EVALUATION OF SORGF SUBROUTINES
A CONSULTANCY REPORT

By

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EVALUATION OF SORGF SUBROUTINES
-- A Consultancy Report

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In the seasonally dry rainfed semi-arid tropics (SAT) crop yields are generally low and variable from year to year. The task of improving and stabilizing agricultural production in the SAT is complicated by the presence of several constraints in these areas. However, lack of water is the key limiting factor for crop production in the SAT (Virmani et al., 1980). Attempts are made through interdisciplinary research to increase and stabilize agricultural production through improved soil, water and crop management practices. Water available for crop production is highly location specific. In order to match crops and cropping systems to available water, a method of integrating rainfall, soil water storage, evaporative demand and crop characteristics is needed. Process based soil and climate driven crop models should be useful for integrating crop environment effectively for many climatic constraints enabling the assessment of crop production and the quantification of associated production risks.

Sorghum (Sorghum bicolor L.) is an important component of the cropping systems in the SAT. It was, therefore, initially decided to study sorghum and sorghum based cropping systems and extend the knowledge gained to other crops/cropping system. A previously developed grain sorghum model (SORGF) reported by Arkin et al. (1976) was selected for testing and validation to determine its utility for assessing sorghum production. If SORGF is adaptable to SAT conditions it will be used to determine optimum date of planting, plant population, and maturity genotype for various soil water and climatic conditions.

To develop a data base to test and improve SORGF, a collaborative multilocation sorghum modeling experiment was initiated in the 1979 rainy season by ICRISAT in cooperation with several research centers in India and abroad (Table 1). During the past 3 years, scientists from different disciplines have collected data sets on soils, crops, weather and management factors.

At a cooperators' meeting held at the ICRISAT research center, 2-4 April 1980 (Huda et al., 1980), several subroutines in SORGF were identified as needing modification for adoption to SAT regions. These subroutines deal with light interception, phenology, dry matter accumulation, and partitioning, soil water and leaf development. A cooperative consultancy program was established between ICRISAT and Texas A&M University following the meeting. Dr. M. V. K. Sivakumar, visited Temple (March - June, 1981) as a consultant and revised the subroutines on light interception, dry matter accumulation, and soil water (Sivakumar, 1981). I visited Temple (November, 1981 - February, 1982) as a consultant with the objectives of:

i) determining the status of collaborative multilocation sorghum modeling experiment by examining all the relevant data sets thus far collected,

ii) studying the phenology subroutine,

iii) studying the dry matter partitioning scheme,

iv) examining leaf development algorithms, and

v) to assess the improvements made in SORGF with recent revisions.

Table 1. Summary of collaborative multilocation sorghum modeling field studies.

LOCATION	YEAR	SEASON	GENOTYPES	MOISTURE TREATMENT	LATITUDE (°N)
ICRISAT*	1979	Rainy	CSH-1, CSH-6 SPV-351	Rainfed	17' 27'
	1979	Postrainy	CSH-8, M-35-1	A and B	
	1980	Rainy	CSH-1, CSH-6 SPV-351	Rainfed and A	
	1980	Postrainy	CSH-6, CSH-8 M-35-1	A and B	
Coimbatore	1980	Postrainy	CSH-8	A	11' 00'
Delhi	1979	Rainy	CSH-1, CSH-6	Rainfed	28' 35'
	1980	Rainy	CSH-1, CSH-6	Rainfed and A	
Hissar	1979	Rainy	CSH-1, CSH-6	Rainfed	29' 10'
	1980	Rainy	CSH-6	Rainfed and A	
Khon Kaen (Thailand)	1979	Rainy	KU-300	Rainfed	16' 26'
	1980	Rainy	Hegari	Rainfed	
Ludhiana	1980	Rainy	CSH-1, CSH-6	Rainfed	30' 56'
Parbhani	1979	Rainy	CSH-1, CSH-6	Rainfed	19' 08'
		Postrainy	CSH-8, M-35-1	Residual moisture	
	1980	Rainy	CSH-1, CSH-6	Rainfed	
		Postrainy	CSH-8	A	
Pune	1979	Rainy	CSH-1, CSH-6	Rainfed	18' 32'
		Postrainy	CSH-8, M-35-1	A	
	1980	Rainy	CSH-1, CSH-6	Rainfed	
		Postrainy	CSH-8	A	
Rahuri	1979	Rainy	CSH-1, CSH-6	Rainfed	19' 24'
		Postrainy	CSH-6, CSH-8, M-35-1	Residual moisture	
	1980	Rainy	CSH-1, CSH-6	Rainfed	
		Postrainy	CSH-8, M-35-1	A	
Sholapur	1979	Postrainy	CSH-8, M-35-1	Residual moisture	17' 40'

= adequately watered; B = water stressed

= both vertisols and alfisols

FIELD STUDIES

Replicated trials involving two standard Indian sorghum genotypes CSH-1 and CSH-6 during the rainy season and CSH-8 and M-35-1 during the postrainy season, were conducted at most of the locations (Table 1). Sorghum is not grown during the postrainy season at Delhi, Hissar, and Ludhiana because of cold temperature. Additional moisture treatments of adequate water and water stress at certain critical growth stages were included in the postrainy season experiments. Data on crop phenology, leaf growth and development, dry matter production and partitioning, soil water, weather and management factors were collected at each of the 71 field studies (Huda et al., 1982).

1. Phenology.

Accurate simulation of phenological development is important because the stage of development determines the daily dry matter partitioning to various plant parts. The period from anthesis to physiological maturity is underestimated by SORGF. In SORGF, the grain filling period is dependent upon the time until anthesis. The period from emergence to panicle initiation is overestimated by SORGF particularly in lower latitudes (e.g., ICRISAT). This overestimation by SORGF algorithms appears to be a result of the U. S. data bases used for their development that had relatively higher daylengths.

The phenological stage of growth for the modeled sorghum plant in SORGF is calculated in four stages.

STAGE	Period (from/to)
1	Emergence to panicle initiation
2	Panicle initiation to end of leaf growth
3	End of leaf growth to anthesis
4	Anthesis to physiological maturity

The time from emergence to panicle initiation is computed as the sum of heat units (base temperature = 7.0°C and the upper limit of mean temperature = 30.0°C) and is a function of the maximum number of leaves. The time from emergence to anthesis is calculated as the computed date ~ the flag leaf was expanded plus 0.86 times the computed number of days from panicle initiation to flag leaf appearance. The time from emergence to physiological maturity is calcualated as 1.4 times the computed number of days from emergence to anthesis.

Crop phenological data for almost all the growth stages are available in 50 data sets. Of these, ten were randomly selected for independent tests. The remaining 40 data sets were used to study the phenological development in order to develop new algorithms. This study concentrated on three stages of sorghum development as defined by Eastin (1971). These stages are:

growth stage 1 (GS1) - the time from emergence to panicle initiation,

growth stage 2 (GS2) - the time from panicle initiation to anthesis,

growth stage 3 (GS3) - the time from anthesis to physiological maturity.

CALENDAR DAYS

Pauli et al. (1964) reported that in general the sorghum plant spends 1/3 of its life cycle in each of the three major stages. This is not true for the data sets studied as is evident from Table 2. These data represent medium and long maturity genotypes, season with high and low temperatures and different daylengths. It is, however, clear that the duration of GS2 and GS3 are similar. The mean days for GS2 and

Table 2. Days required between different sorghum growth stages. (Data pooled over locations, seasons, and genotypes.)

Stage	N	Mean	Standard Deviation	Minimum Value	Maximum Value	C.
GS 1	29	23	4	17	31	19
GS 2	29	37	6	30	50	10
GS 3	39	35	6	22	53	18
GS 1 + GS 2	39	60	7	50	80	11
GS 1 + GS 2 + GS 3	40	96	10	80	115	15

GS3 are 37 and 35 days, respectively. The range of the duration of both these stages are almost similar. The maximum days for GS2 and GS3 were obtained for the postrainy season genotypes when the temperature is cooler than rainy season. The minimum duration for both these stages was obtained for rainy season genotypes. The mean temperature during the postrainy season range between 20-26° C while it ranges between 26-31° C during rainy season. The maximum values for both GS2 and GS3 were similar. For GS2, except one observation (22 day), the minimum value was 30 which is similar to that obtained for GS3. The duration of GS3 at ICRISAT for CSH-6 was 29 days (when the mean temperature was 27° C) during the rainy season, however, the duration increased to 38 days in the postrainy season (when the mean temperature was 21°C).

