and maturity stages, F<sub>2</sub> and F<sub>3</sub> levels were at par and produced superior root volume. In all the growth stages of second crop, F<sub>2</sub> level recorded higher Root: Shoot ratio.
- ❖ Varieties had no significant difference for earhead length in the first crop (above average rainfall year), where as in the second crop (below average rainfall year), CSV 15 produced lengthier earheads.
- ❖ The variety CSV 15 produced significantly more number of grains earhead<sup>-1</sup> in both the years (1999-2000 and 2000-2001).

- ❖ Sowing before the receipt of monsoon rainfall ( $D_1$ ) produced higher number of grains earhead<sup>-1</sup> than sowing after the receipt of monsoon rainfall ( $D_2$ ) during 1999-2000 (above average rainfall year).
- ❖ Higher level of nutrient application (60: 30: 0 kg N: P<sub>2</sub>O<sub>5</sub>: K<sub>2</sub>O ha<sup>-1</sup>) gave lengthier earheads with more number of grains earhead<sup>-1</sup> in both the years (1999-2000 and 2000-2001).
- ❖ Higher grain yield was registered by the variety CSV 15 in both the years (1999-2000 and 2000-2001).
- ❖ Sowing before the receipt of monsoon rainfall ( $D_1$ ) produced higher grain yield in the first year (above average rainfall year) while in the second year (below average rainfall year), the difference was not significant.
- ❖ Highest grain yield was registered by higher level of nutrient application ( $F_3$  level) in the first year (above average rainfall year), whereas in the second year (below average rainfall year),  $F_2$  and  $F_3$  levels were at par and produced significantly higher grain yields than control (no nutrient application).
- ❖ All treatments had not influenced the straw yield in both the years (1999-2000 and 2000-2001).
- ❖ The variety CSV 15 registered significantly higher harvest index in the first crop (above average rainfall year).
- ❖ Higher resource use efficiencies viz., Total Rainfall Use Efficiency (TRUE), Effective Rainfall Use Efficiency (ERUE) and Water Use Efficiency (WUE) were recorded by the variety CSV 15 in both the years.
- ❖ Sowing after the receipt of monsoon rainfall ( $D_2$  sowing) in the second year registered higher TRUE and ERUE.
- ❖ Higher level of nutrient application (60: 30: 0 kg N: P<sub>2</sub>O<sub>5</sub>: K<sub>2</sub>O ha<sup>-1</sup>) resulted in higher resource use efficiencies in the first year (above average rainfall year), whereas in the second year  $F_3$  and  $F_2$  levels were at par and registered higher resource use efficiencies.

- ❖ The variety CSV 15 and D<sub>1</sub> sowing recorded higher nutrient uptake (N, P and K) in most of the crop growth stages of both the years (above and below average rainfall years).
- ❖ In the first year (1999-2000), higher level of nutrient application (60: 30: 0 kg N: P<sub>2</sub>O<sub>5</sub>: K<sub>2</sub>O ha<sup>-1</sup>) resulted in higher nutrient uptake, whereas in the second year (2000-2001), F<sub>2</sub> and F<sub>3</sub> levels were at par and recorded significantly higher NPK uptake in most of the crop growth stages.
- ❖ All the treatments had no significant influence on the soil available N, P and K levels at post harvest stage in both the years (1999-2000 and 2000-2001).
- ❖ Sowing of CSV 15 before the receipt of monsoon rainfall with higher level of nutrient application (F<sub>3</sub> level) recorded maximum Benefit: Cost ratio (B: C ratio) during 1999-2000 (above average rainfall year) and during 2000-2001 (below average rainfall year), sowing of CSV 15 before the receipt of monsoon rainfall with F<sub>2</sub> level of nutrient application recorded the maximum B: C ratio.
- ❖ DSSAT V.3.5 Decision Support System's CERES-Sorghum model was evaluated for Coimbatore condition by generating genetic coefficients for the test crop varieties CO 26 and CSV 15. Genetic calculator program of DSSAT V. 3.5 was used for this purpose and Minimum Data Set (MDS) acquired from the separate plots assigned for these purposes were used.
- ❖ DSSAT V.3.5 Decision Support System's CERES-Sorghum model predicted the phenological development of sorghum like panicle initiation, anthesis and physiological maturity closer to that of the observed values in both the years (1999-2000 and 2000-2001).
- ❖ The CERES-Sorghum model under estimated the total biomass production in both the crops (1999-2000 and 2000-2001).
- ❖ The model closely predicted the number of grains earhead<sup>-1</sup> in the nutrient applied treatments of first year (1999-2000) irrespective of varieties and times of sowing while in the control (no nutrient applied treatments) of first year, the model highly under predicted the number of grains earhead<sup>-1</sup>.

In the second year (2000-2001), the model over predicted the number of grains earhead<sup>-1</sup> in the nutrient applied treatments and in control (no nutrient applied treatments), the model predictions closely matched with the observed values irrespective of varieties and times of sowing.

- ❖ The deviation between predicted and observed values of single grain weight were higher in both the years (1999-2000 and 2000-2001).
- ❖ The model closely predicted the grain yield to that of the observed yield in the nutrient applied treatments of first crop whereas, the model highly under predicted the grain yield under control (no nutrient applied treatments) irrespective of the varieties and dates of sowing evaluated.

In respect of second crop, the deviation between the observed yield and predicted yield was very high because of model's over prediction under prolonged moisture stress condition.

- ❖ The sensitivity analysis option provided alternate management strategies for making tactical decision on selecting management practices like level of N application under various dates of sowing.

From the above research highlights given the following conclusions are being drawn:

- ❖ In both the years of experimentation (above and below average rainfall years), sowing before the receipt of monsoon rainfall positively influenced most of the growth and yield parameters and finally resulted in higher sorghum grain yield.
- ❖ The variety CSV 15 performed better than CO 26 under both above and below average rainfall situations and resulted in higher grain yield.
- ❖ Application of higher level of nutrients (60: 30: 0 kg N: P<sub>2</sub>O<sub>5</sub>: K<sub>2</sub>O ha<sup>-1</sup>) resulted in higher yield as well as higher B: C ratio irrespective of varieties and times of sowing during above average rainfall year (1999-2000). But during below average rainfall year (2000-2001), application of 40: 20: 0 kg N: P<sub>2</sub>O<sub>5</sub>: K<sub>2</sub>O ha<sup>-1</sup> resulted in higher grain yield as well as higher B: C ratio.

- ❖ DSSAT V.3.5 CERES-Sorghum model predicted the phenological development of sorghum quite well in both the crops. But inability of the model to correctly predict the growth and yield components especially under moisture stress condition resulted in poor grain yield prediction in the second crop (2000-2001) though the model prediction was fairly good for the first crop (1999-2000).

Considering this, it is recommended that for *Vertisols* of Coimbatore region, sowing of sorghum variety CSV 15 before the receipt of monsoon rainfall with higher level of nutrient application (60: 30: 0 kg N: P<sub>2</sub>O<sub>5</sub>: K<sub>2</sub>O ha<sup>-1</sup>) during above average rainfall years would be economical and with application 40: 20: 0 kg N: P<sub>2</sub>O<sub>5</sub>: K<sub>2</sub>O ha<sup>-1</sup> during below average rainfall years.

The suggested futurology based on the experimentation is as follows:

The sensitivity analysis option of DSSAT V.3.5 may be integrated with agro advisory bulletin of medium range weather forecast and test verified.

Under Seasonal Climate Forecast (SCF), since total seasonal rainfall is predicted well before the start of the season, the tactical decision developed from sensitivity analysis option could be studied with farmers group and assessed.

## **REFERENCES**

---

---

## REFERENCES

- Adhikari, R. N. and Rama Mohan Rao, M.S. 1998. Estimation of water balance and other related parameter in relation to crop growth. *Ad. Agric. Res. India*, **9**: 29-37.
- Ahmed, M. K., Olugremi, L. B. and El-Sebasie, F. A. 1984. Polynomial response of sorghum to varying levels of fertilizers. *J. Res. APAU*, **11**: 49-52.
- Annual Report. 1997-'98. National Research Centre on Sorghum (NRCS-ICAR), Hyderabad, Andhra Pradesh.
- Arunachalam, L. and Subramanian, V. 1984. Comparative economics of selected competitive crops under three different dates of sowing. *Madras Agric. J.*, **71**(11): 701-704.
- Astatke, A., Mohamed Saleem, M. A. and El Wakeel, A. 1995. Soil water dynamics under cereal and forage legume mixtures on drained *Vertisols* in the Ethiopian highlands. *Agric. Water Manage.*, **27**: 17-24.
- Attri, S. D., Lal, B., Anubha Kaushik and Rathore, L. S. 1999. Performance of CERES-Wheat Model in NW India. *In*: Proceedings National Workshop on Dynamic Crop Simulation Modeling for Agrometeorological advisory Services. New Delhi: NCMRWF and DST. pp. 201-214.
- Axel Thomas. 1992. Agricultural water balance of Yunnan province, PR China: agroclimatic zoning with a geographical information system. *Agric. Water Manage.*, **21**: 249-263.
- Ayyangar, G. N. R., Sankara Ayyar, M. A., Hariharan, P. V. and Rajabhooshanam, D. S. 1935. The relation of some plant characters to yield in sorghum. *Indian J. agric. Sci.*, **5**: 75-100.
- \* Backer, E. F. I. and Norman, D. W. 1975. *In*: Proceedings, Cropping System Workshop. IRRI, Los Banos, Philippines: pp. 334 -368.
- Baier, W. and Robertson, G. W. 1965. A new versatile soil moisture budget. *Canadian J. Pl. Sci.*, **46**: 299-315.
- Balasubramanian, A., Ramamoorthy, K. and Purushothaman, S. 1993. Effect of dry seeding and nitrogen level on improved genotype of sorghum (*Sorghum bicolor*) under rainfed condition. *Indian J. Agron.*, **38** (2): 210-213.
- Balasubramanian, T. N., Janarthanam Pillai, Balasubramanian, N. and Balasubramanian, A. 1996. Sustainability planning with agrometeorological observations. *Indian J. Dryland Agric. Res. and Dev.*, **11**(2): 127-129.
- Balyan, J. S. and Singh, S.P. 1985. Effect of plant rectangularity and nitrogen on sorghum under dryland conditions. *Indian J. Agron.*, **30** : 391-392.

- Bhan, S., Singh, H. G. and Singh, A. 1973. Note on root development as an index of drought resistance in sorghum (*sorghum bicolor* L.Moench). *Indian J.agric. Sci.*, **43**: 828-830.
- Bhosekar, V. K. and Kulkarni, B.S. 1990. Effect of level of nitrogen and farm yard manure on grain yield relationship in sorghum and its economic analysis. *Andhra Agric. J.*, **37** : 417-418.
- Bhosekar, V. V. and Raikhelkar, S. V. 1990. Effects of level of nitrogen, Farm yard manure on yield and yield attributing characters of CSH 6 sorghum. *J. Maharashtra agric. Univ.*, **15**(2): 251-252.
- \*Bonnett, O. T. 1979. Response of grain sorghum (*sorghum bicolor* L. Moench) to osmotic stress imposed at various growth stages. Ph.D. Thesis, University of Nebraska, Lincoln, Nebraska.
- Buttery, B. R. 1970. Effect of variation in leaf area index of maize and soybean. *Crop Sci.*, **10**: 9-13.
- Chipanshi, A. C., Ripley, E. A. and Lawford, R. G. 1997. Early prediction of spring wheat yields in Saskatchewan from current and historical weather data using the CERES – Wheat model. *Agric. For. Meteorol.*, **84**: 223-232.
- Chitdeswari, T., Dawood, M. S. and Krishnadoss, D. 1998. Different levels of nitrogen and potassium on the yield and nutrient availability of sorghum under rainfed *Vertisol*. *Madras Agric. J.*, **85**(2): 142-145.
- Chowdhury, A. and Das, H. P. 1993. Soil moisture balance and its application to yield monitoring of rainfed paddy at Raipur. *Mausam*, **44**(4): 343-346.
- Crop Production Guide. 1999. Commissioner of Agriculture, Chennai and Tamil Nadu Agricultural University, Coimbatore.
- Daftardar, S. Y., Narkhede P. L., Surve, S. P. and Ghugare, R. V. 1987. Response of some *Rabi* sorghum cultivars to nitrogen on deep black soil under drought conditions. *J. Maharashtra agric. Univ.*, **12**(1): 130-131.
- Dahatonde, B. N. and Moghe, P. G. 1991. Performance of sorghum genotypes at varied sowing dates in eastern Vidarbha zone. *PKV- Res. J.*, **15**(1): 67-68.
- Daniel Hillel. 1982. Introduction to soil physics. Part VI. Academic publications. pp. 304-319.
- Das, H. P., Kale, A. N. and Ponkshe, A. S. 1993. Effect of soil moisture stress on growth and yield of dryland sorghum. *Mausam*, **44**(3): 261-264.
- Dashora, L. N. and Porwal, B.L. 1994. Response of promising sorghum (*Sorghum bicolor*) genotypes to applied nitrogen in rainy season. *Indian J. Agron.*, **39**(2): 308-309.

- Devarani, N. 1996. Nutrient and drought management packages for rainfed sorghum under *Vertisols*. M.Sc.(Ag.) Thesis, Tamil Nadu Agricultural University, Coimbatore, India.
- Doorenbos, J. and Pruitt, W. O. 1984. Guidelines for predicting crop water requirement. *FAO Irrigation and Drainage paper No. 24*. Rome, Italy.
- Durairaj, S. N., Pandian, J. S. R., Narayanan, A. M. and Iyemperumal, S. 1993. Effect of pre-monsoon sowing on the yield of sorghum under different methods of sowing in *Vertisols* of southern districts. *Madras Agric. J.*, **80**(6): 306-311.
- \*Engel, T. and Jones, J. W. 1995. AEGIS/ WIN User's manual Agric. & Biol. Eng. Dep., Univ. of Florida, Gainesville.
- Enyi, B. A. C. 1962. Comparative growth rates of upland and swamp rice varieties. *Ann. Bot., (N.S.)*, **26**: 467-487.
- Frere, M. and Popov, G. F. 1979. Agrometeorological crop monitoring and forecasting. *Plant production and protection paper No: 17*, Rome, Italy. FAO.
- Gupta, S. K., Tajwani, K. G. and Rambabu. 1972. Effective rainfall of Dehradun under irrigated condition. *In*: Proceedings, Symposium on soil and water management. March 11-13, 1969, Hisar. ICAR. pp. 62-70.
- Gururaja Rao, G., Rajagopal, R., Devakumar, A. S., Sanjeeva Rao, P., George, M. J., Vijayakumar, K. R. and Sethuraj, M. R. 1988. Studies on soil hevea atmosphere system - water relations. *In*: Proceedings, International Conference on Plant Physiologists, New Delhi.
- Halepyati, A. S. and Hosmani, S.A. 1991. Growth and yield of sorghum as influenced by date of sowing and land shaping method in sorghum based cropping systems. *Indian J. Agron.*, **36**(4): 670-672.
- Hirpara, D. S., Patel, J. C., Akbari, K. N. and Sutaria, G. S. 1999. Response of sorghum to nitrogen and phosphorus fertilization on medium black soils. *Ind. J. Agric. Res.*, **33**(1): 57-61.
- Hirpara, D. S., Patel, J. C., Patel, B. S. and Khanpara, V. D. 1992. Evaluation of rainy-season hybrid sorghum (*Sorghum bicolor*) to nitrogen and phosphorus. *Indian J. Agron.*, **37**(3): 581-583.
- Hoogenboom, G., Georgieiv, G. and Singh, U. 1997. Performance of the CERES-Rice model for three locations in the Asian Region. START Rep. 2. Ed. Michael Monton, Anne Phelan and Hassan Virjji. Report on START /WCRP/IGBP/GCTE Workshop, 19-22 February, 1997, Bogor, Indonesia: 43-41.

- Huda, A. K. S. 1987. Simulating yields of sorghum and pearl millet in Semi-Arid Tropics. *Field Crops Res.*, **15**: 309-325.
- Humphries, E. C. 1956. Mineral component and ash analysis in modern methods of plant analysis. *Springer verlag, Berlin*, **1**: 468-502.
- Hundal, S. S. and Prabhjyot Kaur. 1997. Application of the CERES – Wheat model to yield predictions in the irrigated plains of the Indian Punjab. *J. Agric. Science*, **129**: 13-18.
- Hundal, S. S. and Prabhjyot Kaur. 1999. Evaluation of agronomic practices for rice using computer simulation model, CERES-Rice. *Oryza*, **36**.
- ICRISAT. 1978. Annual report of the International Crops Research Institute for Semi-Arid Tropics, Hyderabad (1977 – 78).
- International Benchmark sites Network for Agrotechnology Transfer (IBSNAT) Project Technical Report 2, Field and Laboratory Methods for the Collection of the IBSNAT Minimum Data Set. 1990. Department of Agronomy and Soil Science, Hawaii Institute of Tropical Agriculture and Human Resources, University of Hawaii.
- Ishwar Singh, Chouhan, G. S., Choudhary, L. S. and Singh, I. 1993. Response of sorghum (*Sorghum bicolor*) to nitrogen and phosphorus under western Rajasthan condition. *Indian J. Agron.*, **38**(2): 305-306.
- Itnal, C. J., Sajjan, G.C. and Hebbler, B.G. 1986. Influence of row spacing, sowing time and fertilizer on the grain and fodder yield of *Rabi* sorghum. *Mysore J. agric. Sci.*, **20**: 99-103.
- Jackson, M. L. 1973. Soil chemical analysis. Prentice Hall of India Pvt. Ltd., New Delhi. Indian Reprint. pp. 1-498.
- Jadhav, A. S., Hajare, D. B. and Rathod, R. K. 1991. Effects of split application of nitrogen on yield of sorghum. *J. Maharashtra agric. Univ.*, **16**(3): 401-404.
- Jagtap, B. K. and Pharande, K. S. 1982. Effects of levels of nitrogen, organic matter and moisture regimes on the panicle characters, grain yield and protein content of sorghum (*sorghum bicolor* (L.) Moench). *J. Maharashtra agric. Univ.*, **7**: 51-53.
- \*Jesko, T. 1989. Roots as an integral part of the plant. *In* : Fyziologia Korenoveho systemu Rastlin. *J. Kolek and V. Koninka (Eds.)*. Bratislava, Czechoslovakia, pp. 13-36.
- Jones, J. W. 1993. Decision support systems for agricultural development. *In*: F.W.T. Penning de Vries, P.S. Teng. and K.Metselaar (Editors). Systems Approaches for Agricultural Development Kluwer, Dordrecht, The Netherlands, pp. 459-472.

