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# SIMULATION MODEL FOR SORGHUM CROP AND ITS APPLICATION

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## SUMMARY

Crop growth and development models that are based on physiological and physical principles and are driven by daily weather variables enable quantitative description of the dynamic crop production system. Results of a sorghum growth simulation model-SORGF-were briefly described. The duration from emergence to panicle initiation and from emergence to physiological maturity were simulated within $\pm 2$ and $\pm 4$ days of the observed values, respectively. Simulated light transmission values were within $\pm 15\%$ of the observed values. The model simulated soil water and leaf area index fairly close to the observed values. The correlation coefficient between observed and simulated grain yield was 0.86. Applications of the model were illustrated using the examples in selecting optimum date of sowing and scheduling irrigation.

## INTRODUCTION

Crop yield is the integrated result of a number of interacting physical and physiological processes that occur during the crop growing period. These processes are influenced by the characteristic of the crop, weather, soil, and management factors. Quantitative knowledge on the effect of these factors on crop production is important. Systems analysis and simulation modeling approach could help synthesize empirical data collected from field experiments. Crop simulation models driven by daily weather variable enable quantitative description of the dynamic crop production system. And they have enough potential for yield forecasting, crop management, and identifying research areas. Such models may be used to simulate crop response for a number of years using historical weather and soil data to characterize a given region regarding the possibility of growing a particular crop. Model could also be used to extrapolate research results from the regions that have been studied to other similar areas. The utility of crop growth models have been discussed by many

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crop modelers (Creech *et al.*, 1974; Thornley 1976 and Huda and Virmani, 1980).

The objective of this paper is to describe the results of a sorghum growth simulation model, SORGF, developed by Arkin *et al.* (1976) and modified by Huda *et al.* (1984).

**Sorghum modeling efforts at ICRISAT**

The sorghum growth and development model-SORGF-developed at Texas (Arkin *et al.*, 1976) was adapted and validated (Huda *et al.*, 1984) at ICRISAT for its application in the semi-arid tropics. The model calculates on daily basis the occurrence of physiological events, soil water balance, dry matter accumulation and its distribution to different plant parts of an average plant. Final grain yield per unit area is simulated by multiplying the plant density with

Table I : Input data required for 'SORGF'-A sorghum simulation model.

| | |
|---|---|
| *Plant data* | |
| | Leaf number-total number of leaves produced |
| | Leaf area-maximum area of each leaf |
| *Agronomic data* | |
| | Planting date |
| | Plant population |
| | Row width |
| | Row direction |
| | Depth of sowing |
| *Weather data (daily from planting to maturity)* | |
| | Maximum temperature |
| | Minimum temperature |
| | Solar radiation |
| | Rainfall |
| *Soil data* | |
| | Available water holding capacity |
| | Initial available water content |
| *Location data* | |
| | Latitude |

grain yield of an average plant at physiological maturity. Cooperative interdisciplinary research was carried out at nine locations in India (11-31° N) for four years (1979-82) to collect input data of the model (Table I). These locations included Ludhiana, Hisar, Delhi, Parbhani, Rahuri, Pune, Solapur, Patancheru and Coimbatore. Several subroutines of the model that needed modification (Huda *et al.*, 1980) were revised. Both the revised and original SORGF models were tested for their ability to simulate yields and some crop growth characters (Huda *et al.*, 1984).

## RESULTS

*Phenology*: The duration of different growth stages of sorghum obtained from ICRISAT Center and other cooperating centers is shown in Table II. These

Table II : Duration (days) of different sorghum growth stages (data pooled over locations, seasons, and cultivars).