The duration of GS1 is highly variable (Table 2). The mean days required for GS1 is 23. The minimum and maximum value for GS1 was obtained for the same genotype (CSH-6) grown during rainy season at different locations. The minimum duration was obtained at ICRISAT and Parbhani locations (low latitude) while the maximum duration was observed in Delhi and Hissar (high latitudes). To account for this variability, the data were further analyzed to establish the affect of daylength and temperature on phenolgical development.

GROWING DEGREE DAYS

Phenological models that involve daylength and/or temperature effects have been developed for several crops. Mederski et al. (1973) found that accumulated heat units provide a far better estimate of predicting phenology in the maize genotypes studied than did calendar days. Major et al. (1975) working with soybeans found that growing degree days (GDD) with a base temperature subtracted were best for predicting flowering in the cultivars under study. They also found that accuracy of the GDD was greater for the earlier varieties than for the later varieties.

Several methods for calculating GDD are described in the literature (e.g. Gilmore and Rogers, 1958; Brown, 1972; Cross and Luber, 1972; Thomas, 1980; Stapper and Arkin, 1980). Stapper and Arkin (1980) reported that the best results for predicting silking or maturity of corn plant were obtained by using a base temperature of 10° C and a cutoff temperature of 30° C in GDD calculation:

$$GDD = (CMIN + CMAX)/2 - BASET$$

Cutoff temperature is substituted for the daily maximum temperature (CMAX) if CMAX is higher than cutoff temperature. When the daily minimum temperature (CMIN) is lower than BASET a sine curve is used to approximate the diurnal change in temperature between maximum and minimum.

The approach of Stapper and Arkin (1980) was used to calculate GDD for sorghum with various threshold temperatures. The cutoff temperature was varied from 26, 30, 34, and 38° C. Base temperatures of 7, 9, 11, and 13° C were also used to evaluate GDD. Schaffer (1980) calculated heat units using 30, 34, and 38° C as cutoff temperature and used several base temperature (1, 4, 7, 10, and 13°C). He found that for the grain filling period the heat unit system with the lowest coefficient of variation (CV) was that with a maximum of 38° C and a base temperature of 1° C.

A comparison of CV with the base temperature (7, 9, 11, 13° C) using 38°C as cutoff temperature during grain filling period for the data set studied showed that 7° C provided less coefficient of variation (18) compared to 13° C (23). Therefore, 7° C was used as base temperature in GDD calculations. The CV's using 26, 30, 34 and 38° C as cutoff temperature with 7° C base temperature for the three phenological stages is given in Table 3. The lowest CV was obtained with 26° C, however, there was no marked differences between different cutoff temperature. The 26° C cutoff is very low. More over, the correlation coefficient (r) of the GDD for different growth stages was highest with 38° C cutoff temperature (Table 4). Therefore, a cutoff temperature of 38° C with a base of 7° C was used in further analyses. The CV was highest in GS1 (27) and is in agreement with observations made by Schaffer (1980) (Table 3). CV was the lowest (11) for GS2 and relatively higher (20) for GS3. The mean GDD (cutoff temperature = 38° C and base temperature 7.0° C) for GS2 and GS3 are similar (Table 5). The correlation coefficient between different growth stages was increased with GDD computations compared to when the duration of these stages was expressed in days (Table 4).

DAYLENGTH

Sorghum is considered a short day plant (Doggett, 1970) and daylength therefore affects phenological development. Daylength is not considered in SORGF. The effect of daylength on phenology was studied to explain the variability in duration (days) and GDD for each growth stage across locations. The daylength is calculated with the following algorithms taking into account the twilight period. This algorithm is used in the corn model of Ritchie (personal communication).

S1 = SIN (LAT * 0.01745)

C1 = COS (LAT * 0.01745)

DECLINATION = 0.3979 * SIN (0.0172 * (Julian date - 82.2))

DAYLENGTH = 7.639 * ARCOS (C1 - S1 * SIN (DEC) - 0.044)/
(C1 * COS(DEC)))

Table 3. Coefficients of variation for growing degree days (base temperature = 7° C).

Stage	Cutoff Maximum Temperature (° C)			
	26	30	34	38
GS1	24	24	25	27
GS2	9	9	10	11
GS3	17	17	19	20

Table 4. Correlation coefficients for growing degree days between different growth stages, (A) cutoff temperature = 26° C, (B) cutoff temperature = 38° C, and (C) for days between growth stages.

(A)

	GS1	GS2	GS3
GS1		0.85	0.80
GS2			0.81
GS3			

(B)

	GS1	GS2	GS3
GS1		0.90	0.84
GS2			0.85
GS3			

(C)

	GS1	GS2	GS3
GS1		-0.17	0.26
GS2			0.02
GS3			

Table 5. Growing degree days between sorghum growth stages (cutoff temperature = 38° C and base temperature = 7.0° C).

GROWTH STAGE	MEAN GDD	STANDARD DEVIATION	CV
GS1	440	120	27
GS2	670	60	11
GS3	650	110	20

The daylength at emergence, panicle initiation, anthesis and physiological maturity were computed. Daylength at emergence and panicle initiation are plotted against the GDD values for GS1 for hybrids CSH-1 and CSH-6 (Fig. 1 and 2). A similar relationship was proposed by Major (1980) for short day plant and by Stapper and Arkin (1980) for corn. Daylength at emergence and panicle initiation are highly correlated (r = 0.99) and therefore daylength at emergence can be used in place of daylength at panicle initiation.

There is evidence that genetic variability for daylength sensitivity exists in rice (Vergara et al., 1965); oats (Jenkins, 1973), and sorghum (Lane, 1963) and corn (Stapper and Arkin, 1980). Miller et al. (1968) found that sorghum genotypes could be grouped according to daylength. They also suggested a lower threshold daylength than the sorghums grown in the U. S. Thomas (1980) concluded from his study with serial sowings of five sorghum genotypes that all the genotypes reacted in a similar manner with regard to daylength. For the present study, daylength threshold value of 13.6 hour at emergence was found for two hybrids (CSH-1 and CSH-6). Data for other genotypes were not available above this threshold daylength.

To study the daylength sensitivity among genotypes, four groups were identified. They are:

Group 1 (CSH-1, CSH-6 grown above 13.6 hour daylength)

Group 2 (CSH-1, CSH-6, CSH-8 grown below 13.6 hour daylength)

Group 3 (SPV-351 and Hegari)

Group 4 (M-35-1)

Duncan's multiple range test for three growth stages were computed (Table 6). There is significant difference between group 1 and 2 for

