draft

CROP-WEATHER MODELING EXPERIMENTS: SORGHUM AND PEARL MILLET (1981-1982)

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NOTE TO THE READER

This is an informal report of the Collaborative Multilocation Sorghum and Pearl Millet modeling experiments for 1981-82. The report is designed to stimulate thinking and comments from professional colleagues and is not a formal publication bearing the endorsement of the Institute.

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CROP-WEATHER MODELING EXPERIMENTS: SORGHUM AND PEARL MILLET (1981-1982)

A.K.S. HUDA

Several experiments with sorghum and pearl millet were conducted in 1981-82 at ICRISAT Center, Patancheru with the following objectives:

1. To collect standard data sets on soil, crop, weather and microclimate to test the revised sorghum simulation model (SORGF) and to develop a pearl millet simulation model.

2. To study the behavior of several standard sorghum and pearl millet genotypes in relation to growth, development, and yield.

3. To observe the variation in the growth, development, and yield of several sorghum and pearl millet genotypes with the soils of varying water holding capacities.

During the reporting year, data were also obtained from the collaborative multilocation sorghum modeling trials conducted at Delhi, Ludhiana, Parbhani, and Rahuri to help achieve the above mentioned objectives. A summary of the field experiments conducted during 1981-82 is given in Table 1. Results of sorghum modeling experiments are presented first.

SORGHUM MODELING EXPERIMENTS

ICRISAT CENTER

a) 1981 rainy season

The trials were conducted under rainfed situation in Alfisols and Vertisols with selected genotypes (CSH-1, CSH-5, CSH-6, CSH-8, and SPV-351). The objective of including CSH-8 — a postrainy season sorghum hybrid — was to study its phenology and growth habit in the rainy season. This information will be useful particularly to test the phenology algorithms of the revised sorghum model. The reason for including CSH-5 in the modeling trial for the first time was to assess whether the sorghum simulation model can be applied to the genotypes other than those from which data were collected earlier for model validation.

The trials during 1981 were conducted under the following conditions:

- Alfisol (field RP-4) with 85 mm available water holding capacity under high fertility (100 N, 40 P) and intensive plant protection. Three genotypes (CSH-1, CSH-6, and SPV-351) were planted on 24 June.

- Alfisol (field RUS-3) with 85 mm available water holding capacity under medium fertility (40 N, 20 P) and no plant

Table 1. Summary of the field experiments conducted during 1981-82.

Field	Season	Genotypes	Treatment
ICRISAT		(a) Sorghum	
Alfisol (RP-4)	Rainy	CSH-1	Rainfed
		CSH-6	Rainfed
		SPV-351	Rainfed
Vertisol (BP-12)	Rainy	CSH-1	Rainfed
		CSH-6	Rainfed
		SPV-351	Rainfed
Vertisol (BW-3)	Rainy	CSH-1, CSH-5, CSH-6	Rainfed
		CSH-8, SPV-351	Rainfed
Alfisol (RUS-3)	Rainy	CSH-1, CSH-5, CSH-6	Rainfed, medium
		CSH-8, SPV-351	fertility and
			pesticide free
Alfisol (RP-4)	Postrainy	CSH-8, M-35-1	5 moisture treatments
Vertisol (BW-3)	Postrainy	CSH-1, CSH-5, CSH-6	Ratooning with
		CSH-8, SPV-351	three N levels
Collaborative Centers			
New Delhi	Rainy	CSH-6	Rainfed & irrigated
Ludhiana	Rainy	CSH-1, CSH-6	Rainfed
Parbhani	Rainy	CSH-1, CSH-6	Rainfed
Rahuri	Postrainy	CSH-8, M-35-1	Residual moisture
			& irrigated
ICRISAT		(b) Pearl millet	
Alfisol (RP-4)	Rainy	BJ-104, WC-C75	Rainfed
		ICMS-7703	Rainfed
Vertisol (BP-12)	Rainy	BJ-104, WC-C75	Rainfed
		ICMS-7703	Rainfed
Vertisol (BP-12)	Summer	BJ-104, WC-C75	Residual moisture,
		ICMS-7703	irrigated
Alfisol (RCE-3)	Summer	BJ-104, ICH-226	4 moisture treatments

protection. The objective of this trial was to assess the application of SORGF model (developed and validated with data obtained from high fertility and intensive plant protection) in real world situation. Five genotypes (CSH-1, CSH-5, CSH-6, CSH-8, and SPV-351) were planted on 23 June.