| Growth stage | No. of observations | Duration (days) | | | CV (%) |
|---|---|---|---|---|---|
| | | Mean | Minimum value | Maximum value | |
| GS1 | 29 | 23 | 17 | 31 | 19 |
| GS2 | 29 | 37 | 30 | 50 | 10 |
| GS3 | 39 | 35 | 22 | 53 | 18 |
| GS1+GS2 | 39 | 60 | 50 | 80 | 11 |
| GS1+GS2+GS3 | 40 | 96 | 80 | 115 | 15 |

growth stages are from emergence to panicle initiation (GS1), from panicle initiation to anthesis (GS2), and from anthesis to physiological maturity (GS3). The duration of GS1 was highly variable, ranging from 17 to 31 days, with a mean of 23 days. The minimum and maximum length of GS1 was obtained for the same cultivar (CSH 6) grown during the rainy season at different locations. The minimum duration was observed at ICRISAT Center and Parbhani (17° N); the maximum at Ludhiana (31° N). To account for this variability, the data were further analysed to establish the effect of daylength and temperature on phenological development. The approach of Stapper and Arkin (1980) was used to calculate growing degree days (GDD) for sorghum with a base temperature of 7°C. Daylength at emergence (DAYEM) was highly correlated ($r=0.99$)

with the daylength at panicle initiation (DAYPI) and therefore, DAYEM was used in place of DAYPI. For two sorghum cultivars (CSH 1 and CSH 6) the threshold DAYEM was 13.6 h. Data for other cultivars were not available above this threshold daylength.

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

Group 1 (CSH 1, CSH 6 grown at DAYEM $\geqslant$13.6 h)

Group 2 (CSH 1, CSH 6, CSH 8 grown at DAYEM $<$13.6 h)

Group 3 (SPV 351)

Group 4 (M 35-1)

Duncan's multiple range test for three growth stages showed that there is significant difference between groups 1 and 2 for all three growth stages (Table III). Differences in GS1 and GS2 can be accounted for by daylength.

Table III : 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.

The algorithm for describing DAYEM and GDD effects on GS1 was:

$$GDD=370+400\ (DAYEM-13.6) \quad \text{if } DAYEM \geqslant 13.6 \text{ h}$$

$$GDD=370 \text{ if } DAYEM<13.6 \text{ h}$$

The algorithm for describing DAYEM and GDD effects on GS2 was

$$GDD=650+120\ (DAYEM-13.6) \quad \text{if } DAYEM \geqslant 13.6 \text{ h}$$

$$GDD=650 \text{ if } DAYEM<13.6 \text{ h}$$

Differences in GS3 can be accounted for as a temperature effect only.

GDD=T−7, When T⩽27°C

GDD=(54−T)—7, when T>27°C

Where T=mean air temperature.

The use of these algorithms resulted no significant difference in GDD among the four groups for all growth stages except in GS1 for SPV 351 Table IV.

Table IV : 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 tested against 10 independent field study data sets collected from multilocation experiments. The simulated duration of emergence to panicle initiation, and emergence to physiological maturity were within ±4 and ±3 days of the respective observed values. The simulation of phenological events was separately compared with 19 independent data sets obtained from experiments conducted at ICRISAT Center during 1981/82. The durations of emergence to panicle initiation and from emergence to physiological maturity were simulated within ±2 and ±4 days of the actual values, respectively.

*Light interception* : The light interception portion of the model simulates the relative quantum flux intercepted by a single plant. Intercepted photosynthetically active radiation (PAR) is calculated on an hourly basis following a Beer's law relationship using solar radiation and light transmission values. Hourly solar radiation is computed from the input daily solar radiation, and by accounting for the numbers of sunlight hours for any day, which is calculated as a sine function of the local solar time and daylength.

The quantum flux density in einsteins/$m^2$ is estimated from the energy density (RS) in cal/$cm^2$/day as