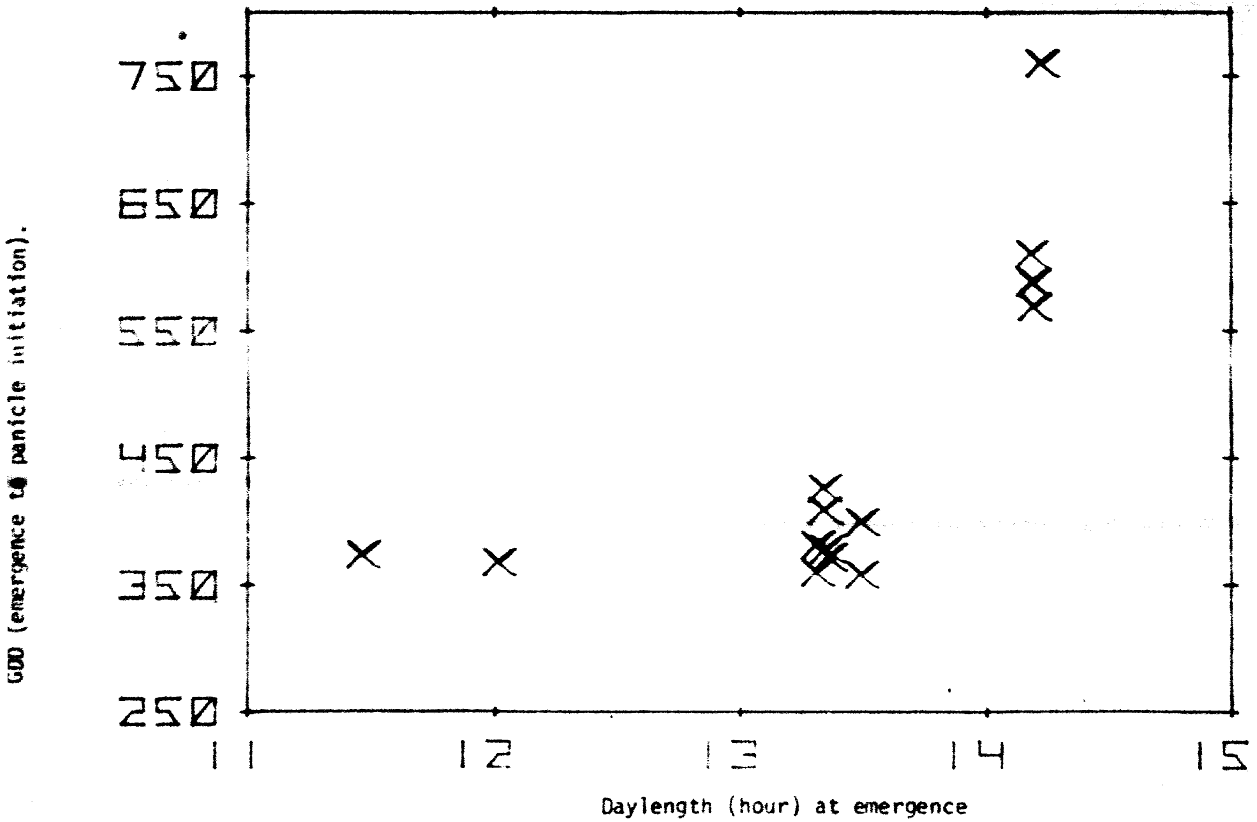


Figure 1. Relationship between growing degree days for emergence to panicle initiation and daylength at emergence for sorghum hybrids CSH-1 and CSH-6.

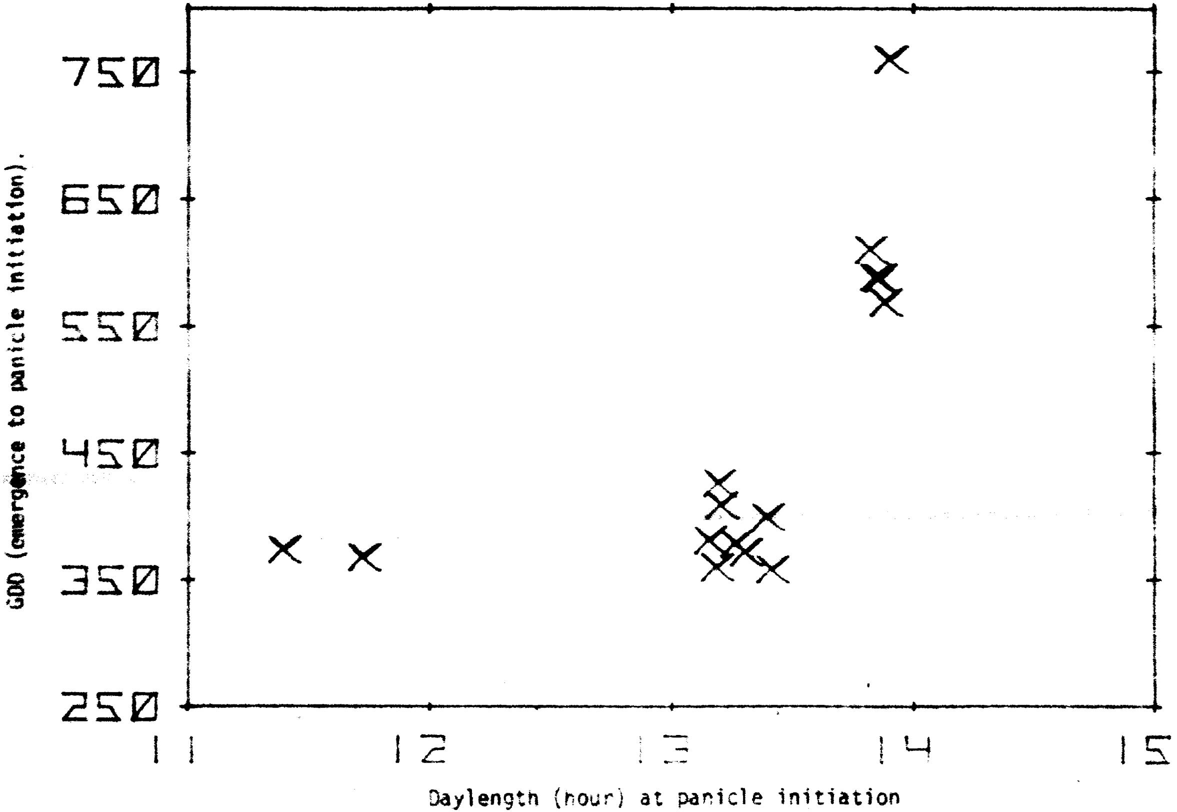


Figure 2. Relationship between growing degree days for emergence to panicle initiation (PI) and daylength at PI for [illegible] hybrids [illegible]

Table 6. Mean growing degree days* for different growth stages for four groups of sorghum.

GROUP	GROWTH STAGE GS1	GROWTH STAGE GS2	GROWTH STAGE GS3
1	610 a	720 a	800 a
2	370 b	650 b	560 c
3	560 a	655 b	555 c
4	365 b	680 b	670 b

Means with the same letter are not significantly different.

all three growth stages. Differences in GS1 can be accounted for by daylength effect as shown in Figs. 1 and 2 and a similar affect was found for GS2.

The algorithm for describing daylength and GDD affects on GS1 derived from Fig. 1 is:

$$GDD = 370 + 400 * (DAYEM - 13.6) \text{ if } DAYEM > 13.6 \text{ hour}$$

$$GDD = 370 \text{ if } DAYEM \le 13.6 \text{ hour}$$

The algorithm for describing daylength and GDD affects on GS2 derived similar to that of GS1 is:

$$GDD = 650 + 120 * (DAYEM - 13.6) \text{ if } DAYEM > 13.6 \text{ hours}$$

$$GDD = 650 \text{ if } DAYEM \le 13.6 \text{ hour}$$

where DAYEM = daylength at emergence.

Differences in GS3 for groups 1 and 2 can be accounted for as a temperature affect as shown by Schaffer (1980). This effect is shown by plotting the inverse of duration (day^{-1}) of GS3 against the mean temperature ($\bar{T}$) of GS3 for hybrids CSH-1 and CSH-6 (Fig. 3). The duration decreases with an increase in $\bar{T}$ to 27° C and increases above 27° C. From Fig. 3 a base temperature of 7° C can be derived for GDD computation in GS3. A base temperature of 7° C was previously selected for all growth stages. Thus, for GS3 the following algorithms are used to account for temperature effects in GDD computation for GS3:

$$GDD = \bar{T} - 7, \text{ when } \bar{T} \le 27^\circ \text{ C}$$

$$GDD = (54 - \bar{T}) - 7, \text{ when } \bar{T} > 27^\circ \text{ C}$$

These algorithms were used to compute GDD for the 40 field studies. The mean GDD computed using these algorithms are presented in Table 7. No significant difference in GDD among groups was found for all growth stages except in GS1 for rainy season variety (SPV-351 and Hegari). The weighted mean GDD for GS3 is 620.

Table 7. Mean growing degree days after daylength correction (GS1 and GS2) and temperature correction (GS3) for different growth stages.

GROUP	GROWTH STAGE GS1	GROWTH STAGE GS2	GROWTH STAGE GS3
1	390 a	655 a	628 a
2	370 a	650 a	640 a
3	560 b	655 a	615 a
4	365 a	680 a	609 a

Means with the same letter are not significantly different.

These algorithms were used to compute GDD for all three growth stages for the 40 field studies from which data to derive these relations were collected. The root mean square error (RMSE) for the three growth stages were compared with SORGF and revised algorithms (Table 8). The RMSE was considerably reduced for all three stages using the revised algorithms.