Medium deep Vertisol with 165 mm available water holding capacity under high fertility (100 N, 60 P) and intensive plant protection. Three genotypes (CSH-1, CSH-6, and SPV-351) were dry sown on 12 June.

- Deep Vertisol with 200 mm available water holding capacity with high fertility (100 N, 60 P) and intensive plant protection. Five genotypes (CSH-1, CSH-5, CSH-6, CSH-8, and SPV-351) were dry sown on 10 June.

Sorghum in the Vertisols was planted 'dry' ahead of monsoon. The available water at the time of planting in the entire soil profile of two Vertisol fields were 29 and 65 mm respectively in medium deep (BP-12) and deep Vertisol (BW-3). However, there was no available water in the top 30 cm layers in both fields. Thus emergence in both these fields occurred on 22 June after 35 mm rainfall was received on 18 June. More than 10 mm rainfall was received daily between 22 to 25 June and sorghum was planted on Alfisols on 23 and 24 June; 93 mm rainfall was received on 26 June. In Alfisol, sorghum emergence occurred on 28 June (RP-4) and on 29 June (RUS-3).

Phenology, leaf area index, total dry matter, and grain yield for different genotypes are compared across the experiments.

Comparison of sorghum phenology

Phenology of sorghum genotypes was monitored in all the four trials. Data for three growth stages as defined by Eastin (1971), such as days after emergence (DAE) to panicle initiation (PI), to anthesis (AN), and to physiological maturity (PM) are given in Table 2.

Since daylength and temperature are similar for all these experiments at ICRISAT Center, no difference in PI was observed for a genotype across the experiments. However, genotypic difference existed, e.g. SPV-351 and CSH-5 took longer to reach PI.

It was observed that to reach anthesis all the genotypes took 5-7 days more in Vertisols compared to Alfisols. Nutrient stress in the Alfisol (RUS-3) experiment with medium fertility caused all the genotypes to reach anthesis 2 days earlier. Again genotypic variability existed. CSH-5, CSH-8, and SPV-351 took 9-11 days more to reach anthesis compared to CSH-1 and CSH-6.

All the genotypes matured earlier in Alfisols. Between the two Vertisol experiments, maturity occurred earlier in medium deep Vertisol (BP-12) with 165 mm water holding capacity. This is an accordance with our earlier results as reported by Huda et al (1982a) which showed that moisture stress hastened the days to maturity. Earliest maturity was obtained for all the genotypes in the medium fertility field (RUS-3) due to nutrient stress. Again CSH-5, CSH-8, and SPV-351 took more days to reach maturity compared to CSH-1 and CSH-6.

One interesting observation can be made from the experiment, that the duration between anthesis to maturity ranged only between 27 to 30 days for all these genotypes/treatments. This supports the finding of Huda (1982) that differences in the growth stage 3 (anthesis to maturity) for all genotypes can be attributed to the effect of temperature. It was

Table 2. Comparison of sorghum phenology.

Genotype	Growth stages	Experiment			
		Alfisol (RP-4)	Alfisol, medium fertility pesticide free (RUS-3)	Medium deep Vertisol (BP-12)	Deep Vertisol (BW-3)
		------------Days after emergence------------			
CSH-1	PI[a]	22	22	22	22
	AN	57	55	62	62
	PM	87	84	89	91
CSH-5	PI	*	--	*	30
	AN	*	65	*	69
	PM	*	92		99
CSH-6	PI	19	19	19	21
	AN	56	54	61	61
	PM	86	84	88	90
CSH-8	PI	*	--	*	22
	AN	*	65	*	69
	PM	*	91	*	99
SPV-351	PI	27	--	26	25
	AN	65	63	--	68
	PM	92	92	96	98

*Not included in the experiment.
-Data not available.
[a]PI - Panicle initiation; AN - Anthesis; PM = Physiological maturity.

found that duration of growth stage 3 decreases with increase in mean temperature up to 27°C and then it decreases when temperature goes beyond 27°C. The mean temperature during this period was around 25°C and there was not significant difference in mean temperature across all the four trials, and thus the duration of growth stage 3 was similar for all genotypes and treatments.