- Jordan, W. R and Monk, R. L. 1980. Enhancement of drought resistance of sorghum: progress and limitations. *In: Proceedings, Annual Corn and Sorghum Research Conference.* **35**: 185-204.
- Jordan, W. R., Clark, R. B. and Seetharama, N. 1983. The role of edaphic factors in disease development. Paper presented at "Consultative Group discussion on Research Needs and Strategies for Control of Sorghum Root and Stalk Rot Diseases". Rockefeller Foundation, Bellagio study Center, Lake Como, Italy.
- Kandiannan, K. 1988. Integrated production technologies for rainfed sorghum (*Sorghum bicolor* (L.) Moench). M.Sc.(Ag.) Thesis, Tamil Nadu Agricultural University, Coimbatore, India.
- Kanwar, J. S., Rego, T. J. and Seetharama, N. 1984. Fertilizer and water - use efficiency in pearl millet and sorghum in *Vertisols* and *Alfisols* of semiarid India. *Ferti. News*, **4**: 42-52.
- Katayama, K., Ito, O., Adu-Gyamfi, J. J., Rao, T. P., Dacanay, E. V. and Yoneyama, T. 1999. Effects of NPK fertilizer combinations on yield and nitrogen balance in sorghum or pigeonpea on a *Vertisol* in the Semi-Arid Tropics. *Soil science and plant nutrition*, **45** (1) : 143-150.
- Klaij, M. C. and Vachaud, G. 1992. Seasonal water balance of a sandy soil in Niger cropped with pearl millet based on profile moisture measurements. *Agric. Water Manage.*, **21**: 313-330.
- Kolekar, P. T., Umrani, N.K. and Indi, D.V. 1998. Effect of moisture conservation techniques and nitrogen on growth and yield of rainfed *Rabi* sorghum. *J. Maharashtra agric. Univ.*, **23**(1): 26-28.
- Kushwaha, H. S. and Rai, H. K. 1999. Simulation of Evapotranspiration for Irrigated Wheat (*Triticum aestivum* L.) using SPAW. *In: Proceedings, National Workshop on Dynamic Crop Simulation Modeling for Agrometeorological advisory Services.* New Delhi. NCMRWF and DST, pp. 17-30.
- Kushwaha, S. S. and Kushwaha, B. B. 1991. Effect of dry sowing and nitrogen levels on some sorghum genotypes. AISIP Project, College of Agriculture, Indore, India, **32**: 64.
- Lakshmaiah, K., Batu, P.R., Reddy, D.L. and Reddy, K. J. 1989. Performance of sorghum hybrids under varied rainfed conditions in Andhra Pradesh. *J. Res. APAU*, **17**(1): 1-3.
- Lal, H., Hoogenboom, G., Calixte, P., Jones, J. W. and Beinroth, F. H. 1993. Using crop simulation models and GIS for regional productivity analysis. *Trans. ASAE.*, **36**(1): 175-184.
- Landsberg, J. J. 1988. Calculated soil-water balances as tools to evaluate crop performance in drought prone regions. *In: Proceedings, International workshop on the Drought Research Priorities for the Dryland Topics.*

- Hyderabad. International Crop Research Institute on Semi-Arid Tropics. pp. 35-39.
- Lemon, E. R. 1977. *In*: Final Report of the USDA Modeling Coordinating Committee. pp. 1-17.
- Levitt, J. 1972. Responses of plants to environmental stresses. Academic Press, New York, 697 pp.
- Lomte, M. H., Kawarkhe, P.K. and Ateeque, M. 1994. Dry sowing for improving the stability and productivity of rainfed sorghum in deep *Vertisol*. *J. Maharashtra agric. Univ.*, **19**(2): 195-197.
- Loomis, R. S., Rabbinge, R. and Ng, E. 1979. Explanatory models in crop physiology. *Ann. Rev. Plant Physiol.*, **30**: 339-367.
- Mahakulkar, B. V., Wanjari, S. S., Shekar, V.B., Potdukhe, N.R. and Dhope, A.M. 1992. Yield of newly evolved genotypes of rainfed sorghum (*Sorghum bicolor*) under different levels of nitrogen and phosphorus. *Indian J. Agric. Sci.*, **62**(4): 247-248.
- Malik, R. S., Yadav, M.D., Dahiya, S.K. and Oswal, M.C. 1987. Some aspects of water budgeting in region of South West Haryana. *Proc. Second. Conv. Agric. Engrs.*, pp. 51-60.
- Mohammad, S. and Hasan, M.V. 1993. Planting date adjustments, nitrogen management and genotypic alterations of sorghum in a scarce rainfall- shallow soils ecosystem. *Int. J. Tropical Agric.*, **11**(4): 255-261.
- Mohammad, S. and Hasan, M.V. 1994. Assessment of the relative performance of sorghum genotypes and their nitrogen need for optimal production in scarcity rainfall ecosystem. *Crop Res.*, **8**(2): 213-221.
- Mohammad, S. and Hasan, M.V. 1995. Influence of change in genotype-input management on production and profitability of rainfed sorghum (*Sorghum bicolor*). *Indian J. Agric. Sci.*, **65**(3): 202-204.
- Monteny, B. A., Barbier, J.M. and Bernos, C.M. 1985. Determination of the energy exchanges of forest type culture: *Hevea brasiliensis*. *In*: The forest atmosphere interaction (eds. Hutchison, B.A. and B.B. Hicks). pp. 211-233.
- Mulik, S. P., Ghadge, H. L., Jadhav, A.S. and Patil, J. D. 1996. Response of winter season sorghum (*Sorghum bicolor*) varieties to sowing time and nitrogen. *Indian J. Agron.*, **41**(2): 252-255.
- Muthuvel, P., Sivasamy, R., Subramanian, V., Udayasoorian, C. and Sree Ramulu, U.S. 1988. Yield and nutrient uptake under varying levels of N in a sorghum-blackgram intercropping system. *Madrass Agric. J.*, **75**(11-12): 403-408.
- Myers, R. J. K. 1980. The root system of a grain sorghum crop. *Field Crops Res.*, **3**: 53-64.

- Myers, R. J. K. and Asher, C. J. 1982. Mineral nutrition of grain sorghum macro nutrients. *In: Sorghum in the Eighties*. L.R. House, L.K. Mughogho and J.M. Peacock (Eds.). ICRISAT, Patancheru, A.P., India, pp. 161-177.
- Nagre, K. T. and Khedekar, P. K. 1984. Effect of nitrogen sources, levels and times of application on the yield of rainfed sorghum. *PKV- Res. J.*, **8**(1): 65-66.
- Nalayini, P., Velusamy, R., Umapathi, K., Kumaresan, M., Naid, K. V., Solaimalai, A., Ramanna, K. N. and Balasubramanian, T. N. 1998. Computation of length of growing period for different districts of Tamil Nadu. *Madras Agric. J.*, **85**(1): 58-61.
- Narkhede, Ghugare, P. L., Surve, S. P. and Daftardar, S. V. 1985. Nutrition status of rainfed sorghum grown in *Vertisol* in Semi-Arid Tropics. *Current Res. Rep.*, **1**(2): 186-187.
- Nazirkar, R. P. and Sonar, K. R. 1991. Calibration of soil test methods for available nitrogen in black soils (*Inceptisols*) for sorghum. *J. Ind. Soc. Soil Sci.*, **39**(2): 383-385.
- Olsen, S. R., Cole, C. V., Watanabe, F. S. and Dean, L. A. 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. USDA.
- \*Omer, M. A. 1984. Simulation of water budget and sowing responses to planting dates in Western Sudan. *Master Thesis*, Washington State University, Washington.
- Oswal, M. C. and Dakshinamurti, C. 1975. Effect of different tillage practices on water use efficiency of pearl millet and mustard under dry farming conditions. *Indian J. Agric. Sci.*, **45**: 264 -269.
- Otter-Nacke, S., Godwin, D. C. and Ritchie, J. T. 1986. Testing and validating the CERES-Wheat model in diverse environments. Muscle Sholas, Alabama: International Fertilizer Development Centre.
- Pal, M. S., Singh, O. P. and Malik, H. P. S. 1996. Nutrient uptake pattern and quality of sorghum (*Sorghum bicolor* (L.) Moench) genotypes as influenced by fertility levels under rainfed conditions. *Tropic. Agric.*, **73**(1): 6-9.
- Panse, V. G. and Sukhatme, P.V. 1978. Statistical methods for agricultural workers. 3<sup>rd</sup> Edn. ICAR, New Delhi.
- Parameshwarappa, S. G. and Dhanelappagol, M. S. 1998. Promising sorghum varieties for rainfed conditions of northern traditional tract of Karnataka. *Karnataka J. Agric. Sci.*, **11**(4): 1065-1066.
- Patel, R. H., Desai, K. B., Desai, M. S., and Patel, P.G. 1989. Response of sorghum variety GJ-37 to graded levels of nitrogen and phosphorus under rainfed conditions. *GAU Res. J.*, **14**(2): 92-96.

- Patil, A. J., Gaikwad, B.G., Sonawane, S.S. and Patil, J. D. 1996. Response of *Rabi* sorghum to application of phosphorus under dryland conditions. *J. Maharashtra agric. Univ.*, **21**(1): 67-70.
- Patil, S. L. and Sheelavantar, M. N. 2000. Effect of moisture conservation practices, organic sources and nitrogen levels on yield, water use and root development of *Rabi* sorghum (*Sorghum bicolor* (L.) Moench. ) in the *Vertisols* of semi arid tropics. *Ann. Agric. Res.*, **21**(1): 32-36.
- Pearsell, W. H. 1927. Growth studies. VI. On the related size of plant organ. *Ann.Bot.*, **41**: 449-556.
- Penman, H. L. 1948. Natural evaporation for open water, bare soil and grass. *Proc. Roy. Soc. (London) A* / **93**: 120 -145.
- Periyathambi, C. 1980. Effect of pre-monsoon sowing, depth of seed placement and seed hardening on rainfed sorghum. M.Sc.(Ag.) Thesis, Tamil Nadu Agricultural University, Coimbatore, India.
- Pinjari, M. B. and Shinde, M. S. 1995. Physiological basis for varietal differences in yield of *Rabi* sorghum on shallow soils. *Ann.of Plant Physiol.*, **9**(1): 47-50.
- Piper, C. S. 1966. Soil and plant analysis. Hans publishers. Bombay. pp. 368.
- Porter, J. R., Jamieson, P. D. and Wilson, D. R. 1993. Comparison of the wheat simulation models AFRCWHEAT2, CERES - Wheat and SWHEAT for nonlimiting conditions of crop growth. *Field Crops Res.*, **33**: 131-157.
- Porwal, B. L. and Pushpendra Singh. 1992. Study on response of sorghum genotypes to levels of nitrogen. *Madras Agric. J.*, **79**(6): 332-335.
- Priestley, C. H. B. and Taylor, R. J. 1972. On the assessment of surface heat flux and evaporation using large-scale parameters. *Monthly weather rev.*, **100**: 81-92.
- Pushpanathan, J. 1987. Integrated moisture and nutrient management in rainfed sorghum. M.Sc.(Ag.) Thesis, Tamil Nadu Agricultural University, Coimbatore, India.
- Quinby, J. R., Hesketh, J. D. and Voigt, R. L. 1973. Influence of temperature and photoperiod on floral initiation and leaf number in sorghum. *Crop Sci.*, **13**: 243-246.
- \*Quinby, J. R., Kramer, N. W., Stephens, J. C., Lahr, K.A. and Karpar, R.E. 1958. Grain sorghum production in Texas. *Bull. 912, Tex. Agric. Exp. Stn.*
- Rajapandian, J. S., Nalliah Durairaj, S., Murganandam, C. K. and Sree Ramulu, U. S. 1991. Optimum seed rate and method of sowing for pre- monsoon sowing of sorghum under rainfed *Vertisols*. *Madras Agric. J.*, **78**(9-12): 361-364.

- Rama Mohan Rao, M. S., Agnihotri, R. C. and Patil, S. L. 1995. Effect of sources and levels of nitrogen on *Rabi* sorghum in *Vertisols* of semiarid tropics of Bellary. *Indian J. Agric. Res.*, **29**(3): 145-152
- Ramakrishna, Y. S. 1990. Crop growth models - CERES millet. *In: Proceedings, crop growth modeling workshop*. October 4-6, 1990. CASAM, Pune, India, 5 pp.
- Rao, U. M. B. and Vijayalakshmi, K. 1986. Rainfall yield relationship in rainfed sorghum in India. *Mausam*, **37** (4): 529-532.
- Ratikanta Maiti. 1996. Sorghum Science. Oxford and IBH Publishing Co. PVT. Ltd. 352 p.
- Rego, T. J., Monteith, J. L., Piara Singh, K. K., Lee, V. N., Rao, Y. V., Srirama and Singh, P. 1998. Response to fertilizer nitrogen and water of post rainy season sorghum on a *Vertisol*. I. Biomass and light interception. *J. Agric. Sci.*, **131**(4): 411-428.
- Retta, A. and Hanks, R. J. 1981. Manual for using model PLANTGRO. Utah Agric. Station Res. Report. no. 48. Logan, Utah, USA: Utah State Univ.,
- Richardson, C. W. and Ritchie, J. T. 1973. Soil water balance of small watersheds. *Trans. ASAE.*, **16**: 2-77.
- Ritchie, J. T. 1989. Crop models and decision making: Scenario for the future. P106-117 *In: Proceedings, Climate and agricultural systems approaches to decision making*. March 1989, American Meteorological Society, Charleston, SC.
- Ritchie, J. T. and Algarswamy. 1989. Simulation of growth and development in CERES models. *ICRISAT Bulletin No. 12*: 23-39.
- Robertson, G. W. 1983a. Weather based mathematical models for estimating development and ripening of crops. Technical Note No. 180. Geneva, Switzerland: *WMO*. pp. 99.
- Robertson, G. W. 1983b. Guidelines on crop weather models. WCP No. 50. Geneva, Switzerland: *WMO*. pp.115.
- Roy, R. N. and Wright, B. C. 1974. Sorghum growth and nutrient uptake in relation to soil fertility and NPK uptake pattern by various plant parts. *Agron. J.*, **66**(1): 5-10.
- Sahrawat, K. L., Rego, T. J., Burford, J. R., Rahman, M. H., Rao, J. K. and Adam, A. 1995. Response of sorghum to fertilizer phosphorus and its residual value in a *Vertisol*. *Ferti. Res.*, **41**(1): 41-47.
- Sahrawat, K. L., Rego, T.J., Rahman, M.H. and Rao, J.K. 1998. Phosphorus response effects on macro and micro nutrient removal by sorghum under rainfed cropping on a *Vertisol*. *J. Indian Soc. Soil Sci.*, **46**(1): 58-60.

- Sahu, D. D., Sastry, P. S. N. and Dixit, S. K. 1993. Growing season and productivity of rainfed groundnut. *J. oilseeds Res.*, **11**(2): 152-159.
- Sanjeeva Rao, P., Jayarathnam, K. and Sethuraj, M.R. 1990. Water balance studies of the rubber growing regions of South India. *J. Applied Hydrology*, **3**(2): 23-30.
- Sarma, P. S. and Ramana, S. 1993. Response of sorghum to nitrogen and potassium in Alfisol. *J. Potassium Res.*, **9**(2): 171-175.
- Saxton, K. E., Johnson, H. P. and Shaw, R.H. 1974. Modeling evapotranspiration and soil moisture. *Trans. of the ASAE.*, **17**: 673- 677.
- Schouwenaars, J. N., Pelgrum, R. and Swennenhuis, J. 1988. Research on plant soil water relations and its role in understanding sowing strategies. *Water Res. Manage.*, **2**: 255-267.
- Seetharama, N., Wade, L. J., Peacock, J. M., Verma, P. K., Rego, T. J. and Singh, S. 1982. Effect of nitrogen and water stress on leaf area development on Sorghum. *In* : Proceedings, Ninth International Plant Nutrition Colloquium, Vol.2. England, Commonwealth Agricultural Bureaux, Warwick University, pp. 595-606.
- Selvaraju, R. 1990. Influence of irrigation scheduling methods and nitrogen levels on maize (*Zea mays* L.). M.Sc.(Ag.) Thesis, Tamil Nadu Agricultural University, Coimbatore, India.
- Shekh, A. M., Patel, H. R., Parmar, R. S. and Reddy, D. R. 1999. Evaluation and comparison of CERES-Maize model with regression model under middle Gujarat Agro-climatic region. *In* : Proceedings, National Workshop on Dynamic Crop Simulation Modeling for Agrometeorological advisory Services. New Delhi. NCMRWF and DST, pp. 55-66.
- Singh, O. P., Pal, M. S. and Malik, H. P. S. 1996. Performance of grain sorghum (*Sorghum bicolor*) genotypes under rainfed conditions at varying fertility levels. *Indian J. Agron.*, **41**(2): 256-260.
- Singh, U. and Wilkens, P. 1999. Predicting the effect of nitrogen deficiency of crop growth duration and yield. *In*: Proceedings, Fourth International conference on Precision Agriculture. Madison, USA. pp. 1379-1393.
- Singh, Upendra, Thornton, Philip. K., Saka, Alex. R. and Barry Dent, J. 1993. Maize modeling in Malawi: A tool for soil fertility research and development. F.W.T Penning de Vries *et al.* (eds.), Systems Approaches for Agricultural Development, Kluwer Academic Publishers. pp. 253-273.
- Smith, F. W. and Myers, R. J. K. 1978. Patterns of uptake and distribution of phosphorus and nitrogen in grain sorghum during its development. *In*: Proceedings, Eighth International Colloquium on Plant Analysis and Fertilizer Problems. Department of Scientific and Industrial Research, Wellington, New Zealand, pp. 491-498.

- Solaiappan, U. and Subramanian, S. 1995. Effect of sowing dates on sorghum, maize and pigeonpea under dryland situation. *Agric. Sci. Digest*, **15**(3): 111-114.
- Solankey, B. S., Shinde, D.A. and Kanugo, M. 1988. Studies on utilization efficiency of observed NPK by local, improved and hybrid sorghum genotypes. *Sorghum Newsletter*, **31**: 72.
- Somasundaram, S. 2000. Sustainable dryland management through water balance and agro advisory approaches. M.Sc.(Ag.) Thesis, Tamil Nadu Agricultural University, Coimbatore, India.
- Srivastava, U. S. L. and Sardar Singh. 1981. Effect of different sowing dates on the yield of sorghum cultivars. *Indian J. Agron.*, **26**(4): 444-445.
- Stanford, S. and English, L. 1949. Use of flame photometer in rapid soil test for K and Ca. *Agron. J.*, **4**: 446-447.
- Stern, R. D. 1988. Interpreting the results from simulated drought experiments. *In: Proceedings, International workshop on the Drought Research Priorities for the Dryland Tropics*. pp. 27-34.
- \*Stockle, C. O. 1985. Simulation of the effect of water and nitrogen stress on growth and yield of spring wheat. Ph.D thesis, Washington State University, Pullman, Washington, USA.
- Stockle, C. O. and Campbell, G. S. 1985. A simulation model for predicting effect of water stress on yield: an example using corn. *Advances in Irrig.*, **3**: 283-311.
- Stout, D. G., Kannangara, T. and Simpson, G. M. 1978. Drought resistance of *sorghum bicolor*. II. Water stress effects on growth. *Can. J. Plant Sci.*, **58**: 225-233.
- Subbiah, and Asija, C. L. 1956. A rapid procedure for the estimation of available nitrogen in soils. *Curr. Sci.*, **25**: 259-260.
- Subramanian, S., Balasubramanian, T. N., Geethalakshmi, V. and Balasubramaniam, N. 1998. Crop coefficient for sorghum crop of Coimbatore. *Madras Agric. J.*, **85**(5,6): 307-309.
- Suraj Bhan, Uttam, S. K. and Radhey Shyam. 1995. Effect of conservation practices and N levels on yield, water use and root developments of rainfed sorghum "Varsha". *Indian J. Soil Cons.*, **23**(1): 24-29.
- Suraj Bhan, Uttam, S. K., Radhey Shyam, Bhan, S. and Shyam, R. 1998. Effect of moisture conservation practices and nitrogen levels on Jowar (*Sorghum bicolor* L.) under rainfed condition. *Bharatiya- Krishi- Anusandhan- Patrika*, **13**(3-4): 93-99.
- Surakod, V. S. and Itnal, C.J. 1997. Response of *Rabi* sorghum to tillage practices and nitrogen levels in deep black soil under dryland conditions. *Karnataka J. Agric. Sci.*, **10**(2): 307-310.

- Sutaria, G. S., Hirpara, D. S., Akbari, K. N., Khokhani, M. N. and Yusufasi, A. S. 1999. Fertilizer management in sorghum CSH 5 under rainfed agriculture. *Indian J. Agric. Res.*, **33**(2): 87-92.
- Thombre, M. V., Patil, R. C. and Joshi, B. P. 1982. Association of panicle components with grain yield in sorghum. *Sorghum Newsletter*, **25**:17-18.
- Thornthwaite, C. W. 1948. An approach towards a rational classification of climate. *Geographical review*, **38**: 85-94
- Thornthwaite, C. W. and Mather, J. R. 1955. The water balance publications in climatology No.8, Philadelphia, Pennsylvania, USA: Drexel Institute of Technology.
- Thornton, P. K., Bowen, W. T., Ravelo, A. C., Wilkens, P. W., Farmer, G., Brock, J. and Brink, J. E. 1997. Estimating millet production for famine early warning: an application of crop simulation modeling using satellite and ground-based data in Burkina Faso. *Agric For. Meteorol.*, **83**: 95-112.
- Tisdale, S. L., Nelson, W. L., Beaton, J. D. and Havlin, J. L. 1997. Soil Fertility and Fertilizers. Prentice Hall of India. 634 p.
- Tripathi, C. N., Diwakar Naidu and Singh, K. K. 1999. Climate variability and rice productivity in Uttar pradesh A simulation approach. *In*: Proceedings, National Workshop on Dynamic Crop Simulation Modeling for Agrometeorological advisory Services. New Delhi. NCMRWF and DST, pp: 189-200.
- Tripathi, R. Y. and Bhan, S. 1993. Moisture use in dryland sorghum 'Varsha' as influenced due to levels and methods of N application and moisture conservation practices. *Indian J. Soil Cons.*, **21**(3): 57-62.
- Umrani, N. K. and Patil, C. B. 1983. Fertilizer use efficiency in relation with management in drylands. *Ferti. News*, **28**(4): 33-34.
- Umrani, N. K. and Patil, C. B. 1985. Studies on the contribution of production parameters for Rabi sorghum under dryland conditions. *J. Maharashtra agric. Univ.*, **10**(3): 294-297.
- Van Keulen, H. 1975. Simulation of water use and herbage growth in arid regions. Wageningen, Netherlands: PUDOC (Center for agricultural publishing and documentation). pp. 176.
- Vanderlip, R. L. and Reeves, H. E. 1972. Growth stages of sorghum (*Sorghum bicolor* (L.) Moench.). *Agron. J.*, **54** : 13-16.
- Varshneya, M. C. 1999. Crop simulation modeling of sorghum. *In*: Proceedings, National Workshop on Dynamic Crop Simulation Modeling for Agrometeorological advisory Services. New Delhi. NCMRWF and DST, pp. 67-78.