These revised algorithms were tested against 10 independent field study data sets. RMSE for SORGF and the revised algorithms are given in Table 9. The RMSE for all the three stages were considerably reduced using the revised algorithms.

2. Dry Matter Partitioning.

Partitioning of dry matter to plant parts varies according to the stage of development. Therefore, an accurate estimate of phenological development is important for simulating the partitioning process. Accurate simulations of grain yield, the component of yield generally of most interest, depends upon the ability to correctly partition dry matter to grain and other plant parts.

In SORGF daily dry matter production is calculated from daily intercepted photosynthetically active radiation after taking into account water and temperature stress as well as respiration losses. Sivakumar (1981) developed seemingly simpler relationships for calculating daily dry matter production from intercepted PAR using the approach of Gallagher and Biscoe (1978) and Stapper and Arkin (1980). The partitioning of dry matter in SORGF is computed in the GROW Subroutine for four phenological stages as described by Vanderlip and Arkin (1977).

Leaf, culm, head + grain weights (g/plant) simulated with SORGF were compared with measured data collected from destructive weekly samples

Table 8. Root mean square error (days) for different growth stages for 40 field studies.

STAGES	SORGI	REVISION
GS1	7	3
GS1 + GS2	7	5
GS1 + GS2 + GS3	19	4

Table 9. Root mean square error (days) for different growth stages for 10 independent field study data sets.

STAGES	SORGI	REVISION
GS1	7	4
GS1 + GS2	7	6
GS1 + GS2 + GS3	18	3

(27 field studies) throughout the growing season at the ICRISAT Center. The root mean square error (RMSE) was calculated for measured and simulated plant part weights for each field study. The highest RMSE was observed for the head + grain component within a range of 7 to 34 (g/plant). The lowest RMSE was observed for culm weight within a range of 2 to 12 (g/plant). The range in RMSE for leaf weight was 6 to 21 (g/plant). These RMSE values are indicative of the accuracy with which SORGF partitions dry matter to the plant organs.

Measured mean total dry matter (TDM) (g/plant) and percent partitioned to the plant parts at panicle initiation (PI), anthesis (AN) and physiological maturity (PM) are given in Table 1.0. The percent TDM partitioned to the leaf decreases from 64 to 11 percent from PI to PM and increases from 36 to 60 percent from PI to AN then decreases to 36 percent at PM for the culm. Forty-one percent of TDM was partitioned to grain at PM.

The percent of TDM partitioned to leaf was not significantly different between hybrids and varieties (Table 11). The percent of TDM partitioned to the culm was significantly higher in the varieties than in the hybrids at both anthesis and maturity. TDM (per plant) at AN and PM was also not significantly different between hybrids and varieties. The percent of TDM partitioned to grain was higher in hybrids (0.45) compared to varieties (0.32). TDM partitioning within a growth stage was not studied.

The significant difference in partitioning TDM to the grain component was due to moisture stress (Table 12) for the hybrids. For adequately watered treatments 50 percent of TDM was partitioned to grain while 43 percent was partitioned to grain for water stressed treatments for hybrids. Moisture treatments did not significantly influence partitioning to any plant part for varieties.

Table 10. Total dry matter and percent partitioned to leaf, culm, head + grain and grain at three growth stages (Data pooled over all genotypes, seasons and moisture treatments, n = 27).

	PANICLE INITIATION		ANTHESIS		PHYSIOLOGICAL MATURITY	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
Leaf	0.64	0.04	0.24	0.04	0.11	0.02
Culm	0.36	0.04	0.60	0.06	0.36	0.07
Head + Grain	0.0	0.0	0.16	0.04	0.53	0.08
Grain	0.0	0.0	0.02	0.01	0.41	0.08
Total Dry Matter (g/plant)	1.6	1.2	35.2	15.0	67.4	23.3

Table 11. **Total dry matter and percent partitioned to leaf, culm, head + grain and grain at three growth stages for hybrid and variety (Data pooled over seasons and moisture treatments, n = 27).**

	PANICLE INITIATION		ANTHESIS		PHYSIOLOGICAL MATURITY*	
	Hybrid	Variety	Hybrid	Variety	Hybrid	Variety
Leaf	0.64 a	0.64 a	0.25 a	0.22 a	0.11 a	0.12 a
Culm	0.36 a	0.36 a	0.57 b	0.66 a	0.32 b	0.45 a
Head + Grain			0.18 a	0.12 b	0.57 a	0.43 b
Grain					0.45 a	0.32 b
Total Dry Matter (g/plant)	1.3 b	2.5 a	32.0 a	43.0 a	65.0 a	73.0 a

Means with different letter are significantly different

Table 12. Comparison of total dry matter and percent partitioned to leaf, culm, head + grain and grain for two moisture treatments during postrainy season for CSH-6, CSH-8, M-35-1.

	CSH-6 & CSH-8		M-35-1	
	Adequately Watered	Water Stressed	Adequately Watered	Water Stressed
A) GS1				
Leaf	0.64	0.63	0.64	0.63
Culm	0.36	0.37	0.36	0.37
Total Dry Matter (g/plant)	0.86	0.99	1.17	1.64
B) GS2				
Leaf	0.22	0.24	0.20	0.21
Culm	0.60	0.57	0.68	0.65
Head + Grain	0.18	0.19	0.12	0.14
Grain			0.02	0.03
Total Dry Matter (g/plant)	31.7	20.8	42.8	30.6
C) GS3				
Leaf	0.10	0.12	0.10	0.12
Culm	0.30	0.30	0.47	0.47
Head + Grain	0.60	0.58	0.43	0.41
Grain	0.50*	0.43*	0.32	0.30
Total Dry Matter (g/plant)	64.4*	38.9*	70.4	51.0

significantly different

3. Leaf Development.

Leaf area is overestimated by SORGF, particularly in the grain filling period. Total number of leaves and maximum area of each leaf are input data requirements for SORGF. In SORGF each leaf achieves its maximum area irrespective of moisture and temperature stress conditions. Leaf senescence is accounted for as follows: the first leaf senesces after the 11th leaf expands fully and as each successive leaf expands fully the next leaf senesces. No leaf senescence occurs after the last leaf is fully expanded. It was previously observed (Huda, 1982) that when leaf 7 is fully expanded the first leaf senesces and that as successive leaves fully expand (leaf 8, 9, 10, ...) consecutive leaves (leaf 2, 3, 4, ...) senesce and that leaf area at PM is 50 percent of leaf area at AN.

Leaf area data were collected at 7-10 days interval at 27 ICRISAT field studies and 16 cooperating field studies. However, analyses were made for only ICRISAT data. The maximum leaf area was achieved at AN (Table 13) with a mean of 1710 cm^2/plant and a standard deviation of 622 cm^2/plant. The leaf area variability is the result of pooling hybrids and varieties and moisture treatments. The highest leaf area at AN was obtained for variety SPV-351 (3227 cm^2/plant) and the lowest leaf area (761 cm^2/plant) was obtained for CSH-6 grown during the postrainy season in the water stressed treatment. Leaf area at PM was 50 percent of the maximum leaf area attained.

Mean leaf area at PI, AN and PM are not significantly different between hybrids and varieties (Table 14). Leaf area was reduced by moisture stress during the postrainy season (Table 15). Leaf area was significantly different at PM for adequately watered and water stressed

Table 13. Leaf area (cm^2/plant) at three growth stages. Data pooled over all genotypes, seasons, and moisture treatments.

STAGE	MEAN	S. D.	MINIMUM	MAXIMUM
GS1	369	208	145	1022
GS2	1710	622	761	3227
GS3	876	449	196	1848

Table 14. Mean leaf area (cm^2/plant) for hybrids and varieties at three growth stages.

STAGE	HYBRID	VARIETY
GS1	314 a	506 a
GS2	1641 a	1873 a
GS3	884 a	856 a

Mean with the same lettter is not significantly different.

Table 15. Mean leaf area (cm^2/plant) for adequately watered and water stressed treatments for both hybrid and variety grown during the postrainy season.

	HYBRID		VARIETY	
	Adequately Watered	Water Stressed	Adequately Watered	Water Stressed
Panicle initiation	218	216	319	304
Anthesis	1490	1113	1764	1273
Physiological Maturity	956*	360*	949	381

* significantly different.

hybrids. From AN to PM leaf area decreased approximately 70 percent for hybrids and varieties experiencing water stress. For adequately watered treatments leaf area decreases 36 to 46 percent from AN to PM for hybrids and varieties, respectively.