$$PAR = RS\,(0.09)$$

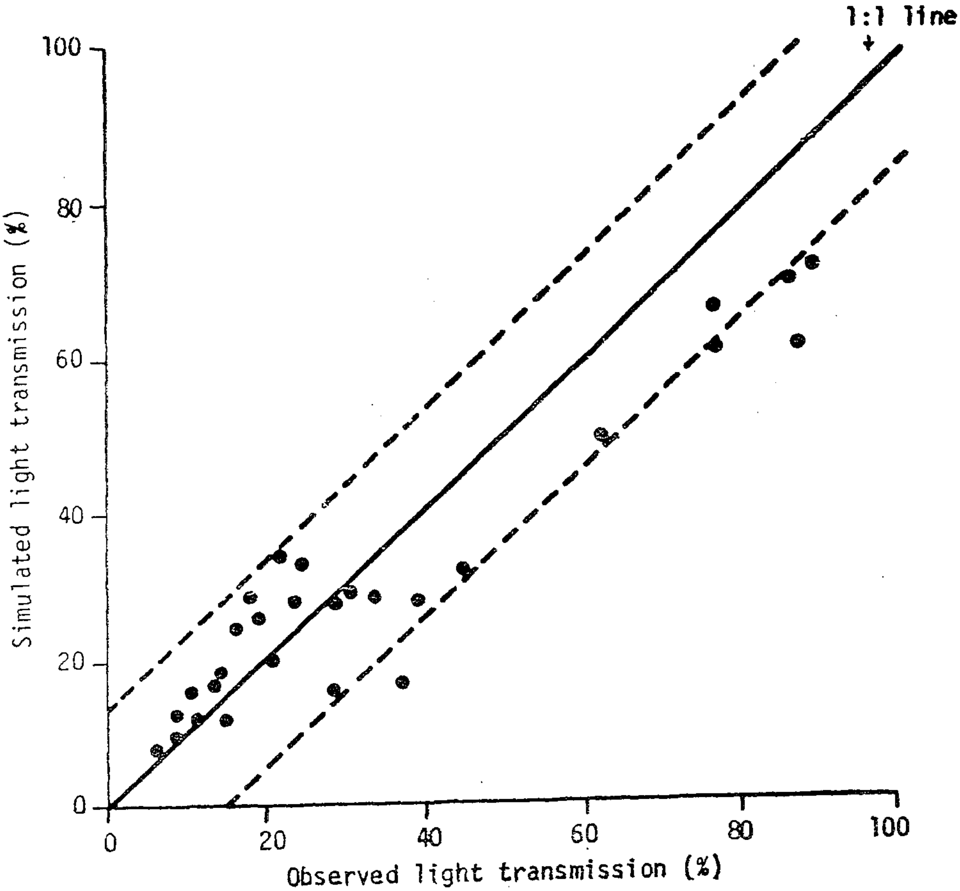


Fig. 1: Observed and simulated light transmission (data pooled from different experiments). Dotted lines represent ±15% from 1:1 line.

Light transmission is calculated from the relationship of maximum light transmission (X1) and extinction coefficient (X2), using information on row spacings and leaf area index (LAI).

$$X1 = 0.1855\ R + 67.2642$$

$$X2 = 0.0026\ R - 0.6469$$

$$\text{Light transmission} = X1e^{X2\ (DLAI)}$$

Where, R = row spacing (cm)

DLAI = daily leaf area index

Figure 1 shows that the simulated light transmission values were within ±15%of the observed data.

Table V : Comparison between observed (O) and simulated (S) available soil water, cumulative evapotranspiration (CET), and the ratio between CET and cumulative open pan evaporation (CEO) during the growing period of sorghum cultivar SPV 351 in 1980 rainy season at ICRISAT Center, Patancheru. Available soil water at seedling emergence was 10.7 cm and the available water holding capacity of the soil was 20 cm, Cumulative rainfall (CR) during the growing season is also given.

| Days after emergence (DAE) | CR (cm) | Soil water (cm) | | CET (cm) | | CET/CEO | |
|---|---|---|---|---|---|---|---|
| | | O | S | O | S | O | S |
| 24 | 7.9 | 12.8 | 19.8 | 5.8 | 5.5 | 0.60 | 0.57 |
| 53 | 40.4 | 20.0 | 19.0 | 17.1 | 13.8 | 0.96 | 0.77 |
| 68 | 49.6 | 20.0 | 18.4 | 21.3 | 18.8 | 0.93 | 0.82 |
| 87 | 55.8 | 18.4 | 17.1 | 29.1 | 26.2 | 0.96 | 0.86 |
| 94 | 55.8 | 13.8 | 13.3* | 33.7 | 30.0 | 0.97 | 0.86 |

Date of emergence was 4 July 1980; observed panicle initiation (PI), anthesis (AN), and physiological maturity (PM) occurred at 29,62, and 94 days after emergence (DAE); simulated PI, AN, and PM were at 28,64, and 97 DAE.