- Varshneya, M. C., Thorat, B. P., Narkhede, B. N., Jadhava, A. S., Naidu, T. R. V. and Karande, B. I. 1998. Performance of CERES-Sorghum model for rainfed sorghum grown on conserved soil moisture. *J. Maharashtra agric. Univ.*, **23** (1) : 55-57.
- Veeraputhiran, R., Sundar Singh, S.D., Geethalakshmi, V., Selvaraju, R. and Balasubramanian, T.N. 1999. Crop planning climatic atlas for Coimbatore (Unpub.). Tamil Nadu Agricultural University, Coimbatore, India.
- Venkataraman, S. 1981. Lysimetric observation on moisture acertion and use by M.35 – 1 Rabi Jowar at Solapur. *J. Maharashtra agric. Univ.*, **6**: 36-40.
- Wanjari, S. S., Mahakulkar, B.V., Shekar, V.B., Potdukhe, N.R. and Dhope, A.M. 1992. Evaluation of sorghum genotypes for their response to applied nitrogen under rainfed conditions. *Agric. Sci. Digest*, **12**(4): 183-184.
- Wanjari, S. S., Mahakulkar, B. V., Shekar, V. B., Potdukhe, N.R. and Dhope, A.M. 1995. Response of *Kharif* sorghum genotypes to applied nitrogen. *Agric. Sci. Digest*, **15**(4): 207-208.
- Warsi, A. S. and Wright, B. C. 1973. Influence of nitrogen on the root growth of grain sorghum. *Indian J. agric. Sci.*, **43**: 142-147.
- Whisler, F. D., Acock, B., Baker, D. N., Fye, R. E., Hodges, H. F., Lambert, J. R., Lemmon, H. E., Mc Kinion, J. M. and Reddt, V. R. 1986. Crop Simulation Models in Agronomic Systems. *Advances in Agronomy*, **40**: 141-208.
- Wright, J. L. 1982. New evapotranspiration crop coefficients. *J. Irrig. Drain. Div., ASCE.*, **108**: 57-74.
- Wright, S. A., Jordan, W. R., Morgan, P. W. and Miller, F. R. 1983. Genetic and hormonal control of shoot and root growth of sorghum. *Agron. J.* **75**: 682-686.
- Yellamanda Reddy, T. and Sankara Reddi, G.H. 1995. Principles of Agronomy. Kalyani Publishers. pp. 78-109.
- Zadoks, J. C., Chang, T. T. and Konzak, C. F. 1974. A decimal code for the growth stages of cereals. *Weed Res.* **14** : 415-421.

\* Originals not seen

## **APPENDICES**

---

---

## Appendix I. Weekly water balance of sorghum crop for Coimbatore

### 1. \*Weekly water balance of sorghum crop for 37<sup>th</sup> standard week during 1999-2000

Week	PPT (mm)	PET	Kc	WR	WU	PPT- WR	SMR	SPL	DEF	WRSI
37	16.40	36.54	0.58	21.19	16.40	-4.79	0.00	0.00	4.79	98.70
38	20.90	37.17	0.39	14.50	14.50	6.40	6.40	0.00	0.00	98.70
39	22.10	30.24	0.32	9.68	9.68	12.42	18.83	0.00	0.00	98.70
40	30.90	28.35	0.33	9.36	9.36	21.54	40.37	0.00	0.00	98.70
41	34.20	25.83	0.79	20.41	20.41	13.79	54.17	0.00	0.00	98.70
42	42.10	23.94	0.95	22.74	22.74	19.36	73.52	0.00	0.00	98.70
43	47.80	22.05	1.09	24.03	24.03	23.77	97.29	0.00	0.00	98.70
44	46.80	20.16	1.65	33.26	33.26	13.54	100.00	10.82	0.00	98.70
45	43.00	18.27	1.47	26.86	26.86	16.14	100.00	16.14	0.00	98.70
46	38.00	20.79	0.92	19.13	19.13	18.87	100.00	18.87	0.00	98.70
47	34.00	18.27	1.27	23.20	23.20	10.80	100.00	10.80	0.00	98.70
48	25.70	21.42	1.61	34.49	34.49	-8.79	91.21	0.00	0.00	98.70
49	24.00	22.05	1.24	27.34	27.34	-3.34	87.87	0.00	0.00	98.70
50	21.10	22.05	1.18	26.02	26.02	-4.92	82.95	0.00	0.00	98.70
51	9.90	21.42	0.98	20.99	20.99	-11.09	71.86	0.00	0.00	98.70
52	13.00	26.46	0.70	18.52	18.52	-5.52	66.34	0.00	0.00	98.70
1	23.70	25.80	0.63	16.25	16.25	7.45	73.79	0.00	0.00	98.70
	493.60			368.00	363.20					

### 2. \*Weekly water balance of sorghum crop for 38<sup>th</sup> standard week during 1999-2000

Week	PPT (mm)	PET	Kc	WR	WU	PPT- WR	SMR	SPL	DEF	WRSI
38	20.90	37.17	0.58	21.56	20.90	-0.66	0.00	0.00	0.66	99.82
39	22.10	30.24	0.39	11.79	11.79	10.31	10.31	0.00	0.00	99.82
40	30.90	28.35	0.32	9.07	9.07	21.83	32.13	0.00	0.00	99.82
41	34.20	25.83	0.33	8.52	8.52	25.68	57.81	0.00	0.00	99.82
42	42.10	23.94	0.79	18.91	18.91	23.19	81.0	0.00	0.00	99.82
43	47.80	22.05	0.95	20.95	20.95	26.85	100.00	7.85	0.00	99.82
44	46.80	20.16	1.09	21.97	21.97	24.83	100.00	24.83	0.00	99.82
45	43.00	18.27	1.65	30.15	30.15	12.85	100.00	12.85	0.00	99.82
46	38.00	20.79	1.47	30.56	30.56	7.44	100.00	7.44	0.00	99.82
47	34.00	18.27	0.92	16.81	16.81	17.19	100.00	17.19	0.00	99.82
48	25.70	21.42	1.27	27.20	27.20	-1.50	98.50	0.00	0.00	99.82
49	24.00	22.05	1.61	35.50	35.50	-11.50	87.00	0.00	0.00	99.82
50	21.10	22.05	1.24	27.34	27.34	-6.24	80.75	0.00	0.00	99.82
51	9.90	21.42	1.18	25.28	25.28	-15.38	65.38	0.00	0.00	99.82
52	13.00	26.46	0.98	25.93	25.93	-12.93	52.45	0.00	0.00	99.82
1	23.70	25.80	0.70	18.06	18.06	5.64	58.09	0.00	0.00	99.82
2	11.20	25.80	0.63	16.25	16.25	-5.05	53.03	0.00	0.00	99.82
	488.40			365.90	365.20					

\* These sowing weeks have been taken for analysis based on experimental results of Somasundaram (2000)

PPT	= Precipitation (mm)	PET	= potential Evapotranspiration (mm)
Kc	= Crop coefficient	WR	= Water requirement (mm)
WU	= Water used (mm)	SMR	= Soil moisture (mm)
SPL	= Surplus (mm)	DEF	= Deficit (mm)
WRSI	= Water Requirement Saturation Index		

Appendix II. Soil morphological characteristics and physio-chemical properties of the experimental field  
Morphological characteristics

Horizon	Ap	BW <sub>1</sub>	BW <sub>2</sub>	BW <sub>3</sub>	BW <sub>4</sub>	BW/C <sub>1</sub>	C <sub>2</sub>
Depth (cm)	0-12	12-42	42-60	60-85	85-105	105-175	175-195
Average Thickness	12	30	18	25	20	70	20
Boundary	Clear Smooth	Clear Smooth	Clear Smooth	Gradual Wavy	Gradual Wavy	-	-
Colour	Dry	DGB (10YR4/2)	-	Dark Brown (10YR6/3)	Brown (10YR5/3)	Brown (10YR5/4)	-
	Moist	Very Dark Grey Brown (10YR3/2)	Very Dark Grey Brown (10YR3/2)	Dark Brown (10YR4/3)	Dark brown (10YR6/3)	Dark brown (10YR4/4)	-
	Moist Rubbed	-	-	-	-	-	Dark brown (10YR6/3)
Mottling	-	-	-	-	-	-	-
Structure	Moderate Medium Sub angular Blocky	strong Medium Sub angular Blocky	strong Medium Sub angular Blocky	strong Medium Sub angular Blocky	strong Medium Sub angular Blocky	strong Medium Sub angular Blocky	-
	Hard	Very Hard	Very Hard	Slightly Hard	Hard	Slightly Hard	Slightly Hard
Consistency	Firm	Firm	Firm	Slightly firm	Firm	Slightly firm	Slightly firm
	Slightly plastic	Slightly plastic	Slightly plastic	Slightly Sticky – Slightly Plastic	Slightly plastic	SSLS	SSLS
Texture	Clay loam	Sandy clay	Sandy clay	Sandy Clay Loam	Sandy clay	Sandy clay	Gravelly SCL to SC
Cutans	-	-	-	-	-	-	-
Roots	Few Fine	Few Fine	Very Few Fine	Very Few Fine	-	-	-
Pores size	Fine	Fine	Fine	Fine	Fine Moderate	Fine Moderate	Fine Moderate
Pore number	Clay	Clay	Clay	Coarse Fine	Coarse Fine	Coarse Fine	Coarse Fine
CaCO <sub>3</sub>	Eses	Effervescence	Effervescence	Effervescence	-	-	-
Permeability	Moderately Slight	Moderately Slight	Moderately Slight	Moderate	Moderately Slight	Moderate	Moderate

## II. Physico chemical properties

Properties	AP	BW <sub>1</sub>	BW <sub>2</sub>	BW <sub>3</sub>	BW <sub>4</sub>	BW/C <sub>1</sub>	C <sub>2</sub>
Sand (%)	45	50	50	67	45	68	68
Silt (%)	25	15	12	9	15	12	12
Clay (%)	30	35	38	24	40	20	20
BD	1.36	1.36	1.39	1.45	1.45	1.50	1.50
FC	18.08	18.08	17.95	17.55	17.05	17.20	17.0
PWP	10.09	10.09	11.20	11.05	11.50	12.01	12.20
pH	7.90	7.90	8.0	8.2	8.0	8.1	8.0
Available N (kg ha <sup>-1</sup> )	120.4	120.4	137.2	131.6	130.2	215.2	302.4
Available P (kg ha <sup>-1</sup> )	12.5	15.0	13.0	15	18.0	18.0	20.0
Available K (kg ha <sup>-1</sup> )	370	390	290	250	380	398	320
Organic carbon (%)	0.45	0.21	0.12	0.06	0.17	0.21	0.33

Appendix III. Description of various growth stages of sorghum

**1. Vegetative stage**

**Germination**

- 00 Seed
- 01 Start of imbibition
- 02 Imbibition
- 03 Imbibition completed
- 04 Radicle emergence from coleoptile
- 05 Radicle emergence from coleoptile
- 06 Coleoptile emerged from seed coat
- 07 Coleoptile emerged from seed coat
- 08 Leaf just at coleoptile tip
- 09 Leaf just at coleoptile tip

**2. Seedling growth**

- 10 First leaf through coleoptile
- 11 First leaf unfolded
- 12 Two leaves unfolded
- 13 Three leaves unfolded
- 14 Four leaves unfolded
- 15 Five leaves unfolded
- 16 Six leaves unfolded
- 17 Seven leaves unfolded
- 18 Eight leaves unfolded
- 19 Nine leaves unfolded

**3. Tillering**

- 20 Main shoot only
- 21 Main shoot and one tiller
- 22 Main shoot and two tiller
- 23 Main shoot and three tiller

Cont'd.,

Cont'n.,

#### 4. Stem elongation

- 30 Nodes not detectable
- 31 1<sup>st</sup> node detectable
- 32 2<sup>nd</sup> node detectable
- 33 3<sup>rd</sup> node detectable
- 34 4<sup>th</sup> node detectable
- 35 5<sup>th</sup> node detectable
- 36 6<sup>th</sup> node detectable
- 37 Flag leaf just visible
- 38 Flag leaf just visible
- 39 Flag leaf ligule just visible

#### 5. Booting

- 40 Flag leaf ligule just visible
- 41 Flag leaf sheath extending
- 42 Flag leaf sheath extending
- 43 Boot just visibly swollen
- 44 Boot just visibly swollen
- 45 Boot swollen
- 46 Boot swollen
- 47 Flag leaf sheath opening
- 48 Flag leaf sheath opening
- 49 First awns visible

#### 6. Reproductive stage

##### Emergence

- 50 First spikelet of ear just visible
- 51 First spikelet of ear just visible
- 52 1/4<sup>th</sup> of ear emerged
- 53 1/4<sup>th</sup> of ear emerged
- 54 1/2 of ear emerged
- 55 1/2 of ear emerged
- 56 3/4<sup>th</sup> of ear emerged
- 57 3/4<sup>th</sup> of ear emerged
- 58 Complete emergence
- 59 Complete emergence

Cont'd.,

Cont'n.,

### 7. Flowering

- 60 Beginning of flowering
- 61 Beginning of flowering
- 62 Flowering (1/4<sup>th</sup> completed)
- 63 Flowering (1/4<sup>th</sup> completed)
- 64 Flowering (1/4<sup>th</sup> completed)
- 65 Flowering halfway
- 66 Flowering halfway
- 67 Flowering (3/4<sup>th</sup> completed)
- 68 Flowering (3/4<sup>th</sup> completed)
- 69 Complete flowering

### 8. Milk development

- 70 Seed coat water ripe
- 71 Seed coat water ripe
- 72 Seed coat water ripe
- 73 Early milk
- 74 Early milk
- 75 Medium milk (increase in solids of liquid endosperm, notable when crushing the seed between fingers)
- 76 Medium milk (increase in solids of liquid endosperm, notable when crushing the seed between fingers)
- 77 Late milk
- 78 Late milk
- 79 Late milk

### 9. Dough development

- 80 Late milk stage
- 81 Late milk stage
- 82 Late milk stage
- 83 Early dough
- 84 Early dough
- 85 Soft dough (Finger nail impression not held)
- 86 Soft dough (Finger nail impression not held)

Cont'd.,

Cont'n.,

- 87 Hard dough (Finger nail impression held, head losing chlorophyll)
- 88 Hard dough (Finger nail impression held, head losing chlorophyll)
- 89 Hard dough (Finger nail impression held, head losing chlorophyll)
- 90 Hard dough (Finger nail impression held, head losing chlorophyll)
- 91 Seed coat hard (Difficult to divide by thumb nail)
- 92 Seed coat hard (can no longer be detected by thumb nail)
- 93 Seed coat loosening in day time

Appendix IV. Effect of varieties and times of sowing on the daily water balance components of sorghum crop during 1999 NEM and 2000 NEM

1. Daily water balance components of CO 26 variety (V<sub>1</sub>) under D<sub>1</sub> sowing (1999 NEM)

Date	Ep (mm)	Kp	PET (mm)	Kc	Et sorghum (mm)	RF (mm)	RF-ET (mm)	SM (mm)	SPL (mm)	DEF (mm)
09/13/99	6.8	0.8	5.44	0.20	1.09	0.00	-1.09	0.00	0	0.00
09/14/99	7.80	0.80	6.24	0.20	1.25	0.00	-1.25	0.00	0.00	0.00
09/15/99	7.00	0.80	5.60	0.20	1.12	0.00	-1.12	0.00	0.00	0.00
09/16/99	6.80	0.80	5.44	0.20	1.09	0.00	-1.09	0.00	0.00	0.00
09/17/99	6.00	0.80	4.80	0.20	0.96	0.00	-0.96	0.00	0.00	0.00
09/18/99	4.60	0.80	3.68	0.20	0.74	0.00	-0.74	0.00	0.00	0.00
09/19/99	5.20	0.80	4.16	0.20	0.83	0.00	-0.83	0.00	0.00	0.00
09/20/99	6.00	0.80	4.80	0.20	0.96	0.00	-0.96	0.00	0.00	0.00
09/21/99	5.60	0.80	4.48	0.20	0.90	0.00	-0.90	0.00	0.00	0.00
09/22/99	5.40	0.80	4.32	0.20	0.86	0.00	-0.86	0.00	0.00	0.00
09/23/99	6.40	0.80	5.12	0.20	1.02	0.00	-1.02	0.00	0.00	0.00
09/24/99	6.00	0.80	4.80	0.20	0.96	0.00	-0.96	0.00	0.00	0.00
09/25/99	5.60	0.80	4.48	0.20	0.90	0.00	-0.90	0.00	0.00	0.00
09/26/99	6.00	0.80	4.80	0.20	0.96	0.00	-0.96	0.00	0.00	0.00
09/27/99	4.00	0.80	3.20	0.58	1.86	18.20	16.34	16.34	0.00	0.00
09/28/99	2.00	0.80	1.60	0.58	0.93	3.80	2.87	19.22	0.00	0.00
09/29/99	3.00	0.80	2.40	0.58	1.39	5.60	4.21	23.42	0.00	0.00
09/30/99	3.40	0.80	2.72	0.58	1.58	9.00	7.42	30.85	0.00	0.00
10/01/99	5.80	0.80	4.64	0.58	2.69	0.00	-2.69	28.16	0.00	1.62
10/02/99	4.40	0.80	3.52	0.58	2.04	10.00	7.96	36.11	0.00	0.00
10/03/99	3.00	0.80	2.40	0.58	1.39	0.00	-1.39	34.72	0.00	0.84
10/04/99	4.00	0.80	3.20	0.58	1.86	26.00	24.14	58.87	0.00	0.00
10/05/99	3.00	0.80	2.40	0.58	1.39	26.40	25.01	83.87	0.00	0.00
10/06/99	2.00	0.80	1.60	0.39	0.62	0.50	-0.12	83.75	0.00	0.30
10/07/99	3.50	0.80	2.80	0.39	1.09	15.50	14.41	98.16	0.00	0.00
10/08/99	3.40	0.80	2.72	0.39	1.06	3.70	2.64	100.00	0.80	0.00
10/09/99	4.70	0.80	3.76	0.39	1.47	17.50	16.03	100.00	16.03	0.00
10/10/99	4.20	0.80	3.36	0.39	1.31	0.60	-0.71	99.29	0.00	1.08
10/11/99	4.60	0.80	3.68	0.39	1.44	0.00	-1.44	97.85	0.00	1.84
10/12/99	4.40	0.80	3.52	0.39	1.37	0.50	-0.87	96.98	0.00	1.26
10/13/99	4.00	0.80	3.20	0.32	1.02	1.80	0.78	97.76	0.00	0.00
10/14/99	4.00	0.80	3.20	0.32	1.02	2.40	1.38	99.13	0.00	0.00
10/15/99	4.20	0.80	3.36	0.32	1.08	7.00	5.92	100.00	5.06	0.00
10/16/99	3.50	0.80	2.80	0.32	0.90	67.40	66.50	100.00	66.50	0.00
10/17/99	3.50	0.80	2.80	0.32	0.90	51.00	50.10	100.00	50.10	0.00
10/18/99	2.80	0.80	2.24	0.32	0.72	17.00	16.28	100.00	16.28	0.00
10/19/99	3.60	0.80	2.88	0.32	0.92	0.50	-0.42	99.58	0.00	1.52
10/20/99	3.30	0.80	2.64	0.33	0.87	26.50	25.63	100.00	25.21	0.00
10/21/99	3.00	0.80	2.40	0.33	0.79	1.00	0.21	100.00	0.21	0.68
10/22/99	3.00	0.80	2.40	0.33	0.79	0.00	-0.79	99.21	0.00	1.68
10/23/99	4.50	0.80	3.60	0.33	1.19	10.50	9.31	100.00	8.52	0.00
10/24/99	3.95	0.80	3.16	0.33	1.04	10.40	9.36	100.00	9.36	0.00
10/25/99	3.40	0.80	2.72	0.33	0.90	3.50	2.60	100.00	2.60	0.00
10/26/99	3.00	0.80	2.40	0.33	0.79	2.50	1.71	100.00	1.71	0.00
10/27/99	2.00	0.80	1.60	0.79	1.26	0.00	-1.26	98.74	0.00	1.12
10/28/99	2.00	0.80	1.60	0.79	1.26	0.00	-1.26	97.47	0.00	1.12