Simulation Comparison.

The following SORGF algorithms for computing growth and development have been revised:

- i) Light interception (Sivakumar, 1981),
- ii) Total dry matter (TDM) (Sivakumar, 1981),
- iii) Phenology (as herein reported),
- iv) TDM partitioning to grain (as herein reported), and
- v) Leaf senescence (as herein reported).

Grain yields and TDM simulation with SORGF and the revised SORGF are compared with observed data from 29 ICRISAT field studies in Figs. 4-7 and for pooled data from all cooperating locations (Figs. 8-11).

The r and RMSE for comparisons of observed and simulated grain yield and TDM with SORGF and revised SORGF were computed from 29 ICRISAT field studies and for pooled data from all cooperating locations (Table 16). The r value increased for both grain yield and TDM with revised SORGF. The RMSE for grain yield was lower for ICRISAT field data with revised SORGF than with SORGF. RMSE for TDM was essentially the same for ICRISAT and pooled field studies for both SORGF and revised SORGF.

5. Suggested Future Work.

- i) Evaluate total dry matter partitioning within growth stages.
- ii) Investigate water and nutrient deficit affects on growth and development.
- iii) Evaluate a multilayered soil water balance for inclusion in SORGF.

iv) Terminate the cooperative field data collection, emphasize on further analysis of the data, and provide archived data for use by others.

v) Emphasize SORGF applications.

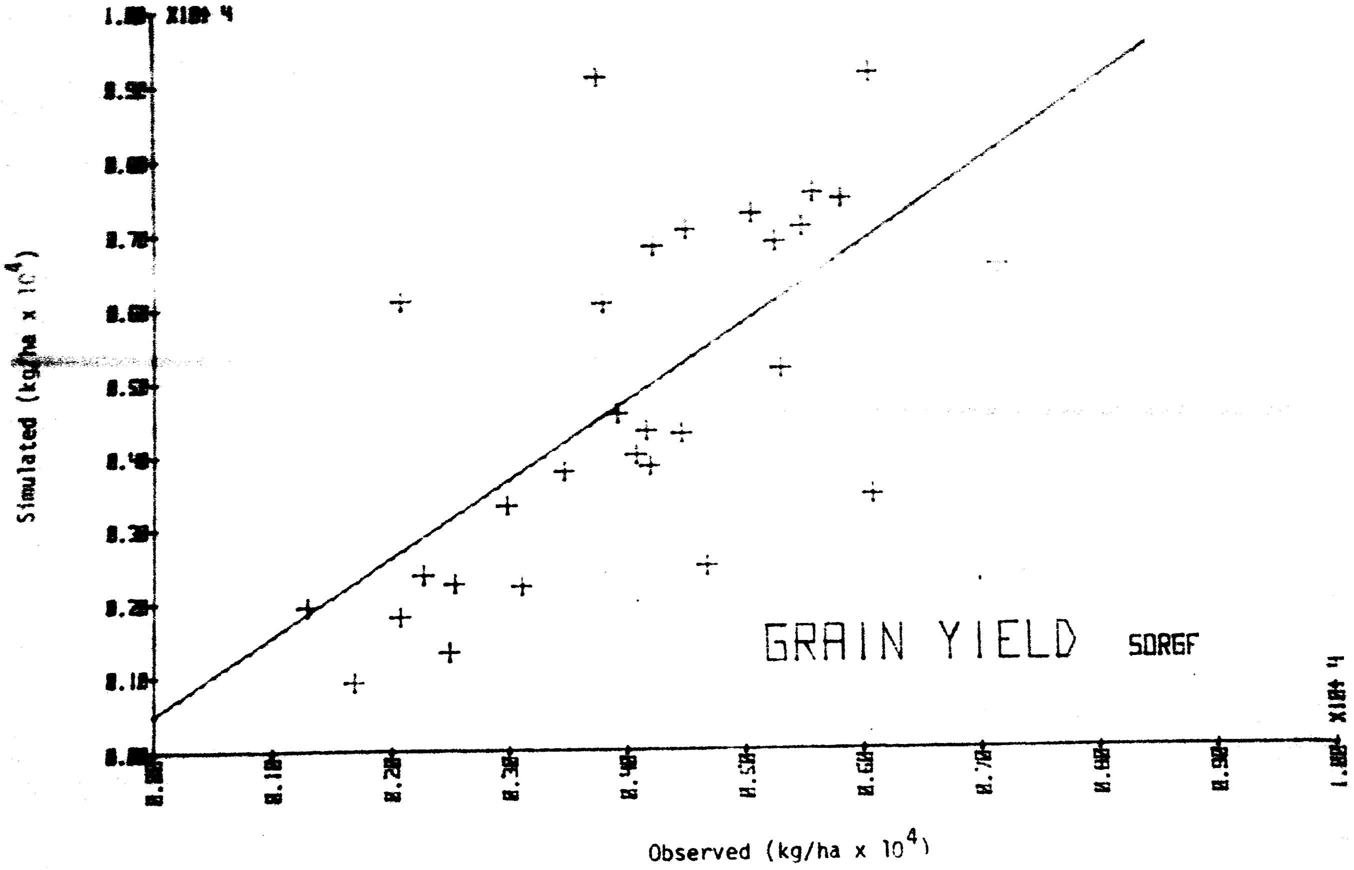
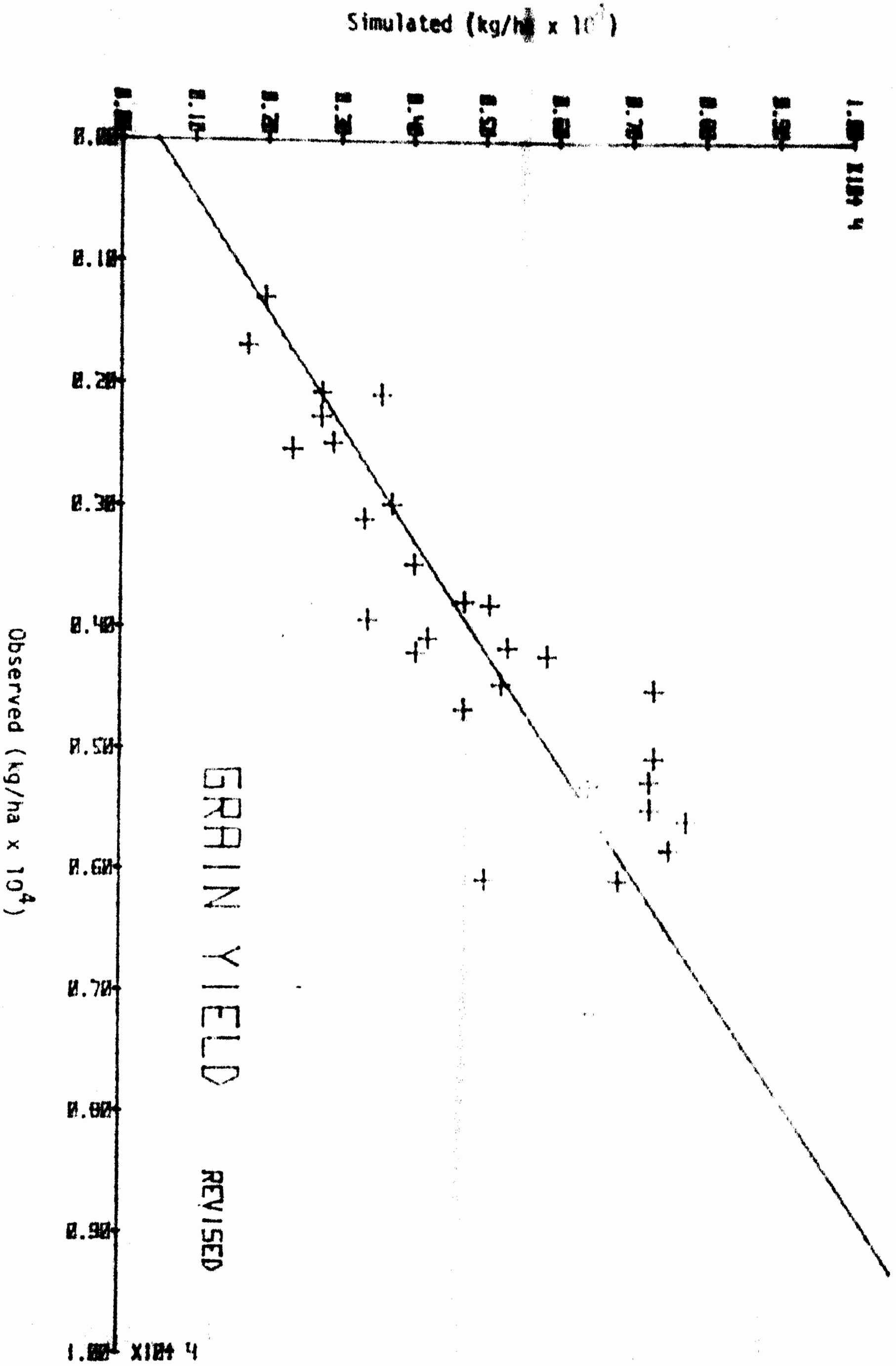