*=Simulated values of 97 DAE are given.

*Soil water* : Available soil water (ASW) was simulated using the information on initial ASW, available water holding capacity of the soil, rainfall/irrigation, and evaporative demand. Simulated soil water was fairly close to the observed values except at 24 days after emergence (DAE) for sorghum cultivar SPV 351 grown in deep Vertisol (ASW=20 cm) during 1980 rainy season at ICRISAT Center (Table V). Comparison between observed and simulated cumulative evapotranspiration (CET) for the growing season showed that the model underestimated CET by 1—19%. Observed ET was calculated as follows:

ET=Initital soil water—final soil water+rainfall—water loss through runoff and deep drainage.

Table VI : Observed (O) and simulated (S) total dry matter and its distribution to different plant parts during the growing period of sorghum cultivar SPV 351 in 1980 rainy season at ICRISAT Center.

| Days after emergence (DAE) | Total dry matter | | Leaf | | Culm | | Head+grain | | Grain | |
|---|---|---|---|---|---|---|---|---|---|---|
| | O | S | O | S | O | S | O | S | O | S |
| | g/m² | | | | | | | | | |
| 20 | 13 | 32 | 8 | 32 | 5 | 0 | | | | |
| 25 | 37 | 60 | 26 | 60 | 11 | 0 | | | | |
| 31 | 54 | 111 | 32 | 102 | 22 | 9 | | | | |
| 38 | 115 | 165 | 64 | 126 | 51 | 39 | | | | |
| 45 | 262 | 231 | 103 | 130 | 157 | 77 | 1 | 24 | | |
| 54 | 339 | 352 | 122 | 145 | 202 | 137 | 15 | 70 | | |
| 59 | 471 | 444 | 125 | 145 | 295 | 189 | 51 | 110 | | |
| 67 | 653 | 572 | 135 | 145 | 421 | 287 | 98 | 140 | | |
| 74 | 752 | 709 | 142 | 145 | 438 | 306 | 172 | 258 | 94 | 112 |
| 81 | 884 | 834 | 138 | 145 | 446 | 343 | 300 | 346 | 230 | 200 |
| 87 | 985 | 976 | 136 | 145 | 449 | 392 | 400 | 439 | 301 | 293 |
| 94 | 1235 | 1217* | 133 | 145 | 527 | 537 | 575 | 535 | 426 | 389 |

Date of emergence was 4 July 1980; observed panicle initiation (PI), anthesis (AN), and physiological maturity (PM) occurred at 29, 62, and 94 DAE; simulated PI, AN, and PM were at 28, 64, and 97 DAE;

* =Simulated values of 97 DAE are given.

Runoff was not measured in this particular experiment, however, the data were available from adjacent plots (personal communication, P. Pathak, Land and Water Engineer, ICRISAT, 1985). There were 10 cm runoff and 4 cm deep drainage during the period of 24 to 53 DAE when 32.5 cm rainfall was received (rainfall in two consecutive days during this period was 11.7 cm on 19 August and 7.3 cm on 20 August). During the period from 53 to 68 DAE, 5 cm water was lost through deep drainage. Deep drainage was not measured; these values were used from the model output. In the model, daily ET was calculated by adding soil evaporation (ES) and transpiration (EP). Potential evaporation below a plant canopy was calculated after simulating the potential evaporation from bare soil and using LAI values (Ritchie, 1972). Net radiation —required for simulating potential evaporation—is calculated from albedo, maximum solar radiation reaching the soil surface, and sky emissivity.