Cont'd.,

Cont'n.,

Date	Ep (mm)	Kp	PET (mm)	Kc	Et sorghum (mm)	RF (mm)	RF-ET (mm)	SM (mm)	SPL (mm)	DEF (mm)
10/29/99	4.00	0.80	3.20	0.79	2.53	1.00	-1.53	95.94	0.00	1.56
10/30/99	3.00	0.80	2.40	0.79	1.90	0.00	-1.90	94.05	0.00	1.92
10/31/99	2.40	0.80	1.92	0.79	1.52	0.00	-1.52	92.53	0.00	1.54
11/01/99	3.40	0.80	2.72	0.79	2.15	0.00	-2.15	90.38	0.00	2.18
11/02/99	3.60	0.80	2.88	0.79	2.28	0.00	-2.28	88.11	0.00	2.30
11/03/99	3.00	0.80	2.40	0.95	2.28	0.00	-2.28	85.83	0.00	1.92
11/04/99	3.00	0.80	2.40	0.95	2.28	0.00	-2.28	83.55	0.00	1.92
11/05/99	2.70	0.80	2.16	0.95	2.05	4.80	2.75	86.30	0.00	0.00
11/06/99	2.70	0.80	2.16	0.95	2.05	23.00	20.95	100.00	7.24	0.00
11/07/99	2.40	0.80	1.92	0.95	1.82	0.00	-1.82	98.18	0.00	1.54
11/08/99	3.20	0.80	2.56	0.95	2.43	0.00	-2.43	95.74	0.00	2.05
11/09/99	3.80	0.80	3.04	0.95	2.89	0.00	-2.89	92.86	0.00	2.43
11/10/99	4.20	0.80	3.36	1.09	3.66	0.00	-3.66	89.19	0.00	2.69
11/11/99	3.80	0.80	3.04	1.09	3.31	0.00	-3.31	85.88	0.00	2.43
11/12/99	4.00	0.80	3.20	1.09	3.49	0.00	-3.49	82.39	0.00	2.56
11/13/99	3.00	0.80	2.40	1.09	2.62	0.00	-2.62	79.78	0.00	1.92
11/14/99	3.20	0.80	2.56	1.09	2.79	0.00	-2.79	76.99	0.00	2.05
11/15/99	4.40	0.80	3.52	1.09	3.84	0.00	-3.84	73.15	0.00	2.82
11/16/99	3.80	0.80	3.04	1.09	3.31	0.00	-3.31	69.84	0.00	2.43
11/17/99	4.00	0.80	3.20	1.65	5.28	0.00	-5.28	64.56	0.00	2.56
11/18/99	3.00	0.80	2.40	1.65	3.96	0.00	-3.96	60.60	0.00	2.40
11/19/99	4.60	0.80	3.68	1.65	6.07	0.00	-6.07	54.52	0.00	3.68
11/20/99	2.20	0.80	1.76	1.65	2.90	2.20	-0.70	53.82	0.00	0.00
11/21/99	4.20	0.80	3.36	1.65	5.54	1.00	-4.54	49.28	0.00	2.36
11/22/99	3.40	0.80	2.72	1.65	4.49	12.50	8.01	57.29	0.00	0.00
11/23/99	3.20	0.80	2.56	1.65	4.22	17.60	13.38	70.66	0.00	0.00
11/24/99	3.00	0.80	2.40	1.29	3.10	1.60	-1.50	69.17	0.00	1.14
11/25/99	3.80	0.80	3.04	1.29	3.92	0.00	-3.92	65.25	0.00	3.47
11/26/99	3.00	0.80	2.40	1.29	3.10	0.00	-3.10	62.15	0.00	2.74
11/27/99	3.00	0.80	2.40	1.29	3.10	0.00	-3.10	59.05	0.00	2.74
11/28/99	3.60	0.80	2.88	1.29	3.72	0.00	-3.72	55.34	0.00	3.28
11/29/99	3.40	0.80	2.72	1.29	3.51	0.00	-3.51	51.83	0.00	3.10
11/30/99	3.00	0.80	2.40	1.29	3.10	4.50	1.40	53.23	0.00	0.00
12/01/99	3.40	0.80	2.72	1.29	3.51	1.20	-2.31	50.92	0.00	1.90
12/02/99	3.20	0.80	2.56	1.29	3.30	0.00	-3.30	47.62	0.00	2.92
12/03/99	3.00	0.80	2.40	1.29	3.10	1.00	-2.10	45.53	0.00	1.64
12/04/99	2.00	0.80	1.60	1.29	2.06	0.00	-2.06	43.46	0.00	1.76
12/05/99	3.80	0.80	3.04	1.29	3.92	0.00	-3.92	39.54	0.00	3.34
12/06/99	3.00	0.80	2.40	1.29	3.10	0.00	-3.10	36.44	0.00	2.64
12/07/99	3.00	0.80	2.40	1.29	3.10	0.00	-3.10	33.35	0.00	2.64
12/08/99	2.00	0.80	1.60	1.29	2.06	0.00	-2.06	31.28	0.00	1.76
12/09/99	2.40	0.80	1.92	1.29	2.48	0.00	-2.48	28.81	0.00	2.11
12/10/99	3.20	0.80	2.56	1.29	3.30	0.00	-3.30	25.51	0.00	2.82
12/11/99	3.00	0.80	2.40	1.29	3.10	0.00	-3.10	22.41	0.00	2.64
12/12/99	4.00	0.80	3.20	1.29	4.13	0.00	-4.13	18.28	0.00	3.52
12/13/99	2.60	0.80	2.08	1.29	2.68	4.00	1.32	19.60	0.00	0.00
12/14/99	2.00	0.80	1.60	1.29	2.06	0.00	-2.06	17.53	0.00	1.76
12/15/99	2.40	0.80	1.92	1.29	2.48	0.00	-2.48	15.06	0.00	2.11
12/16/99	3.00	0.80	2.40	1.29	3.10	0.00	-3.10	11.96	0.00	2.64
12/17/99	2.80	0.80	2.24	1.29	2.89	0.00	-2.89	9.07	0.00	2.46

Cont'd.,

Cont'n.,

Date	Ep (mm)	Kp	PET (mm)	Kc	Et sorghum (mm)	RF (mm)	RF-ET (mm)	SM (mm)	SPL (mm)	DEF (mm)
12/18/99	2.60	0.80	2.08	1.29	2.68	0.00	-2.68	6.39	0.00	1.87
12/19/99	2.80	0.80	2.24	1.29	2.89	0.00	-2.89	3.50	0.00	2.02
12/20/99	3.00	0.80	2.40	1.29	3.10	0.00	-3.10	0.40	0.00	2.16
12/21/99	3.00	0.80	2.40	1.29	3.10	0.00	-3.10	-2.69	0.00	2.16
12/22/99	3.20	0.80	2.56	1.29	3.30	0.00	-3.30	-6.00	0.00	2.30
12/23/99	2.80	0.80	2.24	1.29	2.89	0.00	-2.89	-8.88	0.00	1.79
12/24/99	1.80	0.80	1.44	1.29	1.86	8.00	6.14	-2.74	0.00	0.00
12/25/99	4.00	0.80	3.20	1.29	4.13	0.00	-4.13	-6.87	0.00	2.56
12/26/99	2.80	0.80	2.24	1.29	2.89	1.00	-1.89	-8.76	0.00	0.79
12/27/99	3.00	0.80	2.40	1.29	3.10	0.00	-3.10	-11.86	0.00	1.92
12/28/99	3.40	0.80	2.72	1.29	3.51	0.00	-3.51	-15.36	0.00	1.90
12/29/99	3.10	0.80	2.48	1.00	2.47	0.00	-2.47	-17.83	0.00	1.74
12/30/99	4.00	0.80	3.20	1.00	3.19	0.00	-3.19	-21.02	0.00	2.24
12/31/99	3.00	0.80	2.40	1.00	2.39	0.00	-2.39	-23.41	0.00	1.68
01/01/00	2.60	0.80	2.08	1.00	2.07	0.00	-2.07	-25.48	0.00	1.46
01/02/00	3.20	0.80	2.56	1.00	2.55	0.00	-2.55	-28.03	0.00	1.54
01/03/00	3.00	0.80	2.40	1.00	2.39	0.00	-2.39	-30.42	0.00	1.44
01/04/00	2.20	0.80	1.76	1.00	1.75	0.00	-1.75	-32.18	0.00	1.06
01/05/00	4.40	0.80	3.52	1.00	3.51	0.00	-3.51	-35.68	0.00	2.11
01/06/00	4.20	0.80	3.36	1.00	3.35	0.00	-3.35	-39.03	0.00	2.02
01/07/00	4.40	0.80	3.52	1.00	3.51	0.00	-3.51	-42.54	0.00	1.76
01/08/00	4.20	0.80	3.36	1.00	3.35	0.00	-3.35	-45.88	0.00	1.68
01/09/00	3.40	0.80	2.72	1.00	2.71	0.00	-2.71	-48.59	0.00	1.36
01/10/00	3.80	0.80	3.04	1.00	3.03	0.00	-3.03	-51.62	0.00	1.52
01/11/00	3.00	0.80	2.40	1.00	2.39	5.00	2.61	-49.01	0.00	0.00
01/12/00	3.00	0.80	2.40	1.00	2.39	0.00	-2.39	-51.40	0.00	1.20
01/13/00	3.40	0.80	2.72	1.00	2.71	0.40	-2.31	-53.71	0.00	0.96
01/14/00	3.50	0.80	2.80	1.00	2.79	0.00	-2.79	-56.50	0.00	1.40
01/15/00	3.20	0.80	2.56	1.00	2.55	0.00	-2.55	-59.05	0.00	1.28
01/16/00	3.00	0.80	2.40	1.00	2.39	0.00	-2.39	-61.44	0.00	1.20
01/17/00	3.40	0.80	2.72	1.00	2.71	0.00	-2.71	-64.15	0.00	1.36
01/18/00	4.65	0.80	3.72	1.00	3.71	0.00	-3.71	-67.85	0.00	1.36
Total			307.20	110.13	286.79	427.60			208.82	

Where,

- Ep = Pan evaporation (mm)
- Kp = Pan coefficient
- PET = Potential Evapotranspiration (mm)
- Kc = Crop coefficient
- ET = Evapotranspiration (mm)
- RF = Rainfall (mm)
- RF-ET = Rainfall (mm) - Evapotranspiration (mm)
- SM = Soil moisture (mm)
- SPL = Surplus (mm)
- DEF = Deficit (mm)

2. Daily water balance components of CSV 15 variety (V<sub>2</sub>) under D<sub>1</sub> sowing (1999 NEM)

DATE	Ep (mm)	Kp	PET (mm)	Kc	Et sorghum (mm)	RF (mm)	RF-ET (mm)	SM (mm)	SPL (mm)	DEF (mm)
09/13/99	6.8	0.8	5.44	0.20	1.09	0	-1.09	0.00	0.00	0.00
09/14/99	7.80	0.80	6.24	0.20	1.25	0.00	-1.25	0.00	0.00	0.00
09/15/99	7.00	0.80	5.60	0.20	1.12	0.00	-1.12	0.00	0.00	0.00
09/16/99	6.80	0.80	5.44	0.20	1.09	0.00	-1.09	0.00	0.00	0.00
09/17/99	6.00	0.80	4.80	0.20	0.96	0.00	-0.96	0.00	0.00	0.00
09/18/99	4.60	0.80	3.68	0.20	0.74	0.00	-0.74	0.00	0.00	0.00
09/19/99	5.20	0.80	4.16	0.20	0.83	0.00	-0.83	0.00	0.00	0.00
09/20/99	6.00	0.80	4.80	0.20	0.96	0.00	-0.96	0.00	0.00	0.00
09/21/99	5.60	0.80	4.48	0.20	0.90	0.00	-0.90	0.00	0.00	0.00
09/22/99	5.40	0.80	4.32	0.20	0.86	0.00	-0.86	0.00	0.00	0.00
09/23/99	6.40	0.80	5.12	0.20	1.02	0.00	-1.02	0.00	0.00	0.00
09/24/99	6.00	0.80	4.80	0.20	0.96	0.00	-0.96	0.00	0.00	0.00
09/25/99	5.60	0.80	4.48	0.20	0.90	0.00	-0.90	0.00	0.00	0.00
09/26/99	6.00	0.80	4.80	0.20	0.96	0.00	-0.96	0.00	0.00	0.00
09/27/99	4.00	0.80	3.20	0.58	1.86	18.20	16.34	16.34	0.00	0.00
09/28/99	2.00	0.80	1.60	0.58	0.93	3.80	2.87	19.22	0.00	0.00
09/29/99	3.00	0.80	2.40	0.58	1.39	5.60	4.21	23.42	0.00	0.00
09/30/99	3.40	0.80	2.72	0.58	1.58	9.00	7.42	30.85	0.00	0.00
10/01/99	5.80	0.80	4.64	0.58	2.69	0.00	-2.69	28.16	0.00	1.62
10/02/99	4.40	0.80	3.52	0.58	2.04	10.00	7.96	36.11	0.00	0.00
10/03/99	3.00	0.80	2.40	0.58	1.39	0.00	-1.39	34.72	0.00	0.84
10/04/99	4.00	0.80	3.20	0.58	1.86	26.00	24.14	58.87	0.00	0.00
10/05/99	3.00	0.80	2.40	0.58	1.39	26.40	25.01	83.87	0.00	0.00
10/06/99	2.00	0.80	1.60	0.39	0.62	0.50	-0.12	83.75	0.00	0.30
10/07/99	3.50	0.80	2.80	0.39	1.09	15.50	14.41	98.16	0.00	0.00
10/08/99	3.40	0.80	2.72	0.39	1.06	3.70	2.64	100.00	0.80	0.00
10/09/99	4.70	0.80	3.76	0.39	1.47	17.50	16.03	100.00	16.03	0.00
10/10/99	4.20	0.80	3.36	0.39	1.31	0.60	-0.71	99.29	0.00	1.08
10/11/99	4.60	0.80	3.68	0.39	1.44	0.00	-1.44	97.85	0.00	1.84
10/12/99	4.40	0.80	3.52	0.39	1.37	0.50	-0.87	96.98	0.00	1.26
10/13/99	4.00	0.80	3.20	0.32	1.02	1.80	0.78	97.76	0.00	0.00
10/14/99	4.00	0.80	3.20	0.32	1.02	2.40	1.38	99.13	0.00	0.00
10/15/99	4.20	0.80	3.36	0.32	1.08	7.00	5.92	100.00	5.06	0.00
10/16/99	3.50	0.80	2.80	0.32	0.90	67.40	66.50	100.00	66.50	0.00
10/17/99	3.50	0.80	2.80	0.32	0.90	51.00	50.10	100.00	50.10	0.00
10/18/99	2.80	0.80	2.24	0.32	0.72	17.00	16.28	100.00	16.28	0.00
10/19/99	3.60	0.80	2.88	0.32	0.92	0.50	-0.42	99.58	0.00	1.52
10/20/99	3.30	0.80	2.64	0.33	0.87	26.50	25.63	100.00	25.21	0.00
10/21/99	3.00	0.80	2.40	0.33	0.79	1.00	0.21	100.00	0.21	0.68
10/22/99	3.00	0.80	2.40	0.33	0.79	0.00	-0.79	99.21	0.00	1.68
10/23/99	4.50	0.80	3.60	0.33	1.19	10.50	9.31	100.00	8.52	0.00
10/24/99	3.95	0.80	3.16	0.33	1.04	10.40	9.36	100.00	9.36	0.00
10/25/99	3.40	0.80	2.72	0.33	0.90	3.50	2.60	100.00	2.60	0.00
10/26/99	3.00	0.80	2.40	0.33	0.79	2.50	1.71	100.00	1.71	0.00
10/27/99	2.00	0.80	1.60	0.79	1.26	0.00	-1.26	98.74	0.00	1.12
10/28/99	2.00	0.80	1.60	0.79	1.26	0.00	-1.26	97.47	0.00	1.12
10/29/99	4.00	0.80	3.20	0.79	2.53	1.00	-1.53	95.94	0.00	1.56
10/30/99	3.00	0.80	2.40	0.79	1.90	0.00	-1.90	94.05	0.00	1.92
10/31/99	2.40	0.80	1.92	0.79	1.52	0.00	-1.52	92.53	0.00	1.54

Cont'd.,

Cont'n.,

DATE	Ep (mm)	Kp	PET (mm)	Kc	Et sorghum (mm)	RF (mm)	RF-ET (mm)	SM (mm)	SPL (mm)	DEF (mm)
11/01/99	3.40	0.80	2.72	0.79	2.15	0.00	-2.15	90.38	0.00	2.18
11/02/99	3.60	0.80	2.88	0.79	2.28	0.00	-2.28	88.11	0.00	2.30
11/03/99	3.00	0.80	2.40	0.95	2.28	0.00	-2.28	85.83	0.00	1.92
11/04/99	3.00	0.80	2.40	0.95	2.28	0.00	-2.28	83.55	0.00	1.92
11/05/99	2.70	0.80	2.16	0.95	2.05	4.80	2.75	86.30	0.00	0.00
11/06/99	2.70	0.80	2.16	0.95	2.05	23.00	20.95	100.00	7.24	0.00
11/07/99	2.40	0.80	1.92	0.95	1.82	0.00	-1.82	98.18	0.00	1.54
11/08/99	3.20	0.80	2.56	0.95	2.43	0.00	-2.43	95.74	0.00	2.05
11/09/99	3.80	0.80	3.04	0.95	2.89	0.00	-2.89	92.86	0.00	2.43
11/10/99	4.20	0.80	3.36	1.09	3.66	0.00	-3.66	89.19	0.00	2.69
11/11/99	3.80	0.80	3.04	1.09	3.31	0.00	-3.31	85.88	0.00	2.43
11/12/99	4.00	0.80	3.20	1.09	3.49	0.00	-3.49	82.39	0.00	2.56
11/13/99	3.00	0.80	2.40	1.09	2.62	0.00	-2.62	79.78	0.00	1.92
11/14/99	3.20	0.80	2.56	1.09	2.79	0.00	-2.79	76.99	0.00	2.05
11/15/99	4.40	0.80	3.52	1.09	3.84	0.00	-3.84	73.15	0.00	2.82
11/16/99	3.80	0.80	3.04	1.09	3.31	0.00	-3.31	69.84	0.00	2.43
11/17/99	4.00	0.80	3.20	1.65	5.28	0.00	-5.28	64.56	0.00	2.56
11/18/99	3.00	0.80	2.40	1.65	3.96	0.00	-3.96	60.60	0.00	2.40
11/19/99	4.60	0.80	3.68	1.65	6.07	0.00	-6.07	54.52	0.00	3.68
11/20/99	2.20	0.80	1.76	1.65	2.90	2.20	-0.70	53.82	0.00	0.00
11/21/99	4.20	0.80	3.36	1.65	5.54	1.00	-4.54	49.28	0.00	2.36
11/22/99	3.40	0.80	2.72	1.65	4.49	12.50	8.01	57.29	0.00	0.00
11/23/99	3.20	0.80	2.56	1.65	4.22	17.60	13.38	70.66	0.00	0.00
11/24/99	3.00	0.80	2.40	1.29	3.10	1.60	-1.50	69.17	0.00	1.14
11/25/99	3.80	0.80	3.04	1.29	3.92	0.00	-3.92	65.25	0.00	3.47
11/26/99	3.00	0.80	2.40	1.29	3.10	0.00	-3.10	62.15	0.00	2.74
11/27/99	3.00	0.80	2.40	1.29	3.10	0.00	-3.10	59.05	0.00	2.74
11/28/99	3.60	0.80	2.88	1.29	3.72	0.00	-3.72	55.34	0.00	3.28
11/29/99	3.40	0.80	2.72	1.29	3.51	0.00	-3.51	51.83	0.00	3.10
11/30/99	3.00	0.80	2.40	1.29	3.10	4.50	1.40	53.23	0.00	0.00
12/01/99	3.40	0.80	2.72	1.29	3.51	1.20	-2.31	50.92	0.00	1.90
12/02/99	3.20	0.80	2.56	1.29	3.30	0.00	-3.30	47.62	0.00	2.92
12/03/99	3.00	0.80	2.40	1.29	3.10	1.00	-2.10	45.53	0.00	1.64
12/04/99	2.00	0.80	1.60	1.29	2.06	0.00	-2.06	43.46	0.00	1.76
12/05/99	3.80	0.80	3.04	1.29	3.92	0.00	-3.92	39.54	0.00	3.34
12/06/99	3.00	0.80	2.40	1.29	3.10	0.00	-3.10	36.44	0.00	2.64
12/07/99	3.00	0.80	2.40	1.29	3.10	0.00	-3.10	33.35	0.00	2.64
12/08/99	2.00	0.80	1.60	1.29	2.06	0.00	-2.06	31.28	0.00	1.76
12/09/99	2.40	0.80	1.92	1.29	2.48	0.00	-2.48	28.81	0.00	2.11
12/10/99	3.20	0.80	2.56	1.29	3.30	0.00	-3.30	25.51	0.00	2.82
12/11/99	3.00	0.80	2.40	1.29	3.10	0.00	-3.10	22.41	0.00	2.64
12/12/99	4.00	0.80	3.20	1.29	4.13	0.00	-4.13	18.28	0.00	3.52
12/13/99	2.60	0.80	2.08	1.29	2.68	4.00	1.32	19.60	0.00	0.00
12/14/99	2.00	0.80	1.60	1.29	2.06	0.00	-2.06	17.53	0.00	1.76
12/15/99	2.40	0.80	1.92	1.29	2.48	0.00	-2.48	15.06	0.00	2.11
12/16/99	3.00	0.80	2.40	1.29	3.10	0.00	-3.10	11.96	0.00	2.64
12/17/99	2.80	0.80	2.24	1.29	2.89	0.00	-2.89	9.07	0.00	2.46
12/18/99	2.60	0.80	2.08	1.29	2.68	0.00	-2.68	6.39	0.00	1.87
12/19/99	2.80	0.80	2.24	1.29	2.89	0.00	-2.89	3.50	0.00	2.02