Figure 4   Observed and simulated grain yield [illegible]


Simulated (kg/ha x 10⁴)
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
X10* 4
Observed (kg/ha x 10⁴)
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
X10* 4
GRAIN YIELD
REVISED

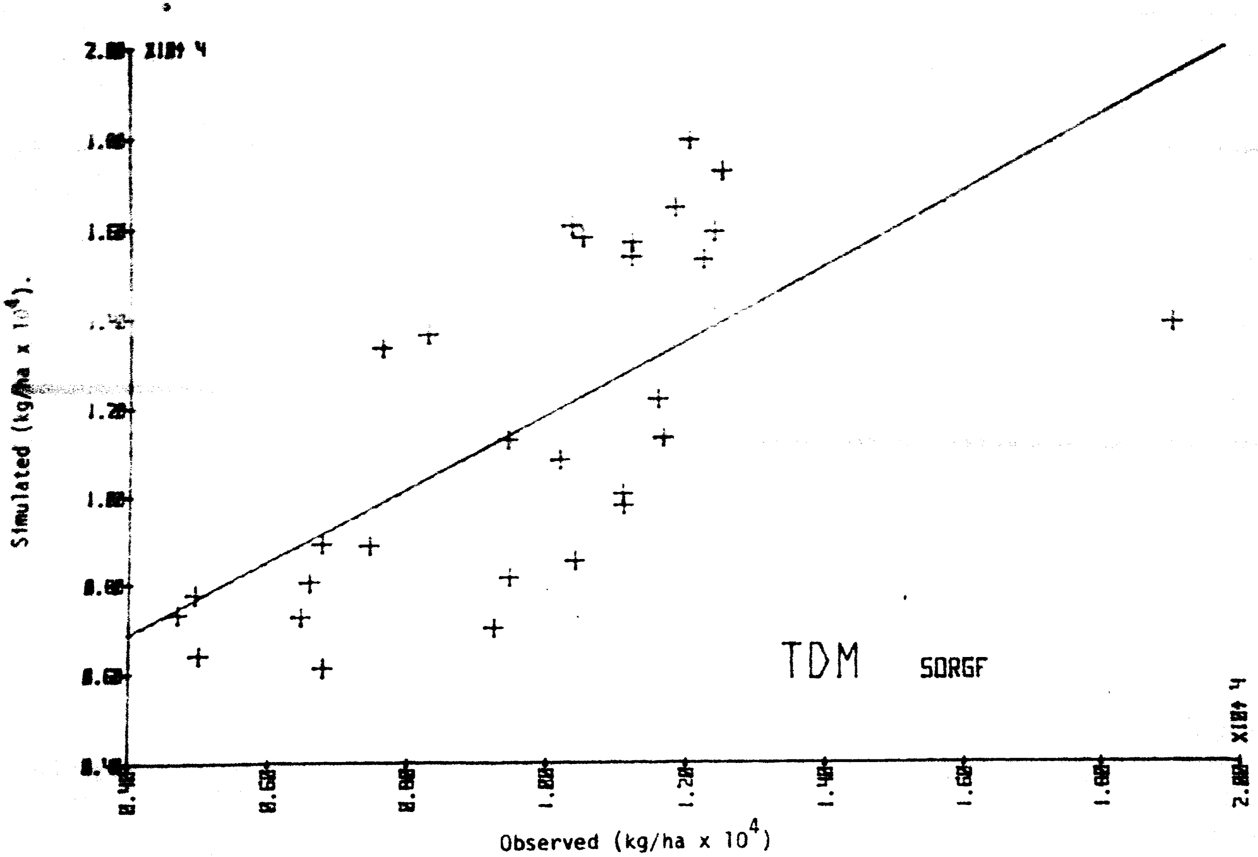


Figure 6. Observed and simulated total dry matter (kg/ha) with SORGF for ICRISAT field data (n = 29).

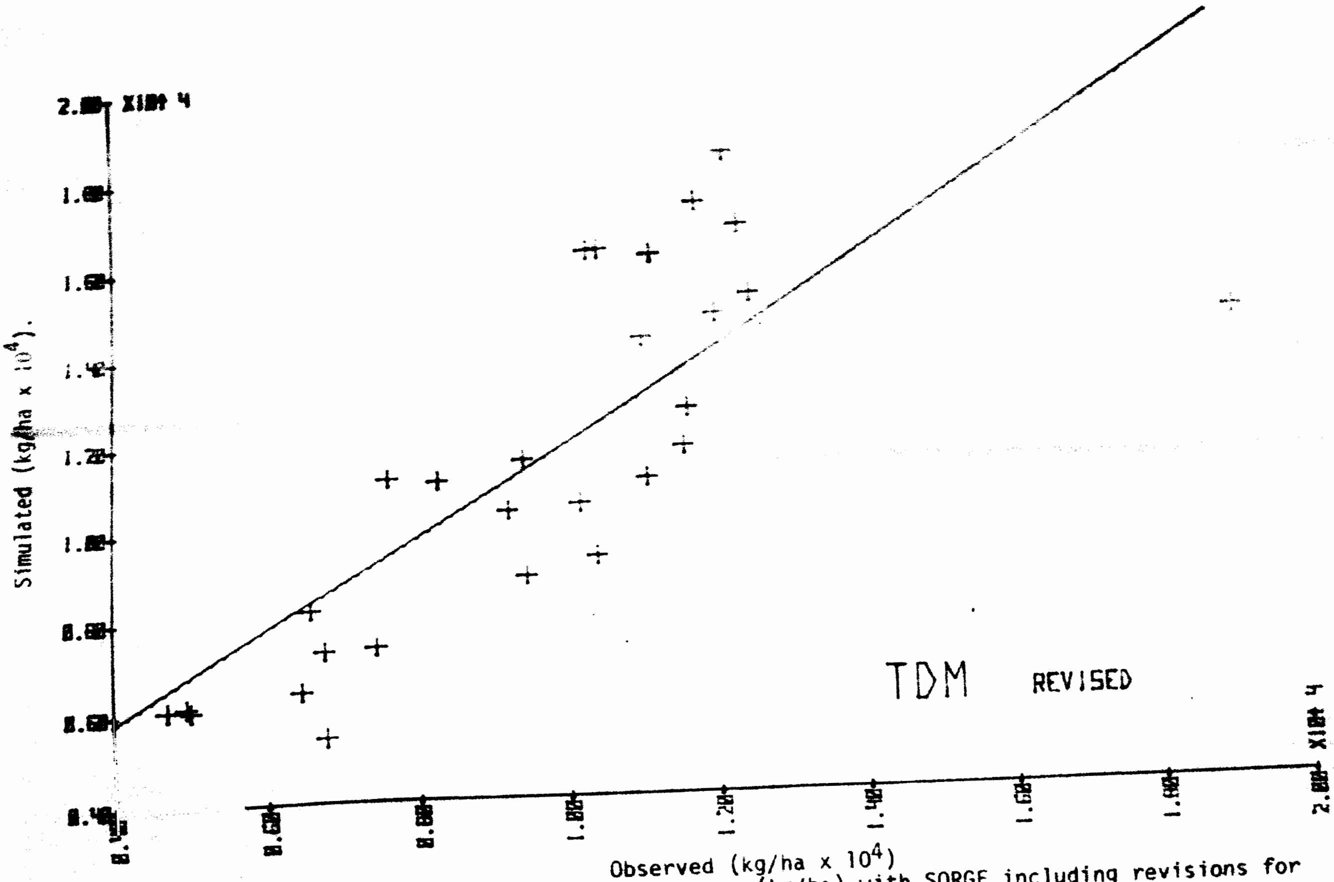


Figure 7. Observed and simulated total dry matter (kg/ha) with SORGF including revisions for ICRISAT field data (n = 29).