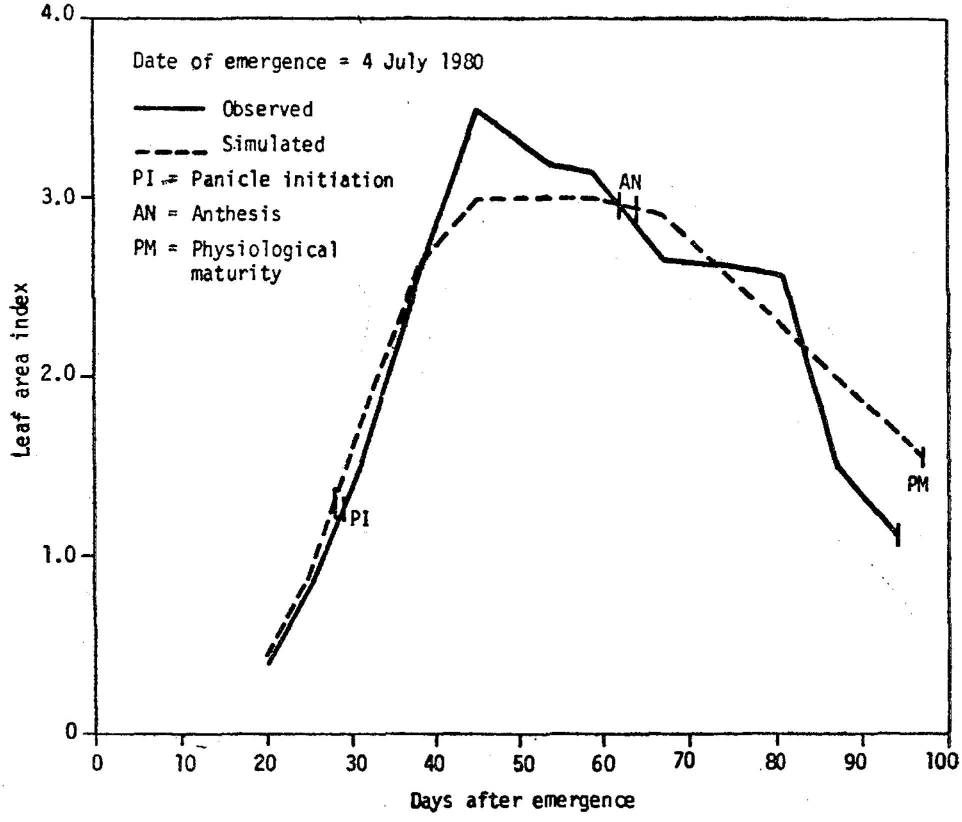


Fig. 2: Observed and simulated leaf area index for sorghum cultivar SPV 351 in 1980 rainy season at ICRISAT Center.

Comparison between CET and cumulative open pan evaporation-CEO (US class 'A' pan) showed that as the growing season advanced the ratio between observed CET and CEO increased from 0.60 to 0.97 while the ratio between simulated CET and CEO increased from 0.58 to 0.86. We have not measured the transpiration (EP) component of the ET, however, the model simulated both EP and soil evaporation on daily basis. The ratio between simulated EP and simulated ET increased as the growing season advanced, and these values were 25% at 24 DAE, 51% at 53 DAE, 58% at 68 DAE, 62% at 87 DAE and 64% at 96 DAE.

*Leaf area index (LAI) :* Simulated values of LAI for sorghum cultivar SPV 351 grown at ICRISAT Center during 1980 rainy season were fairly close to observed values throughout the growing season (Fig. 2).

*Distribution of total dry matter*: Observed and simulated total dry matter and its distribution to different plant parts e.g., leaf, culm (leafsheath + stem), head and grain during the growing season of sorghum cultivar SPV 351