Cont'd.,

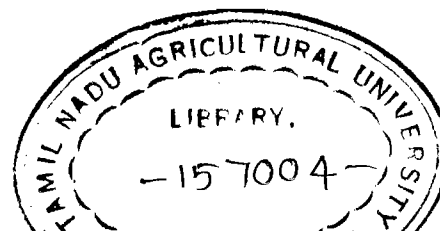
Cont'n.,

DATE	Ep (mm)	Kp	PET (mm)	Kc	Et sorghum (mm)	RF (mm)	RF-ET (mm)	SM (mm)	SPL (mm)	DEF (mm)
12/20/99	3.00	0.80	2.40	1.29	3.10	0.00	-3.10	0.40	0.00	2.16
12/21/99	3.00	0.80	2.40	1.29	3.10	0.00	-3.10	-2.69	0.00	2.16
12/22/99	3.20	0.80	2.56	1.29	3.30	0.00	-3.30	-6.00	0.00	2.30
12/23/99	2.80	0.80	2.24	1.29	2.89	0.00	-2.89	-8.88	0.00	1.79
12/24/99	1.80	0.80	1.44	1.29	1.86	8.00	6.14	-2.74	0.00	0.00
12/25/99	4.00	0.80	3.20	1.29	4.13	0.00	-4.13	-6.87	0.00	2.56
12/26/99	2.80	0.80	2.24	1.29	2.89	1.00	-1.89	-8.76	0.00	0.79
12/27/99	3.00	0.80	2.40	1.29	3.10	0.00	-3.10	-11.86	0.00	1.92
12/28/99	3.40	0.80	2.72	1.29	3.51	0.00	-3.51	-15.36	0.00	1.90
12/29/99	3.10	0.80	2.48	1.00	2.47	0.00	-2.47	-17.83	0.00	1.74
12/30/99	4.00	0.80	3.20	1.00	3.19	0.00	-3.19	-21.02	0.00	2.24
12/31/99	3	0.80	2.40	1.00	2.39	0.00	-2.39	-23.41	0.00	1.68
01/01/00	2.6	0.80	2.08	1.00	2.07	0.00	-2.07	-25.48	0.00	1.46
01/02/00	3.2	0.80	2.56	1.00	2.55	0.00	-2.55	-28.03	0.00	1.54
01/03/00	3	0.80	2.40	1.00	2.39	0.00	-2.39	-30.42	0.00	1.44
01/04/00	2.2	0.80	1.76	1.00	1.75	0.00	-1.75	-32.18	0.00	1.06
01/05/00	4.4	0.80	3.52	1.00	3.51	0.00	-3.51	-35.68	0.00	2.11
01/06/00	4.2	0.80	3.36	1.00	3.35	0.00	-3.35	-39.03	0.00	2.02
01/07/00	4.4	0.80	3.52	1.00	3.51	0.00	-3.51	-42.54	0.00	1.76
01/08/00	4.2	0.80	3.36	1.00	3.35	0.00	-3.35	-45.88	0.00	1.68
01/09/00	3.4	0.80	2.72	1.00	2.71	0.00	-2.71	-48.59	0.00	1.36
01/10/00	3.8	0.80	3.04	1.00	3.03	0.00	-3.03	-51.62	0.00	1.52
01/11/00	3	0.80	2.40	1.00	2.39	5	2.61	-49.01	0.00	0
01/12/00	3	0.80	2.40	1.00	2.39	0	-2.39	-51.40	0.00	1.2
01/13/00	3.4	0.80	2.72	1.00	2.71	0.4	-2.31	-53.71	0.00	0.96
01/14/00	3.5	0.80	2.80	1.00	2.79	0	-2.79	-56.50	0.00	1.4
01/15/00	3.2	0.80	2.56	1.00	2.55	0	-2.55	-59.05	0.00	1.28
01/16/00	3	0.80	2.40	1.00	2.39	0	-2.39	-61.44	0.00	1.2
01/17/00	3.4	0.80	2.72	1.00	2.71	0	-2.71	-64.15	0.00	1.36
01/18/00	4.65	0.80	3.72	1.00	3.71	0.00	-3.71	-67.85	0.00	1.36
Total			307.20	110.13	289.79	427.60				208.82

3. Daily water balance components of CO 26 variety (V<sub>1</sub>) under D<sub>2</sub> sowing (1999 NEM)

DATE	Ep (mm)	Kp	PET (mm)	Kc	Et sorghum (mm)	RF (mm)	RF-ET (mm)	SM (mm)	SPL (mm)	DEF (mm)
09/13/99	6.8	0.8	5.44	0.20	1.09	0.00	-1.09	0.00	0.00	1.09
09/14/99	7.80	0.80	6.24	0.20	1.25	0.00	-1.25	0.00	0.00	1.25
09/15/99	7.00	0.80	5.60	0.20	1.12	0.00	-1.12	0.00	0.00	1.12
09/16/99	6.80	0.80	5.44	0.20	1.09	0.00	-1.09	0.00	0.00	1.09
09/17/99	6.00	0.80	4.80	0.20	0.96	0.00	-0.96	0.00	0.00	0.96
09/18/99	4.60	0.80	3.68	0.20	0.74	0.00	-0.74	0.00	0.00	0.74
09/19/99	5.20	0.80	4.16	0.20	0.83	0.00	-0.83	0.00	0.00	0.83
09/20/99	6.00	0.80	4.80	0.20	0.96	0.00	-0.96	0.00	0.00	0.96
09/21/99	5.60	0.80	4.48	0.20	0.90	0.00	-0.90	0.00	0.00	0.90
09/22/99	5.40	0.80	4.32	0.20	0.86	0.00	-0.86	0.00	0.00	0.86
09/23/99	6.40	0.80	5.12	0.20	1.02	0.00	-1.02	0.00	0.00	1.02
09/24/99	6.00	0.80	4.80	0.20	0.96	0.00	-0.96	0.00	0.00	0.96
09/25/99	5.60	0.80	4.48	0.20	0.90	0.00	-0.90	0.00	0.00	0.90
09/26/99	6.00	0.80	4.80	0.20	0.96	0.00	-0.96	0.00	0.00	0.96
09/27/99	4.00	0.80	3.20	0.20	0.64	18.20	17.56	17.56	0.00	0.00
09/28/99	2.00	0.80	1.60	0.20	0.32	3.80	3.48	21.04	0.00	0.00
09/29/99	3.00	0.80	2.40	0.20	0.48	5.60	5.12	26.16	0.00	0.00
09/30/99	3.40	0.80	2.72	0.20	0.54	9.00	8.46	34.62	0.00	0.00
10/01/99	5.80	0.80	4.64	0.20	0.93	0.00	-0.93	33.69	0.00	1.62
10/02/99	4.40	0.80	3.52	0.58	2.04	10.00	7.96	41.65	0.00	0.00
10/03/99	3.00	0.80	2.40	0.58	1.39	0.00	-1.39	40.25	0.00	0.84
10/04/99	4.00	0.80	3.20	0.58	1.86	26.00	24.14	64.40	0.00	0.00
10/05/99	3.00	0.80	2.40	0.58	1.39	26.40	25.01	89.41	0.00	0.00
10/06/99	2.00	0.80	1.60	0.58	0.93	0.50	-0.43	88.98	0.00	0.30
10/07/99	3.50	0.80	2.80	0.58	1.62	15.50	13.88	100.00	2.85	0.00
10/08/99	3.40	0.80	2.72	0.58	1.58	3.70	2.12	100.00	2.12	0.00
10/09/99	4.70	0.80	3.76	0.58	2.18	17.50	15.32	100.00	15.32	0.00
10/10/99	4.20	0.80	3.36	0.58	1.95	0.60	-1.35	98.65	0.00	1.08
10/11/99	4.60	0.80	3.68	0.39	1.44	0.00	-1.44	97.22	0.00	1.84
10/12/99	4.40	0.80	3.52	0.39	1.37	0.50	-0.87	96.34	0.00	1.26
10/13/99	4.00	0.80	3.20	0.39	1.25	1.80	0.55	96.90	0.00	0.00
10/14/99	4.00	0.80	3.20	0.39	1.25	2.40	1.15	98.05	0.00	0.00
10/15/99	4.20	0.80	3.36	0.39	1.31	7.00	5.69	100.00	3.74	0.00
10/16/99	3.50	0.80	2.80	0.39	1.09	67.40	66.31	100.00	66.31	0.00
10/17/99	3.50	0.80	2.80	0.39	1.09	51.00	49.91	100.00	49.91	0.00
10/18/99	2.80	0.80	2.24	0.32	0.72	17.00	16.28	100.00	16.28	0.00
10/19/99	3.60	0.80	2.88	0.32	0.92	0.50	-0.42	99.58	0.00	1.52
10/20/99	3.30	0.80	2.64	0.32	0.84	26.50	25.66	100.00	25.23	0.00
10/21/99	3.00	0.80	2.40	0.32	0.77	1.00	0.23	100.00	0.23	0.68
10/22/99	3.00	0.80	2.40	0.32	0.77	0.00	-0.77	99.23	0.00	1.68
10/23/99	4.50	0.80	3.60	0.32	1.15	10.50	9.35	100.00	8.58	0.00
10/24/99	3.95	0.80	3.16	0.32	1.01	10.40	9.39	100.00	9.39	0.00
10/25/99	3.40	0.80	2.72	0.33	0.90	3.50	2.60	100.00	2.60	0.00
10/26/99	3.00	0.80	2.40	0.33	0.79	2.50	1.71	100.00	1.71	0.00
10/27/99	2.00	0.80	1.60	0.33	0.53	0.00	-0.53	99.47	0.00	1.12

Cont'd.,



Cont'n.,

DATE	Ep (mm)	Kp	PET (mm)	Kc	Et sorghum (mm)	RF (mm)	RF-ET (mm)	SM (mm)	SPL (mm)	DEF (mm)
10/28/99	2.00	0.80	1.60	0.33	0.53	0.00	-0.53	98.94	0.00	1.12
10/29/99	4.00	0.80	3.20	0.33	1.06	1.00	-0.06	98.89	0.00	1.56
10/30/99	3.00	0.80	2.40	0.33	0.79	0.00	-0.79	98.10	0.00	1.92
10/31/99	2.40	0.80	1.92	0.33	0.63	0.00	-0.63	97.46	0.00	1.54
11/01/99	3.40	0.80	2.72	0.79	2.15	0.00	-2.15	95.31	0.00	2.18
11/02/99	3.60	0.80	2.88	0.79	2.28	0.00	-2.28	93.04	0.00	2.30
11/03/99	3.00	0.80	2.40	0.79	1.90	0.00	-1.90	91.14	0.00	1.92
11/04/99	3.00	0.80	2.40	0.79	1.90	0.00	-1.90	89.25	0.00	1.92
11/05/99	2.70	0.80	2.16	0.79	1.71	4.80	3.09	92.34	0.00	0.00
11/06/99	2.70	0.80	2.16	0.79	1.71	23.00	21.29	100.00	13.63	0.00
11/07/99	2.40	0.80	1.92	0.79	1.52	0.00	-1.52	98.48	0.00	1.54
11/08/99	3.20	0.80	2.56	0.95	2.43	0.00	-2.43	96.05	0.00	2.05
11/09/99	3.80	0.80	3.04	0.95	2.89	0.00	-2.89	93.16	0.00	2.43
11/10/99	4.20	0.80	3.36	0.95	3.19	0.00	-3.19	89.97	0.00	2.69
11/11/99	3.80	0.80	3.04	0.95	2.89	0.00	-2.89	87.08	0.00	2.43
11/12/99	4.00	0.80	3.20	0.95	3.04	0.00	-3.04	84.04	0.00	2.56
11/13/99	3.00	0.80	2.40	0.95	2.28	0.00	-2.28	81.76	0.00	1.92
11/14/99	3.20	0.80	2.56	0.95	2.43	0.00	-2.43	79.33	0.00	2.05
11/15/99	4.40	0.80	3.52	1.09	3.84	0.00	-3.84	75.49	0.00	2.82
11/16/99	3.80	0.80	3.04	1.09	3.31	0.00	-3.31	72.18	0.00	2.43
11/17/99	4.00	0.80	3.20	1.09	3.49	0.00	-3.49	68.69	0.00	2.56
11/18/99	3.00	0.80	2.40	1.09	2.62	0.00	-2.62	66.08	0.00	2.40
11/19/99	4.60	0.80	3.68	1.09	4.01	0.00	-4.01	62.07	0.00	3.68
11/20/99	2.20	0.80	1.76	1.09	1.92	2.20	0.28	62.35	0.00	0.00
11/21/99	4.20	0.80	3.36	1.09	3.66	1.00	-2.66	59.68	0.00	2.36
11/22/99	3.40	0.80	2.72	1.65	4.49	12.50	8.01	67.70	0.00	0.00
11/23/99	3.20	0.80	2.56	1.65	4.22	17.60	13.38	81.07	0.00	0.00
11/24/99	3.00	0.80	2.40	1.65	3.96	1.60	-2.36	78.71	0.00	1.14
11/25/99	3.80	0.80	3.04	1.65	5.02	0.00	-5.02	73.70	0.00	3.47
11/26/99	3.00	0.80	2.40	1.65	3.96	0.00	-3.96	69.74	0.00	2.74
11/27/99	3.00	0.80	2.40	1.65	3.96	0.00	-3.96	65.78	0.00	2.74
11/28/99	3.60	0.80	2.88	1.65	4.75	0.00	-4.75	61.02	0.00	3.28
11/29/99	3.40	0.80	2.72	1.29	3.51	0.00	-3.51	57.52	0.00	3.10
11/30/99	3.00	0.80	2.40	1.29	3.10	4.50	1.40	58.92	0.00	0.00
12/01/99	3.40	0.80	2.72	1.29	3.51	1.20	-2.31	56.61	0.00	1.90
12/02/99	3.20	0.80	2.56	1.29	3.30	0.00	-3.30	53.31	0.00	2.92
12/03/99	3.00	0.80	2.40	1.29	3.10	1.00	-2.10	51.21	0.00	1.64
12/04/99	2.00	0.80	1.60	1.29	2.06	0.00	-2.06	49.15	0.00	1.76
12/05/99	3.80	0.80	3.04	1.29	3.92	0.00	-3.92	45.23	0.00	3.34
12/06/99	3.00	0.80	2.40	1.29	3.10	0.00	-3.10	42.13	0.00	2.64
12/07/99	3.00	0.80	2.40	1.29	3.10	0.00	-3.10	39.04	0.00	2.64
12/08/99	2.00	0.80	1.60	1.29	2.06	0.00	-2.06	36.97	0.00	1.76
12/09/99	2.40	0.80	1.92	1.29	2.48	0.00	-2.48	34.49	0.00	2.11
12/10/99	3.20	0.80	2.56	1.29	3.30	0.00	-3.30	31.19	0.00	2.82
12/11/99	3.00	0.80	2.40	1.29	3.10	0.00	-3.10	28.10	0.00	2.64

Cont'd.,

Cont'n.,

DATE	Ep (mm)	Kp	PET (mm)	Kc	Et sorghum (mm)	RF (mm)	RF-ET (mm)	SM (mm)	SPL (mm)	DEF (mm)
12/12/99	4.00	0.80	3.20	1.29	4.13	0.00	-4.13	23.97	0.00	3.52
12/13/99	2.60	0.80	2.08	1.29	2.68	4.00	1.32	25.28	0.00	0.00
12/14/99	2.00	0.80	1.60	1.29	2.06	0.00	-2.06	23.22	0.00	1.76
12/15/99	2.40	0.80	1.92	1.29	2.48	0.00	-2.48	20.74	0.00	2.11
12/16/99	3.00	0.80	2.40	1.29	3.10	0.00	-3.10	17.65	0.00	2.64
12/17/99	2.80	0.80	2.24	1.29	2.89	0.00	-2.89	14.76	0.00	2.46
12/18/99	2.60	0.80	2.08	1.29	2.68	0.00	-2.68	12.08	0.00	1.87
12/19/99	2.80	0.80	2.24	1.29	2.89	0.00	-2.89	9.19	0.00	2.02
12/20/99	3.00	0.80	2.40	1.29	3.10	0.00	-3.10	6.09	0.00	2.16
12/21/99	3.00	0.80	2.40	1.29	3.10	0.00	-3.10	2.99	0.00	2.16
12/22/99	3.20	0.80	2.56	1.29	3.30	0.00	-3.30	-0.31	0.00	2.30
12/23/99	2.80	0.80	2.24	1.29	2.89	0.00	-2.89	-3.20	0.00	1.79
12/24/99	1.80	0.80	1.44	1.29	1.86	8.00	6.14	2.94	0.00	0.00
12/25/99	4.00	0.80	3.20	1.29	4.13	0.00	-4.13	-1.18	0.00	2.56
12/26/99	2.80	0.80	2.24	1.29	2.89	1.00	-1.89	-3.07	0.00	0.79
12/27/99	3.00	0.80	2.40	1.29	3.10	0.00	-3.10	-6.17	0.00	1.92
12/28/99	3.40	0.80	2.72	1.29	3.51	0.00	-3.51	-9.68	0.00	1.90
12/29/99	3.10	0.80	2.48	1.29	3.20	0.00	-3.20	-12.88	0.00	1.74
12/30/99	4.00	0.80	3.20	1.29	4.13	0.00	-4.13	-17.01	0.00	2.24
12/31/99	3	0.80	2.40	1.29	3.10	0.00	-3.10	-20.10	0.00	1.68
01/01/00	2.6	0.80	2.08	1.29	2.68	0.00	-2.68	-22.78	0.00	1.46
01/02/00	3.2	0.80	2.56	1.29	3.30	0.00	-3.30	-26.09	0.00	1.54
01/03/00	3	0.80	2.40	1.00	2.39	0.00	-2.39	-28.48	0.00	1.44
01/04/00	2.2	0.80	1.76	1.00	1.75	0.00	-1.75	-30.23	0.00	1.06
01/05/00	4.4	0.80	3.52	1.00	3.51	0.00	-3.51	-33.74	0.00	2.11
01/06/00	4.2	0.80	3.36	1.00	3.35	0.00	-3.35	-37.08	0.00	2.02
01/07/00	4.4	0.80	3.52	1.00	3.51	0.00	-3.51	-40.59	0.00	1.76
01/08/00	4.2	0.80	3.36	1.00	3.35	0.00	-3.35	-43.94	0.00	1.68
01/09/00	3.4	0.80	2.72	1.00	2.71	0.00	-2.71	-46.64	0.00	1.36
01/10/00	3.8	0.80	3.04	1.00	3.03	0.00	-3.03	-49.67	0.00	1.52
01/11/00	3	0.80	2.40	1.00	2.39	5	2.61	-47.06	0.00	0
01/12/00	3	0.80	2.40	1.00	2.39	0	-2.39	-49.45	0.00	1.2
01/13/00	3.4	0.80	2.72	1.00	2.71	0.4	-2.31	-51.76	0.00	0.96
01/14/00	3.5	0.80	2.80	1.00	2.79	0	-2.79	-54.55	0.00	1.4
01/15/00	3.2	0.80	2.56	1.00	2.55	0	-2.55	-57.10	0.00	1.28
01/16/00	3	0.80	2.40	1.00	2.39	0	-2.39	-59.49	0.00	1.2
01/17/00	3.4	0.80	2.72	1.00	2.71	0	-2.71	-62.20	0.00	1.36
01/18/00	4.65	0.80	3.72	1.00	3.71	0	-3.71	-65.91	0.00	1.36
01/19/00	4.65	0.80	3.72	1.00	3.71	0	-3.71	-69.61	0.00	1.36
01/20/00	4.65	0.80	3.72	1.00	3.71	0	-3.71	-73.32	0.00	1.36
01/21/00	4.65	0.80	3.72	1.00	3.71	0	-3.71	-77.02	0.00	1.36
01/22/00	4.7	0.80	3.76	1.00	3.74	0	-3.74	-80.77	0.00	1.36
01/23/00	4.7	0.80	3.76	1.00	3.74	0	-3.74	-84.51	0.00	1.36
01/24/00	4.7	0.80	3.76	1.00	3.74	0	-3.74	-88.26	0.00	
Total			314.92		295.96	391.00			217.90	

4. Daily water balance components of CSV 15 variety (V<sub>2</sub>) under D<sub>2</sub> sowing (1999 NEM)

DATE	Ep (mm)	Kp	PET (mm)	Kc	Et sorghum (mm)	RF mm)	RF-ET (mm)	SM (mm)	SPL (mm)	DEF (mm)
09/13/99	6.8	0.8	5.44	0.2	1.09	0.00	-1.09	0.00	0.00	1.09
09/14/99	7.80	0.80	6.24	0.20	1.25	0.00	-1.25	0.00	0.00	1.25
09/15/99	7.00	0.80	5.60	0.20	1.12	0.00	-1.12	0.00	0.00	1.12
09/16/99	6.80	0.80	5.44	0.20	1.09	0.00	-1.09	0.00	0.00	1.09
09/17/99	6.00	0.80	4.80	0.20	0.96	0.00	-0.96	0.00	0.00	0.96
09/18/99	4.60	0.80	3.68	0.20	0.74	0.00	-0.74	0.00	0.00	0.74
09/19/99	5.20	0.80	4.16	0.20	0.83	0.00	-0.83	0.00	0.00	0.83
09/20/99	6.00	0.80	4.80	0.20	0.96	0.00	-0.96	0.00	0.00	0.96
09/21/99	5.60	0.80	4.48	0.20	0.90	0.00	-0.90	0.00	0.00	0.90
09/22/99	5.40	0.80	4.32	0.20	0.86	0.00	-0.86	0.00	0.00	0.86
09/23/99	6.40	0.80	5.12	0.20	1.02	0.00	-1.02	0.00	0.00	1.02
09/24/99	6.00	0.80	4.80	0.20	0.96	0.00	-0.96	0.00	0.00	0.96
09/25/99	5.60	0.80	4.48	0.20	0.90	0.00	-0.90	0.00	0.00	0.90
09/26/99	6.00	0.80	4.80	0.20	0.96	0.00	-0.96	0.00	0.00	0.96
09/27/99	4.00	0.80	3.20	0.20	0.64	18.20	17.56	17.56	0.00	0.00
09/28/99	2.00	0.80	1.60	0.20	0.32	3.80	3.48	21.04	0.00	0.00
09/29/99	3.00	0.80	2.40	0.20	0.48	5.60	5.12	26.16	0.00	0.00
09/30/99	3.40	0.80	2.72	0.20	0.54	9.00	8.46	34.62	0.00	0.00
10/01/99	5.80	0.80	4.64	0.20	0.93	0.00	-0.93	33.69	0.00	1.62
10/02/99	4.40	0.80	3.52	0.58	2.04	10.00	7.96	41.65	0.00	0.00
10/03/99	3.00	0.80	2.40	0.58	1.39	0.00	-1.39	40.25	0.00	0.84
10/04/99	4.00	0.80	3.20	0.58	1.86	26.00	24.14	64.40	0.00	0.00
10/05/99	3.00	0.80	2.40	0.58	1.39	26.40	25.01	89.41	0.00	0.00
10/06/99	2.00	0.80	1.60	0.58	0.93	0.50	-0.43	88.98	0.00	0.30
10/07/99	3.50	0.80	2.80	0.58	1.62	15.50	13.88	100.00	2.85	0.00
10/08/99	3.40	0.80	2.72	0.58	1.58	3.70	2.12	100.00	2.12	0.00
10/09/99	4.70	0.80	3.76	0.58	2.18	17.50	15.32	100.00	15.32	0.00
10/10/99	4.20	0.80	3.36	0.58	1.95	0.60	-1.35	98.65	0.00	1.08
10/11/99	4.60	0.80	3.68	0.39	1.44	0.00	-1.44	97.22	0.00	1.84
10/12/99	4.40	0.80	3.52	0.39	1.37	0.50	-0.87	96.34	0.00	1.26
10/13/99	4.00	0.80	3.20	0.39	1.25	1.80	0.55	96.90	0.00	0.00
10/14/99	4.00	0.80	3.20	0.39	1.25	2.40	1.15	98.05	0.00	0.00
10/15/99	4.20	0.80	3.36	0.39	1.31	7.00	5.69	100.00	3.74	0.00
10/16/99	3.50	0.80	2.80	0.39	1.09	67.40	66.31	100.00	66.31	0.00
10/17/99	3.50	0.80	2.80	0.39	1.09	51.00	49.91	100.00	49.91	0.00
10/18/99	2.80	0.80	2.24	0.32	0.72	17.00	16.28	100.00	16.28	0.00
10/19/99	3.60	0.80	2.88	0.32	0.92	0.50	-0.42	99.58	0.00	1.52
10/20/99	3.30	0.80	2.64	0.32	0.84	26.50	25.66	100.00	25.23	0.00
10/21/99	3.00	0.80	2.40	0.32	0.77	1.00	0.23	100.00	0.23	0.68
10/22/99	3.00	0.80	2.40	0.32	0.77	0.00	-0.77	99.23	0.00	1.68
10/23/99	4.50	0.80	3.60	0.32	1.15	10.50	9.35	100.00	8.58	0.00
10/24/99	3.95	0.80	3.16	0.32	1.01	10.40	9.39	100.00	9.39	0.00
10/25/99	3.40	0.80	2.72	0.33	0.90	3.50	2.60	100.00	2.60	0.00
10/26/99	3.00	0.80	2.40	0.33	0.79	2.50	1.71	100.00	1.71	0.00
10/27/99	2.00	0.80	1.60	0.33	0.53	0.00	-0.53	99.47	0.00	1.12
10/28/99	2.00	0.80	1.60	0.33	0.53	0.00	-0.53	98.94	0.00	1.12
10/29/99	4.00	0.80	3.20	0.33	1.06	1.00	-0.06	98.89	0.00	1.56
10/30/99	3.00	0.80	2.40	0.33	0.79	0.00	-0.79	98.10	0.00	1.92
10/31/99	2.40	0.80	1.92	0.33	0.63	0.00	-0.63	97.46	0.00	1.54