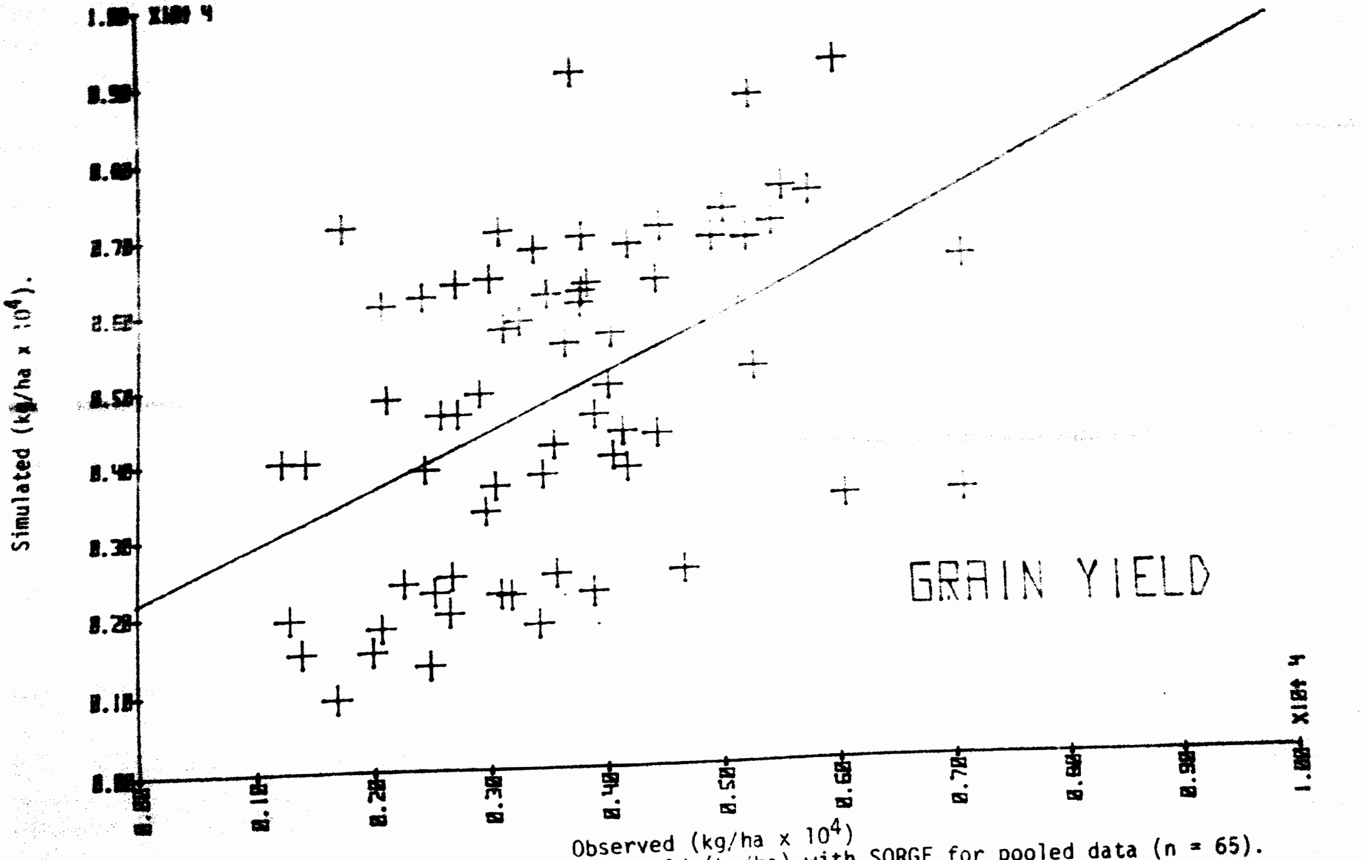


Figure 8. Observed and simulated grain yield (kg/ha) with SORGF for pooled data (n = 65).

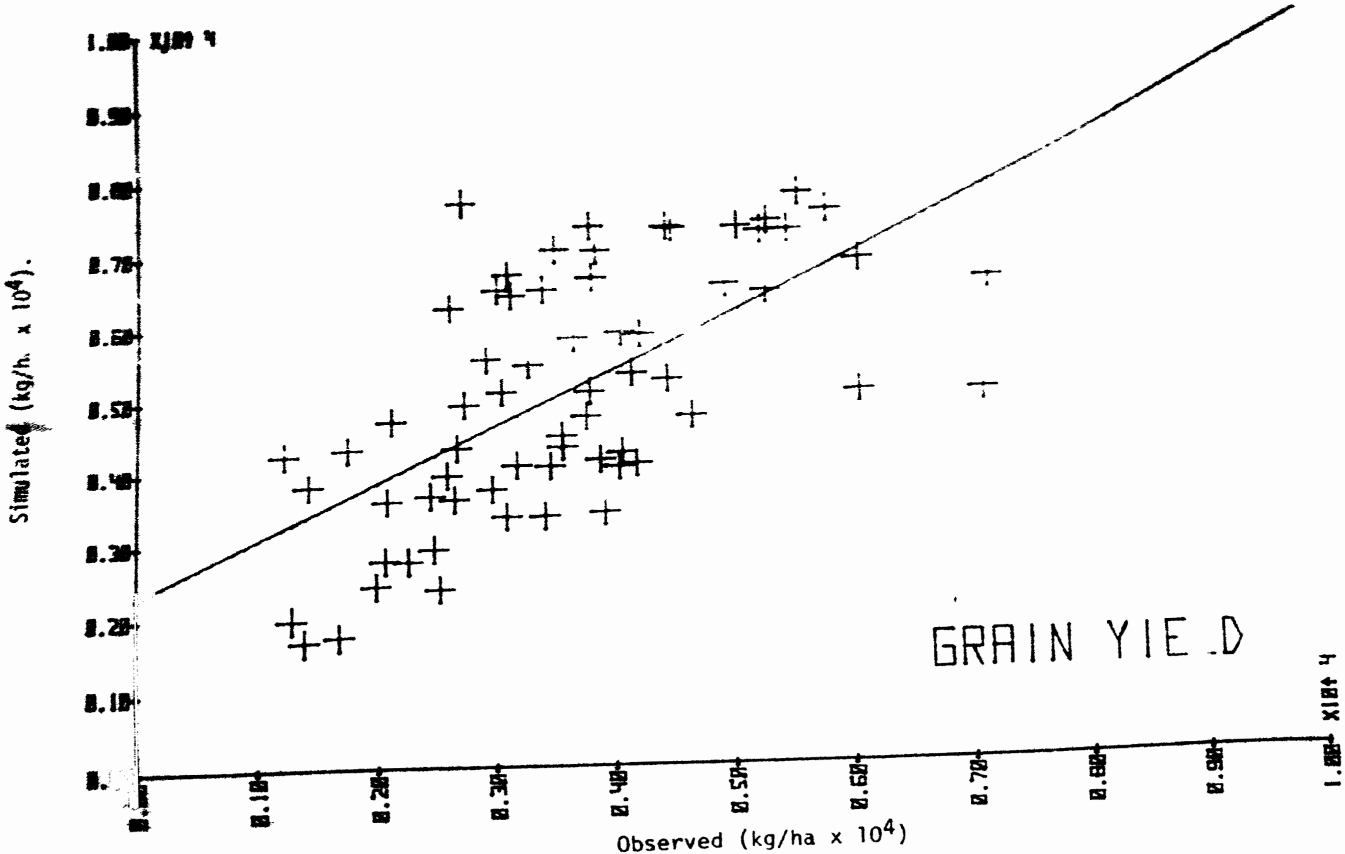


Figure 9. Observed and simulated grain yield (kg/ha) with SORGF including revisions for pooled data (n = 65).