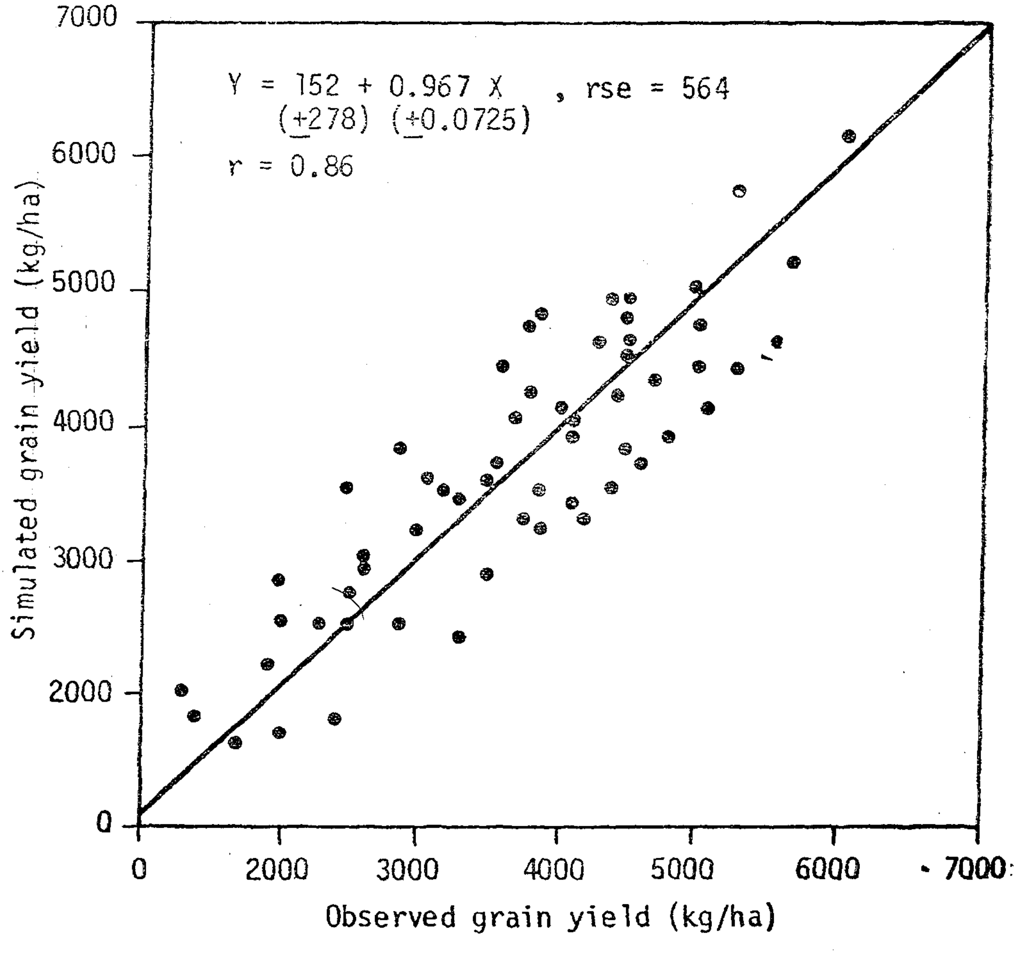


Fig. 3: Relationship between observed and simulated grain yield of sorghum according to revised sorghum model for pooled data (n=59).

in 1980 rainy season are given in Table VI. Simulated total dry matter (TDM) was greater than observed TDM in the beginning of the growing season but they became fairly close as the growing season progressed. At physiological maturity, observed distribution of TDM was 11% to leaf, 43% to culm, and 46% to head+grain, while simulated distribution of TDM was 12% to leaf, 44% to culm, and 44% to head+ grain. Observed and simulated harvest index (per cent of TDM partitioned to grain) was 34% and 32% respectively.

*Grain yield*: Grain yield data over different seasons and sorghum cultivars from ICRISAT Center and other cooperating centers were pooled (n=59) to compare the observed and simulated results. The correlation coefficient between observed and simulated grain yield was 0.86, the intercept of the equation was not significantly different than 0.0, and the regression coefficient was not significantly different than 1.0 (Fig. 3). This shows better agreement between simulated and the observed yields. Simulated grain yields were within±20% of the observed grain yield for 46 of 59 observations.

## APPLICATIONS

Comparison of simulation results with the observed data obtained from date of planting experiments on sorghum during the post-rainy seasons under

Table VII : Simulated response to supplemental irrigation at different growth stages of sorghum in the post-rainy season at Bijapur, Karnataka (simulation base: 16 years).

| Supplemental irrigation (cm) at | | | Grain yield (kg/ha) | | |
|---|---|---|---|---|---|
| Planting* | Panicle initiation | Anthesis | Mean | Maximum | Minimum |
| 0 | 0 | 0 | 2128 | 4263 | 1488 |
| 5 | 0 | 0 | 2181 | 4263 | 1488 |
| 5 | 5 | 0 | 2409 | 4264 | 1668 |
| 5 | 0 | 5 | 3211 | 4263 | 2346 |
| 5 | 5 | 5 | 3433 | 4264 | 2580 |