Cont'd.,

Cont'n.,

DATE	Ep (mm)	Kp	PET (mm)	Kc	Et sorghum (mm)	RF (mm)	RF-ET (mm)	SM (mm)	SPL (mm)	DEF (mm)
11/01/99	3.40	0.80	2.72	0.79	2.15	0.00	-2.15	95.31	0.00	2.18
11/02/99	3.60	0.80	2.88	0.79	2.28	0.00	-2.28	93.04	0.00	2.30
11/03/99	3.00	0.80	2.40	0.79	1.90	0.00	-1.90	91.14	0.00	1.92
11/04/99	3.00	0.80	2.40	0.79	1.90	0.00	-1.90	89.25	0.00	1.92
11/05/99	2.70	0.80	2.16	0.79	1.71	4.80	3.09	92.34	0.00	0.00
11/06/99	2.70	0.80	2.16	0.79	1.71	23.00	21.29	100.00	13.63	0.00
11/07/99	2.40	0.80	1.92	0.79	1.52	0.00	-1.52	98.48	0.00	1.54
11/08/99	3.20	0.80	2.56	0.95	2.43	0.00	-2.43	96.05	0.00	2.05
11/09/99	3.80	0.80	3.04	0.95	2.89	0.00	-2.89	93.16	0.00	2.43
11/10/99	4.20	0.80	3.36	0.95	3.19	0.00	-3.19	89.97	0.00	2.69
11/11/99	3.80	0.80	3.04	0.95	2.89	0.00	-2.89	87.08	0.00	2.43
11/12/99	4.00	0.80	3.20	0.95	3.04	0.00	-3.04	84.04	0.00	2.56
11/13/99	3.00	0.80	2.40	0.95	2.28	0.00	-2.28	81.76	0.00	1.92
11/14/99	3.20	0.80	2.56	0.95	2.43	0.00	-2.43	79.33	0.00	2.05
11/15/99	4.40	0.80	3.52	1.09	3.84	0.00	-3.84	75.49	0.00	2.82
11/16/99	3.80	0.80	3.04	1.09	3.31	0.00	-3.31	72.18	0.00	2.43
11/17/99	4.00	0.80	3.20	1.09	3.49	0.00	-3.49	68.69	0.00	2.56
11/18/99	3.00	0.80	2.40	1.09	2.62	0.00	-2.62	66.08	0.00	2.40
11/19/99	4.60	0.80	3.68	1.09	4.01	0.00	-4.01	62.07	0.00	3.68
11/20/99	2.20	0.80	1.76	1.09	1.92	2.20	0.28	62.35	0.00	0.00
11/21/99	4.20	0.80	3.36	1.09	3.66	1.00	-2.66	59.68	0.00	2.36
11/22/99	3.40	0.80	2.72	1.65	4.49	12.50	8.01	67.70	0.00	0.00
11/23/99	3.20	0.80	2.56	1.65	4.22	17.60	13.38	81.07	0.00	0.00
11/24/99	3.00	0.80	2.40	1.65	3.96	1.60	-2.36	78.71	0.00	1.14
11/25/99	3.80	0.80	3.04	1.65	5.02	0.00	-5.02	73.70	0.00	3.47
11/26/99	3.00	0.80	2.40	1.65	3.96	0.00	-3.96	69.74	0.00	2.74
11/27/99	3.00	0.80	2.40	1.65	3.96	0.00	-3.96	65.78	0.00	2.74
11/28/99	3.60	0.80	2.88	1.65	4.75	0.00	-4.75	61.02	0.00	3.28
11/29/99	3.40	0.80	2.72	1.29	3.51	0.00	-3.51	57.52	0.00	3.10
11/30/99	3.00	0.80	2.40	1.29	3.10	4.50	1.40	58.92	0.00	0.00
12/01/99	3.40	0.80	2.72	1.29	3.51	1.20	-2.31	56.61	0.00	1.90
12/02/99	3.20	0.80	2.56	1.29	3.30	0.00	-3.30	53.31	0.00	2.92
12/03/99	3.00	0.80	2.40	1.29	3.10	1.00	-2.10	51.21	0.00	1.64
12/04/99	2.00	0.80	1.60	1.29	2.06	0.00	-2.06	49.15	0.00	1.76
12/05/99	3.80	0.80	3.04	1.29	3.92	0.00	-3.92	45.23	0.00	3.34
12/06/99	3.00	0.80	2.40	1.29	3.10	0.00	-3.10	42.13	0.00	2.64
12/07/99	3.00	0.80	2.40	1.29	3.10	0.00	-3.10	39.04	0.00	2.64
12/08/99	2.00	0.80	1.60	1.29	2.06	0.00	-2.06	36.97	0.00	1.76
12/09/99	2.40	0.80	1.92	1.29	2.48	0.00	-2.48	34.49	0.00	2.11
12/10/99	3.20	0.80	2.56	1.29	3.30	0.00	-3.30	31.19	0.00	2.82
12/11/99	3.00	0.80	2.40	1.29	3.10	0.00	-3.10	28.10	0.00	2.64
12/12/99	4.00	0.80	3.20	1.29	4.13	0.00	-4.13	23.97	0.00	3.52
12/13/99	2.60	0.80	2.08	1.29	2.68	4.00	1.32	25.28	0.00	0.00
12/14/99	2.00	0.80	1.60	1.29	2.06	0.00	-2.06	23.22	0.00	1.76
12/15/99	2.40	0.80	1.92	1.29	2.48	0.00	-2.48	20.74	0.00	2.11
12/16/99	3.00	0.80	2.40	1.29	3.10	0.00	-3.10	17.65	0.00	2.64
12/17/99	2.80	0.80	2.24	1.29	2.89	0.00	-2.89	14.76	0.00	2.46
12/18/99	2.60	0.80	2.08	1.29	2.68	0.00	-2.68	12.08	0.00	1.87
12/19/99	2.80	0.80	2.24	1.29	2.89	0.00	-2.89	9.19	0.00	2.02

Cont'd.,

Cont'n.,

DATE	Ep (mm)	Kp	PET (mm)	Kc	Et sorghum (mm)	RF mm)	RF-ET (mm)	SM (mm)	SPL (mm)	DEF (mm)
12/20/99	3.00	0.80	2.40	1.29	3.10	0.00	-3.10	6.09	0.00	2.16
12/21/99	3.00	0.80	2.40	1.29	3.10	0.00	-3.10	2.99	0.00	2.16
12/22/99	3.20	0.80	2.56	1.29	3.30	0.00	-3.30	-0.31	0.00	2.30
12/23/99	2.80	0.80	2.24	1.29	2.89	0.00	-2.89	-3.20	0.00	1.79
12/24/99	1.80	0.80	1.44	1.29	1.86	8.00	6.14	2.94	0.00	0.00
12/25/99	4.00	0.80	3.20	1.29	4.13	0.00	-4.13	-1.18	0.00	2.56
12/26/99	2.80	0.80	2.24	1.29	2.89	1.00	-1.89	-3.07	0.00	0.79
12/27/99	3.00	0.80	2.40	1.29	3.10	0.00	-3.10	-6.17	0.00	1.92
12/28/99	3.40	0.80	2.72	1.29	3.51	0.00	-3.51	-9.68	0.00	1.90
12/29/99	3.10	0.80	2.48	1.29	3.20	0.00	-3.20	-12.88	0.00	1.74
12/30/99	4.00	0.80	3.20	1.29	4.13	0.00	-4.13	-17.01	0.00	2.24
12/31/99	3	0.80	2.40	1.29	3.10	0.00	-3.10	-20.10	0.00	1.68
01/01/00	2.6	0.80	2.08	1.29	2.68	0.00	-2.68	-22.78	0.00	1.46
01/02/00	3.2	0.80	2.56	1.29	3.30	0.00	-3.30	-26.09	0.00	1.54
01/03/00	3	0.80	2.40	1.00	2.39	0.00	-2.39	-28.48	0.00	1.44
01/04/00	2.2	0.80	1.76	1.00	1.75	0.00	-1.75	-30.23	0.00	1.06
01/05/00	4.4	0.80	3.52	1.00	3.51	0.00	-3.51	-33.74	0.00	2.11
01/06/00	4.2	0.80	3.36	1.00	3.35	0.00	-3.35	-37.08	0.00	2.02
01/07/00	4.4	0.80	3.52	1.00	3.51	0.00	-3.51	-40.59	0.00	1.76
01/08/00	4.2	0.80	3.36	1.00	3.35	0.00	-3.35	-43.94	0.00	1.68
01/09/00	3.4	0.80	2.72	1.00	2.71	0.00	-2.71	-46.64	0.00	1.36
01/10/00	3.8	0.80	3.04	1.00	3.03	0.00	-3.03	-49.67	0.00	1.52
01/11/00	3	0.80	2.40	1.00	2.39	5	2.61	-47.06	0.00	0
01/12/00	3	0.80	2.40	1.00	2.39	0	-2.39	-49.45	0.00	1.2
01/13/00	3.4	0.80	2.72	1.00	2.71	0.4	-2.31	-51.76	0.00	0.96
01/14/00	3.5	0.80	2.80	1.00	2.79	0	-2.79	-54.55	0.00	1.4
01/15/00	3.2	0.80	2.56	1.00	2.55	0	-2.55	-57.10	0.00	1.28
01/16/00	3	0.80	2.40	1.00	2.39	0	-2.39	-59.49	0.00	1.2
01/17/00	3.4	0.80	2.72	1.00	2.71	0	-2.71	-62.20	0.00	1.36
01/18/00	4.65	0.80	3.72	1.00	3.71	0	-3.71	-65.91	0.00	1.36
Total			292.48		273.61	391.00			217.90	

5. Daily water balance components of CO 26 and CSV 15 (V<sub>1</sub> and V<sub>2</sub> varieties) under D<sub>2</sub> sowing (2000 NEM)

DATE	Ep (mm)	Kp	PET (mm)	Kc	Et sorghum (mm)	RF (mm)	RF-ET (mm)	SM (mm)	SPL (mm)	DEF (mm)
09/13/00	6.70	0.80	5.36	0.20	1.07	0.00	-1.07	0.00	0.00	0.00
09/14/00	3.20	0.80	2.56	0.20	0.51	3.20	2.69	2.69	0.00	0.00
09/15/00	5.20	0.80	4.16	0.20	0.83	0.00	-0.83	1.86	0.00	0.00
09/16/00	5.40	0.80	4.32	0.20	0.86	0.00	-0.86	0.99	0.00	0.00
09/17/00	5.60	0.80	4.48	0.20	0.90	4.80	3.90	4.90	0.00	0.00
09/18/00	6.50	0.80	5.20	0.20	1.04	0.00	-1.04	3.86	0.00	0.00
09/19/00	5.00	0.80	4.00	0.20	0.80	0.60	-0.20	3.66	0.00	0.00
09/20/00	3.80	0.80	3.04	0.20	0.61	0.00	-0.61	3.05	0.00	0.00
09/21/00	3.00	0.80	2.40	0.20	0.48	4.80	4.32	7.37	0.00	0.00
09/22/00	3.30	0.80	2.64	0.20	0.53	0.20	-0.33	7.04	0.00	0.00
09/23/00	0.00	0.80	0.00	0.20	0.00	90.50	90.50	97.54	0.00	0.00
09/24/00	5.60	0.80	4.48	0.20	0.90	15.60	14.70	100.00	12.24	0.00
09/25/00	2.90	0.80	2.32	0.20	0.46	2.40	1.94	100.00	1.94	0.00
09/26/00	4.20	0.80	3.36	0.20	0.67	6.40	5.73	100.00	5.73	0.00
09/27/00	3.20	0.80	2.56	0.20	0.51	0.00	-0.51	99.49	0.00	0.00
09/28/00	0.00	0.80	0.00	0.20	0.00	40.20	40.20	100.00	39.69	0.00
09/29/00	5.00	0.80	4.00	0.20	0.80	0.00	-0.80	99.20	0.00	0.00
09/30/00	2.00	0.80	1.60	0.20	0.32	24.60	24.28	100.00	23.48	0.00
10/01/00	3.00	0.80	2.40	0.58	1.39	3.60	2.21	100.00	2.21	0.00
10/02/00	3.80	0.80	3.04	0.58	1.76	2.80	1.04	100.00	1.04	0.00
10/03/00	3.00	0.80	2.40	0.58	1.39	1.50	0.11	100.00	0.11	0.00
10/04/00	3.40	0.80	2.72	0.58	1.58	0.00	-1.58	98.42	0.00	0.00
10/05/00	4.00	0.80	3.20	0.58	1.86	0.00	-1.86	96.57	0.00	0.00
10/06/00	4.20	0.80	3.36	0.58	1.95	0.00	-1.95	94.62	0.00	0.00
10/07/00	4.40	0.80	3.52	0.58	2.04	0.00	-2.04	92.58	0.00	0.00
10/08/00	3.80	0.80	3.04	0.58	1.76	5.80	4.04	96.61	0.00	0.00
10/09/00	4.00	0.80	3.20	0.58	1.86	2.50	0.64	97.26	0.00	0.00
10/10/00	3.00	0.80	2.40	0.39	0.94	0.00	-0.94	96.32	0.00	0.00
10/11/00	5.20	0.80	4.16	0.39	1.62	0.00	-1.62	94.70	0.00	0.00
10/12/00	6.00	0.80	4.80	0.39	1.87	0.00	-1.87	92.83	0.00	0.00
10/13/00	4.00	0.80	3.20	0.39	1.25	0.00	-1.25	91.58	0.00	0.00
10/14/00	2.70	0.80	2.16	0.39	0.84	3.80	2.96	94.54	0.00	0.00
10/15/00	4.40	0.80	3.52	0.39	1.37	0.00	-1.37	93.16	0.00	0.00
10/16/00	2.60	0.80	2.08	0.39	0.81	0.00	-0.81	92.35	0.00	0.00
10/17/00	4.00	0.80	3.20	0.32	1.02	0.00	-1.02	91.33	0.00	0.00
10/18/00	3.40	0.80	2.72	0.32	0.87	0.00	-0.87	90.46	0.00	0.00
10/19/00	4.00	0.80	3.20	0.32	1.02	2.40	1.38	91.83	0.00	0.00
10/20/00	5.20	0.80	4.16	0.32	1.33	0.00	-1.33	90.50	0.00	0.00
10/21/00	4.00	0.80	3.20	0.32	1.02	0.00	-1.02	89.48	0.00	0.00
10/22/00	5.60	0.80	4.48	0.32	1.43	0.00	-1.43	88.04	0.00	0.00
10/23/00	3.20	0.80	2.56	0.32	0.82	0.00	-0.82	87.23	0.00	0.00
10/24/00	4.40	0.80	3.52	0.33	1.16	0.00	-1.16	86.06	0.00	0.00
10/25/00	3.20	0.80	2.56	0.33	0.84	0.00	-0.84	85.22	0.00	0.00

Cont'd.,

Cont'n.,

DATE	Ep (mm)	Kp	PET (mm)	Kc	Et sorghum (mm)	RF (mm)	RF-ET (mm)	SM (mm)	SPL (mm)	DEF (mm)
10/26/00	4.80	0.80	3.84	0.33	1.27	0.00	-1.27	83.95	0.00	0.00
10/27/00	5.40	0.80	4.32	0.33	1.43	0.00	-1.43	82.53	0.00	0.00
10/28/00	4.60	0.80	3.68	0.33	1.21	0.00	-1.21	81.31	0.00	0.00
10/29/00	4.00	0.80	3.20	0.33	1.06	0.00	-1.06	80.26	0.00	0.00
10/30/00	4.40	0.80	3.52	0.33	1.16	0.00	-1.16	79.09	0.00	0.00
10/31/00	3.00	0.80	2.40	0.79	1.90	0.00	-1.90	77.20	0.00	0.00
11/01/00	3.80	0.80	3.04	0.79	2.40	0.00	-2.40	74.80	0.00	0.00
11/02/00	2.80	0.80	2.24	0.79	1.77	0.00	-1.77	73.03	0.00	0.00
11/03/00	2.00	0.80	1.60	0.79	1.26	0.00	-1.26	71.76	0.00	0.00
11/04/00	3.00	0.80	2.40	0.79	1.90	0.00	-1.90	69.87	0.00	0.00
11/05/00	3.80	0.80	3.04	0.79	2.40	0.00	-2.40	67.47	0.00	0.00
11/06/00	3.20	0.80	2.56	0.79	2.02	0.00	-2.02	65.44	0.00	0.00
11/07/00	5.60	0.80	4.48	0.95	4.26	0.00	-4.26	61.19	0.00	0.00
11/08/00	4.20	0.80	3.36	0.95	3.19	0.00	-3.19	58.00	0.00	0.00
11/09/00	4.60	0.80	3.68	0.95	3.50	0.00	-3.50	54.50	0.00	0.00
11/10/00	3.80	0.80	3.04	0.95	2.89	0.00	-2.89	51.61	0.00	0.00
11/11/00	6.00	0.80	4.80	0.95	4.56	0.00	-4.56	47.05	0.00	0.00
11/12/00	3.60	0.80	2.88	0.95	2.74	0.00	-2.74	44.32	0.00	0.00
11/13/00	4.60	0.80	3.68	0.95	3.50	0.00	-3.50	40.82	0.00	0.00
11/14/00	3.40	0.80	2.72	1.09	2.96	0.00	-2.96	37.85	0.00	0.00
11/15/00	3.00	0.80	2.40	1.09	2.62	0.00	-2.62	35.24	0.00	0.00
11/16/00	5.20	0.80	4.16	1.09	4.53	0.00	-4.53	30.70	0.00	0.00
11/17/00	5.60	0.80	4.48	1.09	4.88	0.00	-4.88	25.82	0.00	0.00
11/18/00	4.60	0.80	3.68	1.09	4.01	0.00	-4.01	21.81	0.00	0.00
11/19/00	1.90	0.80	1.52	1.09	1.66	0.00	-1.66	20.15	0.00	0.00
11/20/00	1.20	0.80	0.96	1.09	1.05	0.60	-0.45	19.71	0.00	0.00
11/21/00	1.60	0.80	1.28	1.65	2.11	0.00	-2.11	17.59	0.00	0.00
11/22/00	2.20	0.80	1.76	1.65	2.90	15.40	12.50	30.09	0.00	0.00
11/23/00	3.50	0.80	2.80	1.65	4.62	2.50	-2.12	27.97	0.00	0.00
11/24/00	2.00	0.80	1.60	1.65	2.64	15.80	13.16	41.13	0.00	0.00
11/25/00	4.60	0.80	3.68	1.65	6.07	0.00	-6.07	35.06	0.00	0.00
11/26/00	3.20	0.80	2.56	1.65	4.22	0.00	-4.22	30.83	0.00	0.00
11/27/00	3.40	0.80	2.72	1.65	4.49	0.00	-4.49	26.35	0.00	0.00
11/28/00	5.20	0.80	4.16	1.29	5.37	0.00	-5.37	20.98	0.00	0.00
11/29/00	4.60	0.80	3.68	1.29	4.75	0.00	-4.75	16.23	0.00	0.00
11/30/00	3.60	0.80	2.88	1.29	3.72	24.00	20.28	36.52	0.00	0.00
12/01/00	3.20	0.80	2.56	1.29	3.30	5.20	1.90	38.42	0.00	0.00
12/02/00	2.80	0.80	2.24	1.29	2.89	0.00	-2.89	35.53	0.00	0.00
12/03/00	2.80	0.80	2.24	1.29	2.89	0.00	-2.89	32.64	0.00	0.00
12/04/00	5.00	0.80	4.00	1.29	5.16	0.00	-5.16	27.48	0.00	0.00
12/05/00	3.00	0.80	2.40	1.29	3.10	0.00	-3.10	24.38	0.00	0.00
12/06/00	3.20	0.80	2.56	1.29	3.30	0.00	-3.30	21.08	0.00	0.00
12/07/00	3.60	0.80	2.88	1.29	3.72	0.00	-3.72	17.36	0.00	0.00
12/08/00	3.00	0.80	2.40	1.29	3.10	0.00	-3.10	14.27	0.00	0.00
12/09/00	4.20	0.80	3.36	1.29	4.33	0.00	-4.33	9.93	0.00	0.00