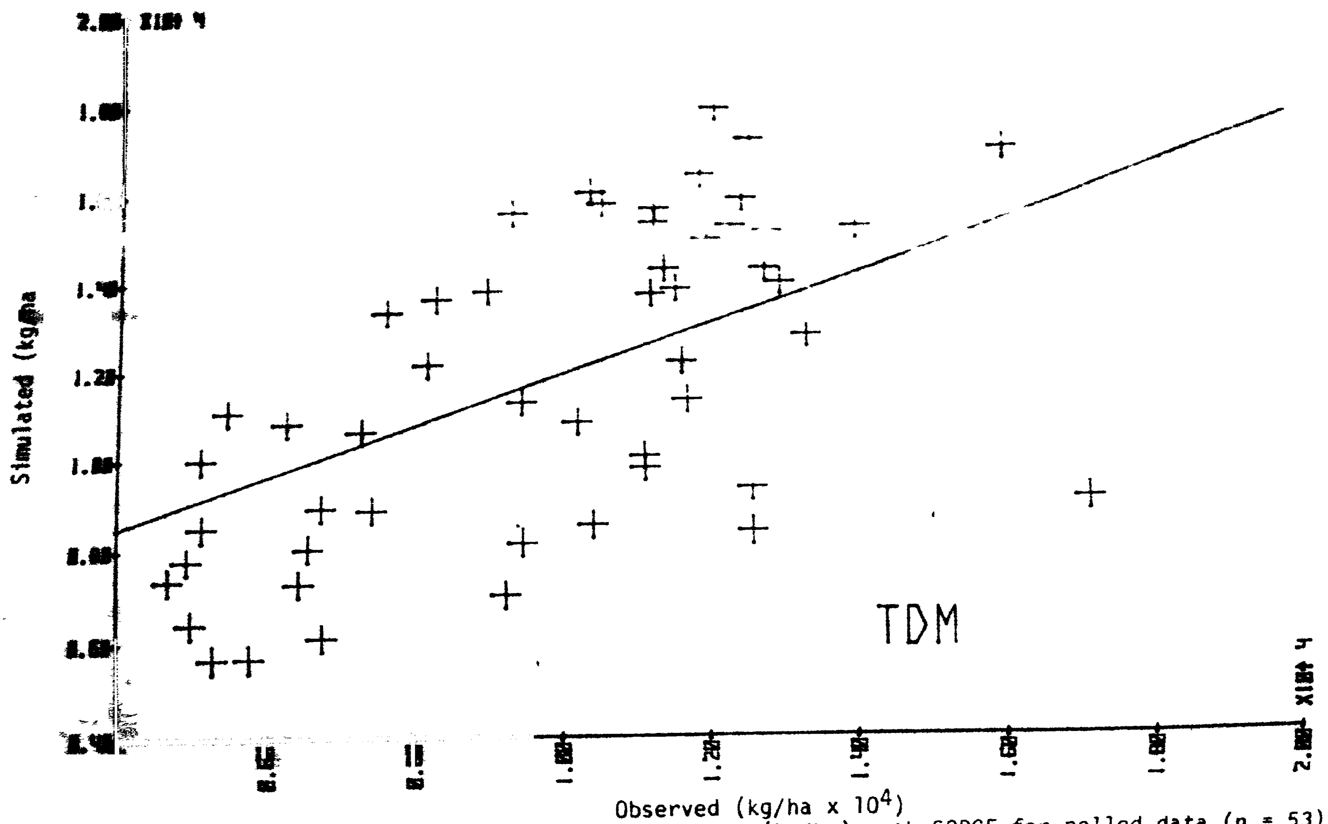


Figure 10. Observed and simulated total dry matter (kg/ha) with SORGF for polled data (n = 53)

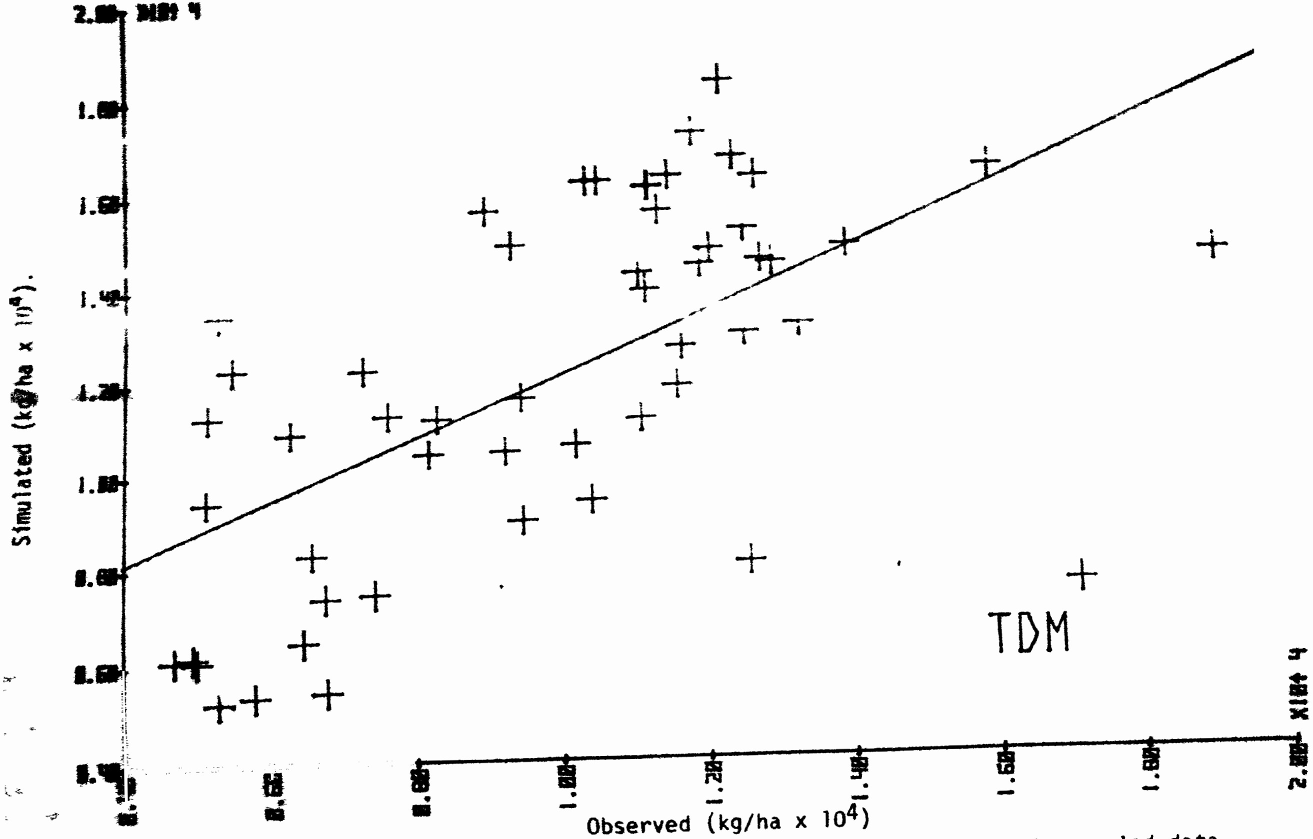


Figure 11. Observed and simulated total dry matter (kg/ha) with revision for pooled data (n = 53).

Table 16 Correlation coefficients (r) and root mean square errors (RMSE) for observed and simulated grain yield (kg/ha) and total dry matter (kg/ha).

	NUMBER OF OBSERVATION	SORGF	REVISED SORGF
Correlation Coefficient (r)			
Grain yield (ICRISAT)	29	0.66	0.87
Grain yield (pooled)	65	0.47	0.62
Total dry matter (ICRISAT)	29	0.66	0.77
Total dry matter (pooled)	53	0.30	0.59
Root Mean Square Error (RMSE)			
Grain yield (ICRISAT)	29	1910	1207
Grain yield (pooled)	65	2228	1962
Total dry matter (ICRISAT)	29	3395	3138
Total dry matter (pooled)	53	4340	4398

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