*Planting date assumed to be 15 September.

residual moisture at ICRISAT Center showed some promise for further use of the model (Fig. 4). Lower grain yield was obtained with the delay in planting,

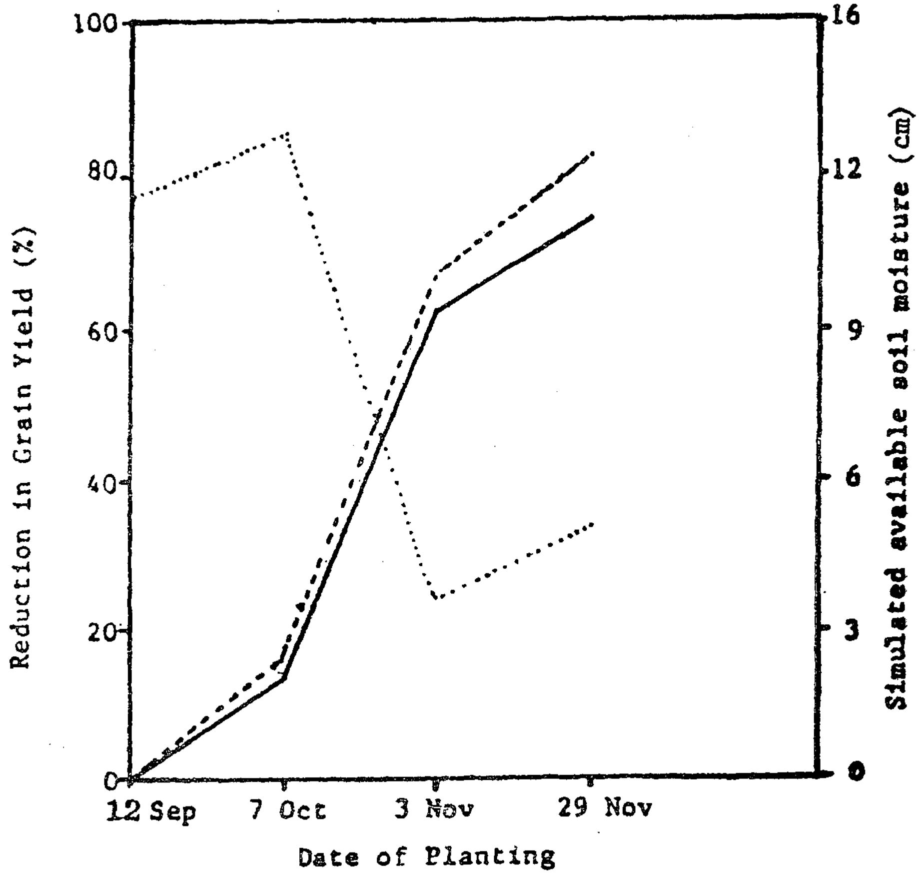


Fig. 4. Comparison between simulated (---) and observed (—) reduction in grain yield of sorghum (cv CSH 1) due to delay in planting under residual moisture during the post-rainy season of 1979/80 at ICRISAT Center, Patancheru. Data on simulated available soil moisture (...) are also shown. (Observed grain yield data obtained from Belum Reddy, ICRISAT. The highest grain yield of 4527 kg/ha was obtained with 12 September planting).

suggesting early planting is the best under the particular agroclimatic environment; similar conclusion can also be drawn from the simulation results. However, simulation values were in general higher than the actual values. The SORGF model did not account for diseases, insects and nutrient stress factors.

The mean annual rainfall for Bijapur is 65 cm. Simulated response of supplemental irrigation to sorghum grain yield showed that the model is sensitive to determine when and how much water should be applied (Table VII). For example, if only 10 cm irrigation water was available, it would be advisable to use 5 cm at planting for crop establishment and another 5 cm at anthesis for grain filling. The revised model thus has potential for being used in developing irrigation strategy.

This study also illustrates the need to record the minimum data set on soil, weather, crop, and management factors. This information is useful for meaningful interpretation of experimental data collected across diverse locations.

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