Cont'd.,

Cont'n.,

DATE	Ep (mm)	Kp	PET (mm)	Kc	Et sorghum (mm)	RF (mm)	RF-ET (mm)	SM (mm)	SPL (mm)	DEF (mm)
12/10/00	3.80	0.80	3.04	1.29	3.92	0.00	-3.92	6.01	0.00	0.00
12/11/00	6.20	0.80	4.96	1.29	6.40	0.00	-6.40	-0.39	0.00	0.00
12/12/00	4.40	0.80	3.52	1.29	4.54	0.00	-4.54	-4.93	0.00	0.00
12/13/00	3.20	0.80	2.56	1.29	3.30	0.00	-3.30	-8.23	0.00	0.00
12/14/00	5.40	0.80	4.32	1.29	5.57	0.00	-5.57	-13.80	0.00	0.00
12/15/00	4.60	0.80	3.68	1.29	4.75	0.00	-4.75	-18.55	0.00	0.00
12/16/00	2.40	0.80	1.92	1.29	2.48	0.00	-2.48	-21.03	0.00	0.00
12/17/00	3.20	0.80	2.56	1.29	3.30	0.00	-3.30	-24.33	0.00	0.00
12/18/00	5.00	0.80	4.00	1.29	5.16	0.00	-5.16	-29.49	0.00	0.00
12/19/00	4.00	0.80	3.20	1.29	4.13	0.00	-4.13	-33.62	0.00	0.00
12/20/00	3.00	0.80	2.40	1.29	3.10	0.00	-3.10	-36.71	0.00	0.00
12/21/00	5.60	0.80	4.48	1.29	5.78	0.00	-5.78	-42.49	0.00	0.00
12/22/00	4.00	0.80	3.20	1.29	4.13	0.00	-4.13	-46.62	0.00	0.00
12/23/00	4.80	0.80	3.84	1.29	4.95	0.00	-4.95	-51.58	0.00	0.00
12/24/00	4.80	0.80	3.84	1.29	4.95	0.00	-4.95	-56.53	0.00	0.00
12/25/00	4.60	0.80	3.68	1.29	4.75	0.00	-4.75	-61.28	0.00	0.00
12/26/00	5.20	0.80	4.16	1.29	5.37	0.00	-5.37	-66.64	0.00	0.00
12/27/00	3.20	0.80	2.56	1.29	3.30	0.00	-3.30	-69.94	0.00	0.00
12/28/00	3.20	0.80	2.56	1.29	3.30	8.80	5.50	-64.45	0.00	0.00
12/29/00	2.30	0.80	1.84	1.29	2.37	4.00	1.63	-62.82	0.00	0.00
12/30/00	2.80	0.80	2.24	1.29	2.89	0.00	-2.89	-65.71	0.00	0.00
12/31/00	3.00	0.80	2.40	1.29	3.10	0.00	-3.10	-68.81	0.00	0.00
01/01/01	2.00	0.80	1.60	1.29	2.06	0.00	-2.06	-70.87	0.00	0.00
01/02/01	2.00	0.80	1.60	1.00	1.59	0.00	-1.59	-72.46	0.00	0.00
01/03/01	3.00	0.80	2.40	1.00	2.39	0.00	-2.39	-74.85	0.00	0.00
01/04/01	5.80	0.80	4.64	1.00	4.62	0.00	-4.62	-79.48	0.00	0.00
01/05/01	4.60	0.80	3.68	1.00	3.67	0.00	-3.67	-83.14	0.00	0.00
01/06/01	3.60	0.80	2.88	1.00	2.87	0.00	-2.87	-86.01	0.00	0.00
01/07/01	5.00	0.80	4.00	1.00	3.98	0.00	-3.98	-89.99	0.00	0.00
01/08/01	4.60	0.80	3.68	1.00	3.67	0.00	-3.67	-93.66	0.00	0.00
01/09/01	3.40	0.80	2.72	1.00	2.71	0.00	-2.71	-96.37	0.00	0.00
01/10/01	3.20	0.80	2.56	1.00	2.55	0.00	-2.55	-98.92	0.00	0.00
01/11/01	3.40	0.80	2.72	1.00	2.71	0.00	-2.71	-101.63	0.00	0.00
01/12/01	5.40	0.80	4.32	1.00	4.30	0.00	-4.30	-105.93	0.00	0.00
01/13/01	5.80	0.80	4.64	1.00	4.62	0.00	-4.62	-110.55	0.00	0.00
01/14/01	4.20	0.80	3.36	1.00	3.35	0.00	-3.35	-113.90	0.00	0.00
01/15/01	6.00	0.80	4.80	1.00	4.78	0.00	-4.78	-118.68	0.00	0.00
01/16/01	3.00	0.80	2.40	1.00	2.39	0.00	-2.39	-121.07	0.00	0.00
01/17/01	3.00	0.80	2.40	1.00	2.39	0.00	-2.39	-123.46	0.00	0.00
01/18/01	4.40	0.80	3.52	1.00	3.51	0.00	-3.51	-126.97	0.00	0.00
01/19/01	5.60	0.80	4.48	1.00	4.46	0.00	-4.46	-131.43	0.00	0.00
Total			351.20		327.89	123.30			26.84	

6. Daily water balance components of CO 26 and CSV 15 (V<sub>1</sub> and V<sub>2</sub> varieties) under D<sub>2</sub> sowing (2000 NEM)

DATE	Ep (mm)	Kp	PET (mm)	Kc	Et sorghum (mm)	RF (mm)	RF-ET (mm)	SM (mm)	SPL (mm)	DEF (mm)
09/13/00	6.70	0.80	5.36	0.20	1.07	0.00	-1.07	0.00	0.00	0.00
09/14/00	3.20	0.80	2.56	0.20	0.51	3.20	2.69	2.69	0.00	0.00
09/15/00	5.20	0.80	4.16	0.20	0.83	0.00	-0.83	1.86	0.00	0.00
09/16/00	5.40	0.80	4.32	0.20	0.86	0.00	-0.86	0.99	0.00	0.00
09/17/00	5.60	0.80	4.48	0.20	0.90	4.80	3.90	4.90	0.00	0.00
09/18/00	6.50	0.80	5.20	0.20	1.04	0.00	-1.04	3.86	0.00	0.00
09/19/00	5.00	0.80	4.00	0.20	0.80	0.60	-0.20	3.66	0.00	0.00
09/20/00	3.80	0.80	3.04	0.20	0.61	0.00	-0.61	3.05	0.00	0.00
09/21/00	3.00	0.80	2.40	0.20	0.48	4.80	4.32	7.37	0.00	0.00
09/22/00	3.30	0.80	2.64	0.20	0.53	0.20	-0.33	7.04	0.00	0.00
09/23/00	0.00	0.80	0.00	0.20	0.00	90.50	90.50	97.54	0.00	0.00
09/24/00	5.60	0.80	4.48	0.20	0.90	15.60	14.70	100.00	12.24	0.00
09/25/00	2.90	0.80	2.32	0.20	0.46	2.40	1.94	100.00	1.94	0.00
09/26/00	4.20	0.80	3.36	0.20	0.67	6.40	5.73	100.00	5.73	0.00
09/27/00	3.20	0.80	2.56	0.20	0.51	0.00	-0.51	99.49	0.00	0.00
09/28/00	0.00	0.80	0.00	0.20	0.00	40.20	40.20	100.00	39.69	0.00
09/29/00	5.00	0.80	4.00	0.20	0.80	0.00	-0.80	99.20	0.00	0.00
09/30/00	2.00	0.80	1.60	0.20	0.32	24.60	24.28	100.00	23.48	0.00
10/01/00	3.00	0.80	2.40	0.58	1.39	3.60	2.21	100.00	2.21	0.00
10/02/00	3.80	0.80	3.04	0.58	1.76	2.80	1.04	100.00	1.04	0.00
10/03/00	3.00	0.80	2.40	0.58	1.39	1.50	0.11	100.00	0.11	0.00
10/04/00	3.40	0.80	2.72	0.58	1.58	0.00	-1.58	98.42	0.00	0.00
10/05/00	4.00	0.80	3.20	0.58	1.86	0.00	-1.86	96.57	0.00	0.00
10/06/00	4.20	0.80	3.36	0.58	1.95	0.00	-1.95	94.62	0.00	0.00
10/07/00	4.40	0.80	3.52	0.58	2.04	0.00	-2.04	92.58	0.00	0.00
10/08/00	3.80	0.80	3.04	0.58	1.76	5.80	4.04	96.61	0.00	0.00
10/09/00	4.00	0.80	3.20	0.58	1.86	2.50	0.64	97.26	0.00	0.00
10/10/00	3.00	0.80	2.40	0.39	0.94	0.00	-0.94	96.32	0.00	0.00
10/11/00	5.20	0.80	4.16	0.39	1.62	0.00	-1.62	94.70	0.00	0.00
10/12/00	6.00	0.80	4.80	0.39	1.87	0.00	-1.87	92.83	0.00	0.00
10/13/00	4.00	0.80	3.20	0.39	1.25	0.00	-1.25	91.58	0.00	0.00
10/14/00	2.70	0.80	2.16	0.39	0.84	3.80	2.96	94.54	0.00	0.00
10/15/00	4.40	0.80	3.52	0.39	1.37	0.00	-1.37	93.16	0.00	0.00
10/16/00	2.60	0.80	2.08	0.39	0.81	0.00	-0.81	92.35	0.00	0.00
10/17/00	4.00	0.80	3.20	0.32	1.02	0.00	-1.02	91.33	0.00	0.00
10/18/00	3.40	0.80	2.72	0.32	0.87	0.00	-0.87	90.46	0.00	0.00
10/19/00	4.00	0.80	3.20	0.32	1.02	2.40	1.38	91.83	0.00	0.00
10/20/00	5.20	0.80	4.16	0.32	1.33	0.00	-1.33	90.50	0.00	0.00
10/21/00	4.00	0.80	3.20	0.32	1.02	0.00	-1.02	89.48	0.00	0.00
10/22/00	5.60	0.80	4.48	0.32	1.43	0.00	-1.43	88.04	0.00	0.00
10/23/00	3.20	0.80	2.56	0.32	0.82	0.00	-0.82	87.23	0.00	0.00
10/24/00	4.40	0.80	3.52	0.33	1.16	0.00	-1.16	86.06	0.00	0.00
10/25/00	3.20	0.80	2.56	0.33	0.84	0.00	-0.84	85.22	0.00	0.00

Cont'd.,

Cont'n.,

DATE	Ep (mm)	Kp	PET (mm)	Kc	Et sorghum (mm)	RF (mm)	RF-ET (mm)	SM (mm)	SPL (mm)	DEF (mm)
10/26/00	4.80	0.80	3.84	0.33	1.27	0.00	-1.27	83.95	0.00	0.00
10/27/00	5.40	0.80	4.32	0.33	1.43	0.00	-1.43	82.53	0.00	0.00
10/28/00	4.60	0.80	3.68	0.33	1.21	0.00	-1.21	81.31	0.00	0.00
10/29/00	4.00	0.80	3.20	0.33	1.06	0.00	-1.06	80.26	0.00	0.00
10/30/00	4.40	0.80	3.52	0.33	1.16	0.00	-1.16	79.09	0.00	0.00
10/31/00	3.00	0.80	2.40	0.79	1.90	0.00	-1.90	77.20	0.00	0.00
11/1/00	3.80	0.80	3.04	0.79	2.40	0.00	-2.40	74.80	0.00	0.00
11/2/00	2.80	0.80	2.24	0.79	1.77	0.00	-1.77	73.03	0.00	0.00
11/3/00	2.00	0.80	1.60	0.79	1.26	0.00	-1.26	71.76	0.00	0.00
11/4/00	3.00	0.80	2.40	0.79	1.90	0.00	-1.90	69.87	0.00	0.00
11/5/00	3.80	0.80	3.04	0.79	2.40	0.00	-2.40	67.47	0.00	0.00
11/6/00	3.20	0.80	2.56	0.79	2.02	0.00	-2.02	65.44	0.00	0.00
11/7/00	5.60	0.80	4.48	0.95	4.26	0.00	-4.26	61.19	0.00	0.00
11/8/00	4.20	0.80	3.36	0.95	3.19	0.00	-3.19	58.00	0.00	0.00
11/9/00	4.60	0.80	3.68	0.95	3.50	0.00	-3.50	54.50	0.00	0.00
11/10/00	3.80	0.80	3.04	0.95	2.89	0.00	-2.89	51.61	0.00	0.00
11/11/00	6.00	0.80	4.80	0.95	4.56	0.00	-4.56	47.05	0.00	0.00
11/12/00	3.60	0.80	2.88	0.95	2.74	0.00	-2.74	44.32	0.00	0.00
11/13/00	4.60	0.80	3.68	0.95	3.50	0.00	-3.50	40.82	0.00	0.00
11/14/00	3.40	0.80	2.72	1.09	2.96	0.00	-2.96	37.85	0.00	0.00
11/15/00	3.00	0.80	2.40	1.09	2.62	0.00	-2.62	35.24	0.00	0.00
11/16/00	5.20	0.80	4.16	1.09	4.53	0.00	-4.53	30.70	0.00	0.00
11/17/00	5.60	0.80	4.48	1.09	4.88	0.00	-4.88	25.82	0.00	0.00
11/18/00	4.60	0.80	3.68	1.09	4.01	0.00	-4.01	21.81	0.00	0.00
11/19/00	1.90	0.80	1.52	1.09	1.66	0.00	-1.66	20.15	0.00	0.00
11/20/00	1.20	0.80	0.96	1.09	1.05	0.60	-0.45	19.71	0.00	0.00
11/21/00	1.60	0.80	1.28	1.65	2.11	0.00	-2.11	17.59	0.00	0.00
11/22/00	2.20	0.80	1.76	1.65	2.90	15.40	12.50	30.09	0.00	0.00
11/23/00	3.50	0.80	2.80	1.65	4.62	2.50	-2.12	27.97	0.00	0.00
11/24/00	2.00	0.80	1.60	1.65	2.64	15.80	13.16	41.13	0.00	0.00
11/25/00	4.60	0.80	3.68	1.65	6.07	0.00	-6.07	35.06	0.00	0.00
11/26/00	3.20	0.80	2.56	1.65	4.22	0.00	-4.22	30.83	0.00	0.00
11/27/00	3.40	0.80	2.72	1.65	4.49	0.00	-4.49	26.35	0.00	0.00
11/28/00	5.20	0.80	4.16	1.29	5.37	0.00	-5.37	20.98	0.00	0.00
11/29/00	4.60	0.80	3.68	1.29	4.75	0.00	-4.75	16.23	0.00	0.00
11/30/00	3.60	0.80	2.88	1.29	3.72	24.00	20.28	36.52	0.00	0.00
12/01/00	3.20	0.80	2.56	1.29	3.30	5.20	1.90	38.42	0.00	0.00
12/02/00	2.80	0.80	2.24	1.29	2.89	0.00	-2.89	35.53	0.00	0.00
12/03/00	2.80	0.80	2.24	1.29	2.89	0.00	-2.89	32.64	0.00	0.00
12/04/00	5.00	0.80	4.00	1.29	5.16	0.00	-5.16	27.48	0.00	0.00
12/05/00	3.00	0.80	2.40	1.29	3.10	0.00	-3.10	24.38	0.00	0.00
12/06/00	3.20	0.80	2.56	1.29	3.30	0.00	-3.30	21.08	0.00	0.00
12/07/00	3.60	0.80	2.88	1.29	3.72	0.00	-3.72	17.36	0.00	0.00
12/08/00	3.00	0.80	2.40	1.29	3.10	0.00	-3.10	14.27	0.00	0.00

Cont'd.,

Cont'n.,

DATE	Ep (mm)	Kp	PET (mm)	Kc	Et sorghum (mm)	RF (mm)	RF-ET (mm)	SM (mm)	SPL (mm)	DEF (mm)
12/09/00	4.20	0.80	3.36	1.29	4.33	0.00	-4.33	9.93	0.00	0.00
12/10/00	3.80	0.80	3.04	1.29	3.92	0.00	-3.92	6.01	0.00	0.00
12/11/00	6.20	0.80	4.96	1.29	6.40	0.00	-6.40	-0.39	0.00	0.00
12/12/00	4.40	0.80	3.52	1.29	4.54	0.00	-4.54	-4.93	0.00	0.00
12/13/00	3.20	0.80	2.56	1.29	3.30	0.00	-3.30	-8.23	0.00	0.00
12/14/00	5.40	0.80	4.32	1.29	5.57	0.00	-5.57	-13.80	0.00	0.00
12/15/00	4.60	0.80	3.68	1.29	4.75	0.00	-4.75	-18.55	0.00	0.00
12/16/00	2.40	0.80	1.92	1.29	2.48	0.00	-2.48	-21.03	0.00	0.00
12/17/00	3.20	0.80	2.56	1.29	3.30	0.00	-3.30	-24.33	0.00	0.00
12/18/00	5.00	0.80	4.00	1.29	5.16	0.00	-5.16	-29.49	0.00	0.00
12/19/00	4.00	0.80	3.20	1.29	4.13	0.00	-4.13	-33.62	0.00	0.00
12/20/00	3.00	0.80	2.40	1.29	3.10	0.00	-3.10	-36.71	0.00	0.00
12/21/00	5.60	0.80	4.48	1.29	5.78	0.00	-5.78	-42.49	0.00	0.00
12/22/00	4.00	0.80	3.20	1.29	4.13	0.00	-4.13	-46.62	0.00	0.00
12/23/00	4.80	0.80	3.84	1.29	4.95	0.00	-4.95	-51.58	0.00	0.00
12/24/00	4.80	0.80	3.84	1.29	4.95	0.00	-4.95	-56.53	0.00	0.00
12/25/00	4.60	0.80	3.68	1.29	4.75	0.00	-4.75	-61.28	0.00	0.00
12/26/00	5.20	0.80	4.16	1.29	5.37	0.00	-5.37	-66.64	0.00	0.00
12/27/00	3.20	0.80	2.56	1.29	3.30	0.00	-3.30	-69.94	0.00	0.00
12/28/00	3.20	0.80	2.56	1.29	3.30	8.80	5.50	-64.45	0.00	0.00
12/29/00	2.30	0.80	1.84	1.29	2.37	4.00	1.63	-62.82	0.00	0.00
12/30/00	2.80	0.80	2.24	1.29	2.89	0.00	-2.89	-65.71	0.00	0.00
12/31/00	3.00	0.80	2.40	1.29	3.10	0.00	-3.10	-68.81	0.00	0.00
01/01/01	2.00	0.80	1.60	1.29	2.06	0.00	-2.06	-70.87	0.00	0.00
01/02/01	2.00	0.80	1.60	1.00	1.59	0.00	-1.59	-72.46	0.00	0.00
01/03/01	3.00	0.80	2.40	1.00	2.39	0.00	-2.39	-74.85	0.00	0.00
01/04/01	5.80	0.80	4.64	1.00	4.62	0.00	-4.62	-79.48	0.00	0.00
01/05/01	4.60	0.80	3.68	1.00	3.67	0.00	-3.67	-83.14	0.00	0.00
01/06/01	3.60	0.80	2.88	1.00	2.87	0.00	-2.87	-86.01	0.00	0.00
01/07/01	5.00	0.80	4.00	1.00	3.98	0.00	-3.98	-89.99	0.00	0.00
01/08/01	4.60	0.80	3.68	1.00	3.67	0.00	-3.67	-93.66	0.00	0.00
01/09/01	3.40	0.80	2.72	1.00	2.71	0.00	-2.71	-96.37	0.00	0.00
01/10/01	3.20	0.80	2.56	1.00	2.55	0.00	-2.55	-98.92	0.00	0.00
01/11/01	3.40	0.80	2.72	1.00	2.71	0.00	-2.71	-101.63	0.00	0.00
01/12/01	5.40	0.80	4.32	1.00	4.30	0.00	-4.30	-105.93	0.00	0.00
01/13/01	5.80	0.80	4.64	1.00	4.62	0.00	-4.62	-110.55	0.00	0.00
01/14/01	4.20	0.80	3.36	1.00	3.35	0.00	-3.35	-113.90	0.00	0.00
01/15/01	6.00	0.80	4.80	1.00	4.78	0.00	-4.78	-118.68	0.00	0.00
01/16/01	3.00	0.80	2.40	1.00	2.39	0.00	-2.39	-121.07	0.00	0.00
01/17/01	3.00	0.80	2.40	1.00	2.39	0.00	-2.39	-123.46	0.00	0.00
01/18/01	4.40	0.80	3.52	1.00	3.51	0.00	-3.51	-126.97	0.00	0.00
01/19/01	5.60	0.80	4.48	1.00	4.46	0.00	-4.46	-131.43	0.00	0.00
Total			351.20		327.89	123.30			26.84	

Appendix V. Soil moisture content (mm) estimated at 0-15 cm and 15-30 cm by gravimetric method during 1999-2000 and 2000-2001

Treatments	Initial	7	14	21	28	35	42	49	56	63	70	77	84	Harvest
				Soil moisture content (mm 15 cm depth <sup>-1</sup> ) at 0-15 cm soil depth during 1999-2000 (first crop)										
V <sub>1</sub> D <sub>1</sub> F <sub>1</sub>	14.83	28.38	28.07	Rain	34.11	22.71	24.42	18.63	Rain	26.48	21.71	22.50	21.42	16.75
V <sub>1</sub> D <sub>1</sub> F <sub>2</sub>	10.61	32.62	29.46	Rain	34.76	23.11	25.50	19.89	Rain	26.50	23.26	23.87	22.22	16.52
V <sub>1</sub> D <sub>1</sub> F <sub>3</sub>	14.08	33.21	31.86	Rain	29.17	25.07	25.03	17.50	Rain	27.56	24.54	24.30	22.48	17.87
V <sub>1</sub> D <sub>2</sub> F <sub>1</sub>	27.50	31.07	Rain	34.48	29.93	25.72	19.62	Rain	24.99	26.95	21.60	21.18	22.85	18.77
V <sub>1</sub> D <sub>2</sub> F <sub>2</sub>	27.52	33.66	Rain	32.56	28.44	23.79	18.99	Rain	24.50	25.09	21.32	20.91	23.15	20.42
V <sub>1</sub> D <sub>2</sub> F <sub>3</sub>	28.70	36.70	Rain	35.39	30.40	26.01	18.14	Rain	25.26	26.03	19.65	20.03	22.17	19.46
V <sub>2</sub> D <sub>1</sub> F <sub>1</sub>	18.28	37.15	29.68	Rain	26.38	23.34	27.25	19.26	Rain	22.83	21.38	20.77	19.50	18.28
V <sub>2</sub> D <sub>1</sub> F <sub>2</sub>	11.91	32.84	30.01	Rain	22.15	22.26	27.13	17.38	Rain	22.79	21.73	20.62	19.99	14.81
V <sub>2</sub> D <sub>1</sub> F <sub>3</sub>	20.01	37.43	29.68	Rain	29.66	23.66	24.64	19.22	Rain	22.99	24.89	23.66	20.83	17.32
V <sub>2</sub> D <sub>2</sub> F <sub>1</sub>	29.31	33.74	Rain	32.76	29.05	26.30	17.77	Rain	23.48	21.26	18.34	18.05	20.07	20.81
V <sub>2</sub> D <sub>2</sub> F <sub>2</sub>	28.23	35.94	Rain	34.82	28.66	25.85	18.56	Rain	25.42	23.99	18.34	17.58	20.18	20.36
V <sub>2</sub> D <sub>2</sub> F <sub>3</sub>	27.01	35.43	Rain	34.99	28.48	24.15	19.07	Rain	27.11	20.50	19.60	19.34	20.97	19.69
				Soil moisture content (mm 15 cm depth <sup>-1</sup> ) at 15-30 cm soil depth during 1999-2000 (first crop)										
V <sub>1</sub> D <sub>1</sub> F <sub>1</sub>	17.71	33.80	27.70	Rain	31.31	24.93	24.77	22.26	Rain	23.56	23.70	23.05	22.15	17.71
V <sub>1</sub> D <sub>1</sub> F <sub>2</sub>	14.67	17.16	29.09	Rain	30.23	27.32	25.79	21.77	Rain	26.01	25.58	24.68	23.83	17.14
V <sub>1</sub> D <sub>1</sub> F <sub>3</sub>	17.65	31.82	30.91	Rain	33.11	30.01	25.23	25.87	Rain	28.89	25.68	24.64	23.91	18.26
V <sub>1</sub> D <sub>2</sub> F <sub>1</sub>	30.05	30.84	Rain	33.44	27.89	25.95	20.11	Rain	24.75	26.56	24.09	23.19	24.68	19.22
V <sub>1</sub> D <sub>2</sub> F <sub>2</sub>	25.72	31.33	Rain	31.97	29.87	24.05	23.48	Rain	23.83	23.99	23.24	22.34	23.52	21.01
V <sub>1</sub> D <sub>2</sub> F <sub>3</sub>	30.23	33.97	Rain	35.09	31.17	28.97	23.01	Rain	24.91	27.44	25.03	23.75	25.17	20.81
V <sub>2</sub> D <sub>1</sub> F <sub>1</sub>	14.55	35.92	32.80	Rain	32.80	24.85	28.93	22.58	Rain	24.91	24.81	23.46	22.34	18.60
V <sub>2</sub> D <sub>1</sub> F <sub>2</sub>	18.09	33.70	28.36	Rain	26.95	24.11	26.05	18.07	Rain	21.64	23.79	22.40	20.54	17.52
V <sub>2</sub> D <sub>1</sub> F <sub>3</sub>	16.93	33.50	29.99	Rain	32.80	23.03	24.09	20.28	Rain	24.91	27.42	24.38	22.38	17.87
V <sub>2</sub> D <sub>2</sub> F <sub>1</sub>	31.29	30.58	Rain	33.62	29.21	25.19	18.81	Rain	22.93	22.62	18.16	17.95	19.91	22.44
V <sub>2</sub> D <sub>2</sub> F <sub>2</sub>	28.23	33.03	Rain	32.76	28.62	26.07	21.34	Rain	26.62	26.03	21.11	20.42	22.44	20.60
V <sub>2</sub> D <sub>2</sub> F <sub>3</sub>	25.99	33.76	Rain	38.11	31.09	25.85	21.28	Rain	23.01	22.81	22.52	21.83	23.58	20.56

Cont'd.,

Cont'n.,

Soil moisture content (mm) estimated at 0-15 cm and 15-30 cm by gravimetric method during 2000-2001(second crop)

Treatments	Initial	7	14	21	28	35	42	49	56	63	70	77	84	Harvest
Soil moisture content (mm 15 cm depth <sup>1</sup> ) at 0-15 cm soil depth during 2000-2001 (second crop)														
V <sub>1</sub> D <sub>1</sub> F <sub>1</sub>	16.52	35.70	28.76	25.70	20.56	18.05	17.65	16.95	15.75	21.90	22.50	20.70	18.75	14.94
V <sub>1</sub> D <sub>1</sub> F <sub>2</sub>	17.54	36.31	27.95	24.58	22.38	18.86	17.14	15.86	15.30	22.68	23.10	21.00	19.65	14.45
V <sub>1</sub> D <sub>1</sub> F <sub>3</sub>	16.93	35.50	29.58	25.50	22.91	16.69	16.32	16.86	16.05	21.69	22.47	20.25	18.15	13.72
V <sub>1</sub> D <sub>2</sub> F <sub>1</sub>	34.58	28.56	31.42	22.22	21.18	17.34	16.80	15.25	18.75	24.20	21.43	19.35	17.70	15.19
V <sub>1</sub> D <sub>2</sub> F <sub>2</sub>	34.68	28.15	30.80	22.66	16.97	15.22	17.10	16.54	20.25	25.44	21.80	18.75	17.23	13.69
V <sub>1</sub> D <sub>2</sub> F <sub>3</sub>	35.09	29.38	31.82	23.05	13.37	14.67	16.20	15.21	18.60	24.64	21.03	19.80	17.74	14.20
V <sub>2</sub> D <sub>1</sub> F <sub>1</sub>	18.28	36.52	29.58	25.11	22.44	18.40	18.09	17.14	16.65	21.36	22.05	20.10	18.44	15.79
V <sub>2</sub> D <sub>1</sub> F <sub>2</sub>	15.46	35.50	27.95	26.11	21.32	17.86	17.38	16.31	15.90	22.54	23.25	20.55	18.80	15.60
V <sub>2</sub> D <sub>1</sub> F <sub>3</sub>	16.24	35.90	28.36	24.44	20.62	19.35	16.10	15.49	16.05	22.83	23.85	21.30	19.78	16.53
V <sub>2</sub> D <sub>2</sub> F <sub>1</sub>	35.43	29.13	30.56	24.58	17.81	15.30	15.00	15.78	19.65	21.76	20.64	19.20	17.34	15.35
V <sub>2</sub> D <sub>2</sub> F <sub>2</sub>	34.78	29.58	31.46	24.44	4.53	14.59	14.25	15.25	18.48	20.38	20.25	19.01	16.66	15.66
V <sub>2</sub> D <sub>2</sub> F <sub>3</sub>	35.90	29.99	28.66	25.30	16.02	16.63	16.20	15.80	18.04	20.73	20.59	18.30	16.19	15.00
Soil moisture content (mm 15 cm depth <sup>1</sup> ) at 15-30 cm soil depth during 2000-2001 (second crop)														
V <sub>1</sub> D <sub>1</sub> F <sub>1</sub>	17.71	36.72	31.42	27.03	22.56	18.99	18.30	17.73	16.35	22.52	22.20	21.60	20.70	16.25
V <sub>1</sub> D <sub>1</sub> F <sub>2</sub>	17.36	36.31	30.40	27.54	23.36	20.72	19.65	18.85	16.65	22.38	21.90	21.15	20.10	16.12
V <sub>1</sub> D <sub>1</sub> F <sub>3</sub>	17.65	35.70	31.21	26.70	24.44	21.14	20.25	19.47	17.19	21.99	22.20	20.70	19.05	16.98
V <sub>1</sub> D <sub>2</sub> F <sub>1</sub>	34.70	30.60	29.72	25.40	26.58	17.95	17.23	16.37	17.25	21.05	20.72	20.10	18.37	15.12
V <sub>1</sub> D <sub>2</sub> F <sub>2</sub>	35.50	31.21	28.97	26.25	20.36	18.26	18.00	17.75	18.60	21.30	19.87	19.05	16.90	15.66
V <sub>1</sub> D <sub>2</sub> F <sub>3</sub>	36.31	30.50	27.95	26.62	23.60	17.87	18.30	16.13	17.25	21.60	20.20	19.34	16.63	16.09
V <sub>2</sub> D <sub>1</sub> F <sub>1</sub>	16.59	36.72	32.84	27.70	23.17	22.00	19.50	18.63	17.55	22.71	23.70	21.75	19.35	15.78
V <sub>2</sub> D <sub>1</sub> F <sub>2</sub>	16.34	36.31	31.01	26.81	23.54	22.58	18.75	17.44	17.10	22.08	22.80	21.30	18.97	16.59
V <sub>2</sub> D <sub>1</sub> F <sub>3</sub>	16.93	36.11	31.42	28.52	24.99	24.93	19.80	15.98	16.50	22.10	23.06	20.82	18.03	16.88
V <sub>2</sub> D <sub>2</sub> F <sub>1</sub>	35.37	30.80	28.87	26.30	21.82	14.79	16.35	15.75	16.80	20.59	19.69	19.05	16.88	14.89
V <sub>2</sub> D <sub>2</sub> F <sub>2</sub>	35.70	30.76	28.56	24.46	23.32	18.32	16.15	14.80	16.20	19.78	20.14	18.60	16.32	14.29
V <sub>2</sub> D <sub>2</sub> F <sub>3</sub>	34.84	30.54	27.70	23.60	21.16	19.42	17.28	16.70	18.00	21.25	20.28	19.08	14.93	13.69

Appendix VI. Returning period for Northeast monsoon season of Coimbatore

YEAR	NEM total RF(mm)	Rainfall (Ascending order)	Order Number	Cumulative Frequency (CF)*	1-CF	Returning period** (uncorrected)	Multi-Plier	Product	Corrected Returning period
1907	305.4	82.8	1	0.0105	0.9895	1.0106	1	1.01	1/1
1908	283.7	97.2	2	0.0211	0.9789	1.0215	1	1.02	1/1
1909	212.5	108.6	3	0.0316	0.9684	1.0326	1	1.03	1/1
1910	364.7	120.8	4	0.0421	0.9579	1.0440	1	1.04	1/1
1911	277.6	126.2	5	0.0526	0.9474	1.0556	1	1.06	1/1
1912	515.4	131.8	6	0.0632	0.9368	1.0674	1	1.07	1/1
1913	258.3	134.7	7	0.0737	0.9263	1.0795	1	1.08	1/1
1914	255.5	138.0	8	0.0842	0.9158	1.0920	1	1.09	1/1
1915	224.2	147.7	9	0.0947	0.9053	1.1047	1	1.10	1/1
1916	222.7	165.6	10	0.1053	0.8947	1.1176	9	10.06	9/10
1917	261.7	167.8	11	0.1158	0.8842	1.1310	8	9.05	8/9
1918	475.8	170.8	12	0.1263	0.8737	1.1446	7	8.01	7/8
1919	347.7	177.8	13	0.1368	0.8632	1.1585	6	6.95	6/7
1920	218.7	182.6	14	0.1474	0.8526	1.1728	6	7.04	6/7
1921	251.7	190.5	15	0.1579	0.8421	1.1875	5	5.94	5/6
1922	439.1	194.3	16	0.1684	0.8316	1.2025	5	6.01	5/6
1923	190.5	209.8	17	0.1789	0.8211	1.2179	5	6.09	5/6
1924	305.8	210.0	18	0.1895	0.8105	1.2338	4	4.94	4/5
1925	382.1	212.5	19	0.2000	0.8000	1.2500	4	5.00	4/5
1926	318.8	215.6	20	0.2105	0.7895	1.2667	4	5.07	4/5
1927	302.8	218.7	21	0.2211	0.7789	1.2838	7	8.99	7/9
1928	227.1	222.7	22	0.2316	0.7684	1.3014	3	3.90	3/4
1929	182.6	224.2	23	0.2421	0.7579	1.3194	3	3.96	3/4
1930	662.3	225.0	24	0.2526	0.7474	1.3380	3	4.01	3/4
1931	242.8	227.1	25	0.2632	0.7368	1.3571	3	4.07	3/4
1932	352.9	229.0	26	0.2737	0.7263	1.3768	8	11.01	8/11
1933	299.4	233.7	27	0.2842	0.7158	1.3971	5	6.99	5/7
1934	302.5	237.6	28	0.2947	0.7053	1.4179	5	7.09	5/7
1935	242.1	238.4	29	0.3053	0.6947	1.4394	9	12.95	9/13
1936	210.0	242.1	30	0.3158	0.6842	1.4615	2	2.92	2/3
1937	165.6	242.8	31	0.3263	0.6737	1.4844	2	2.97	2/3
1938	126.2	250.0	32	0.3368	0.6632	1.5079	2	3.02	2/3
1939	431.6	251.7	33	0.3474	0.6526	1.5323	2	3.06	2/3
1940	474.0	252.2	34	0.3579	0.6421	1.5574	9	14.02	9/14
1941	274.4	255.5	35	0.3684	0.6316	1.5833	7	11.08	7/11
1942	276.6	258.3	36	0.3789	0.6211	1.6102	5	8.05	5/8
1943	335.1	259.7	37	0.3895	0.6105	1.6379	3	4.91	3/5
1944	584.5	261.7	38	0.4000	0.6000	1.6667	3	5.00	3/5
1945	434.9	261.9	39	0.4105	0.5895	1.6964	3	5.09	3/5
1946	518.8	262.1	40	0.4211	0.5789	1.7273	7	12.09	7/12
1947	120.8	273.6	41	0.4316	0.5684	1.7593	4	7.04	4/7
1948	238.4	274.4	42	0.4421	0.5579	1.7925	5	8.96	5/9
1949	177.8	276.6	43	0.4526	0.5474	1.8269	6	10.96	6/11
1950	225.0	277.6	44	0.4632	0.5368	1.8627	7	13.04	7/13
1951	252.2	283.7	45	0.4737	0.5263	1.9000	1	1.90	1/2
1952	170.8	299.0	46	0.4842	0.5158	1.9388	1	1.94	1/2
1953	273.6	299.4	47	0.4947	0.5053	1.9792	1	1.98	1/2
1954	322.3	302.5	48	0.5053	0.4947	2.0213	2	4.04	2/4

Cont'd.,

Cont'n.,

YEAR	NEM total RF(mm)	Rainfall (Ascending order)	Order Number	Cumulative Frequency (CF)*	1-CF	Returning period** (uncorrected)	Multiplier	Product	Corrected Returning period
1955	131.8	302.8	49	0.5158	0.4842	2.0652	2	4.13	2/4
1956	395.4	305.4	50	0.5263	0.4737	2.1111	9	19.00	9/19
1957	683.8	305.8	51	0.5368	0.4632	2.1591	6	12.95	6/13
1958	261.9	318.8	52	0.5474	0.4526	2.2093	5	11.05	5/11
1959	372.6	322.3	53	0.5579	0.4421	2.2619	4	9.05	4/9
1960	386.7	331.8	54	0.5684	0.4316	2.3171	3	6.95	3/7
1961	262.1	335.1	55	0.5789	0.4211	2.3750	8	19.00	8/19
1962	424.2	341.9	56	0.5895	0.4105	2.4359	7	17.05	7/17
1963	233.7	347.7	57	0.6000	0.4000	2.5000	4	10.00	4/10
1964	331.8	352.9	58	0.6105	0.3895	2.5676	7	17.97	7/18
1965	250.0	353.1	59	0.6211	0.3789	2.6389	3	7.92	3/8
1966	405.7	364.7	60	0.6316	0.3684	2.7143	7	19.00	7/19
1967	147.7	372.6	61	0.6421	0.3579	2.7941	7	19.56	7/20
1968	167.8	376.2	62	0.6526	0.3474	2.8788	8	23.03	8/23
1969	444.3	382.1	63	0.6632	0.3368	2.9688	1	2.97	1/3
1970	194.3	384.2	64	0.6737	0.3263	3.0645	1	3.06	1/3
1971	384.2	386.7	65	0.6842	0.3158	3.1667	6	19.00	6/19
1972	654.0	392.0	66	0.6947	0.3053	3.2759	7	22.93	7/23
1973	450.2	395.4	67	0.7053	0.2947	3.3929	5	16.96	5/17
1974	82.8	401.4	68	0.7158	0.2842	3.5185	4	14.07	4/14
1975	138.0	401.8	69	0.7263	0.2737	3.6538	3	10.96	3/11
1976	259.7	405.7	70	0.7368	0.2632	3.8000	5	19.00	5/19
1977	564.1	417.0	71	0.7474	0.2526	3.9583	1	3.96	1/4
1978	392.0	424.2	72	0.7579	0.2421	4.1304	8	33.04	8/33
1979	832.4	425.0	73	0.7684	0.2316	4.3182	3	12.95	3/13
1980	401.4	430.3	74	0.7789	0.2211	4.5238	4	18.10	4/18
1981	341.9	431.6	75	0.7895	0.2105	4.7500	4	19.00	4/19
1982	353.1	432.3	76	0.8000	0.2000	5.0000	1	5.00	1/5
1983	425.0	433.5	77	0.8105	0.1895	5.2778	7	36.94	7/37
1984	417.0	434.9	78	0.8211	0.1789	5.5882	5	27.94	5/28
1985	229.0	439.1	79	0.8316	0.1684	5.9375	1	5.94	1/6
1986	215.6	444.3	80	0.8421	0.1579	6.3333	3	19.00	3/19
1987	509.0	450.2	81	0.8526	0.1474	6.7857	5	33.93	5/34
1988	97.2	474.0	82	0.8632	0.1368	7.3077	3	21.92	3/22
1989	299.0	475.8	83	0.8737	0.1263	7.9167	1	7.92	1/8
1990	237.6	495.3	84	0.8842	0.1158	8.6364	3	25.91	3/26
1991	108.6	509.0	85	0.8947	0.1053	9.5000	2	19.00	2/19
1992	401.8	515.4	86	0.9053	0.0947	10.5556	9	95.00	9/95
1993	432.3	518.8	87	0.9158	0.0842	11.8750	8	95.00	8/95
1994	430.3	564.1	88	0.9263	0.0737	13.5714	7	95.00	7/95
1995	209.8	584.5	89	0.9368	0.0632	15.8333	6	95.00	6/95
1996	376.2	595.4	90	0.9474	0.0526	19.0000	1	19.00	1/19
1997	595.4	654.0	91	0.9579	0.0421	23.7500	4	95.00	4/95
1998	495.3	662.3	92	0.9684	0.0316	31.6667	3	95.00	3/95
1999	433.5	683.8	93	0.9789	0.0211	47.5000	2	95.00	2/95
2000	134.7	832.4	94	0.9895	0.0105	95.0000	1	95.00	1/95

\* Cumulative frequency =  $\frac{\text{Number of the concerned order}}{\text{Total number of order} + 1}$

\*\* Return period =  $\frac{1}{1 - \text{cumulative frequency}}$