Comparison of sorghum leaf area index

Destructive plant samples from 1 m² area were taken at regular time intervals during the growing season from two fields — Alfisol (RP-4) and medium deep Vertisol (BP-12) for three genotypes (CSH-1, CSH-6, and SPV-351) to determine LAI. Data on LAI are given in Figures 1 and 2.

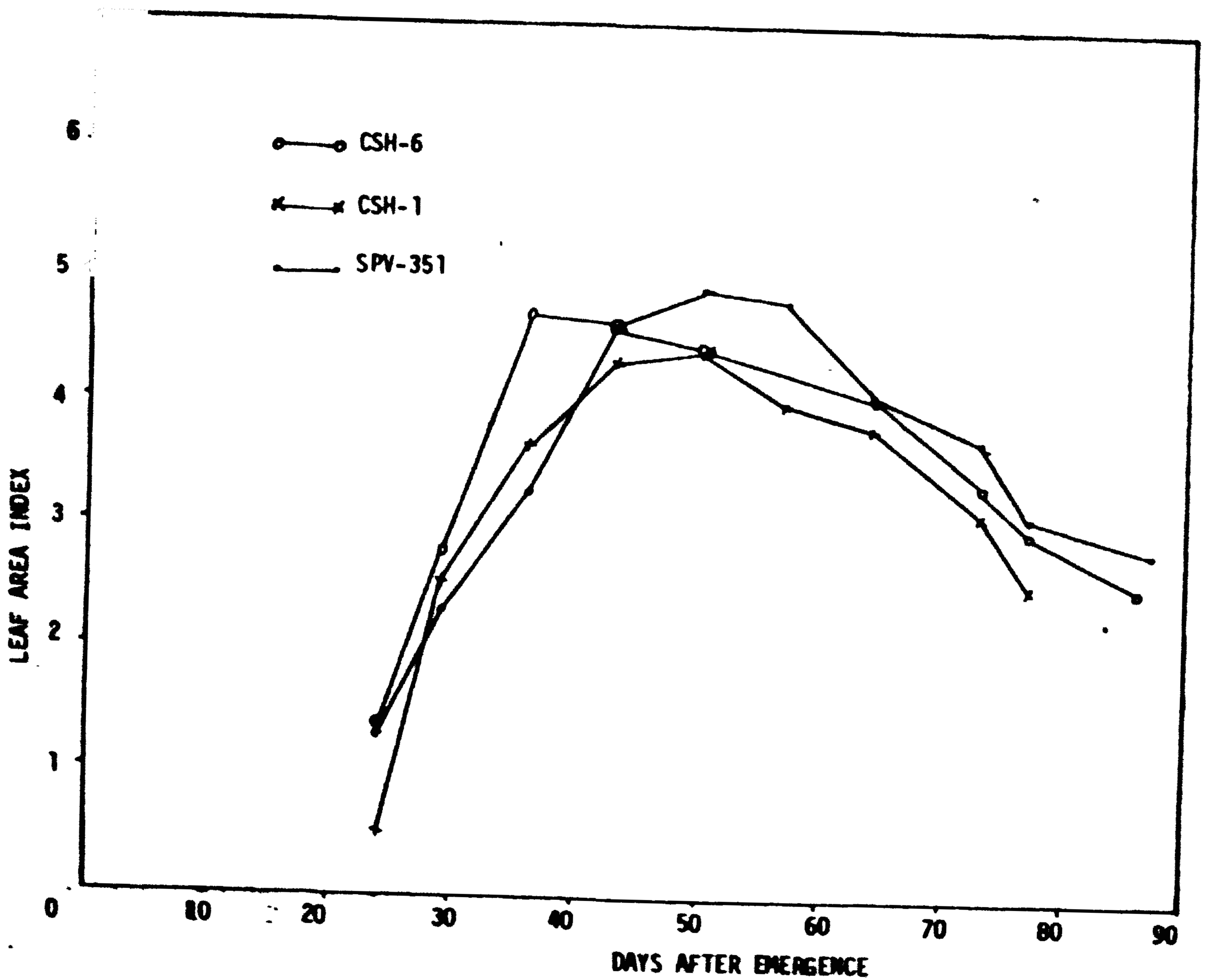

Figure 1. Comparison of LAI for three sorghum genotypes during the growing season (Field RP-4, 1981 rainy)

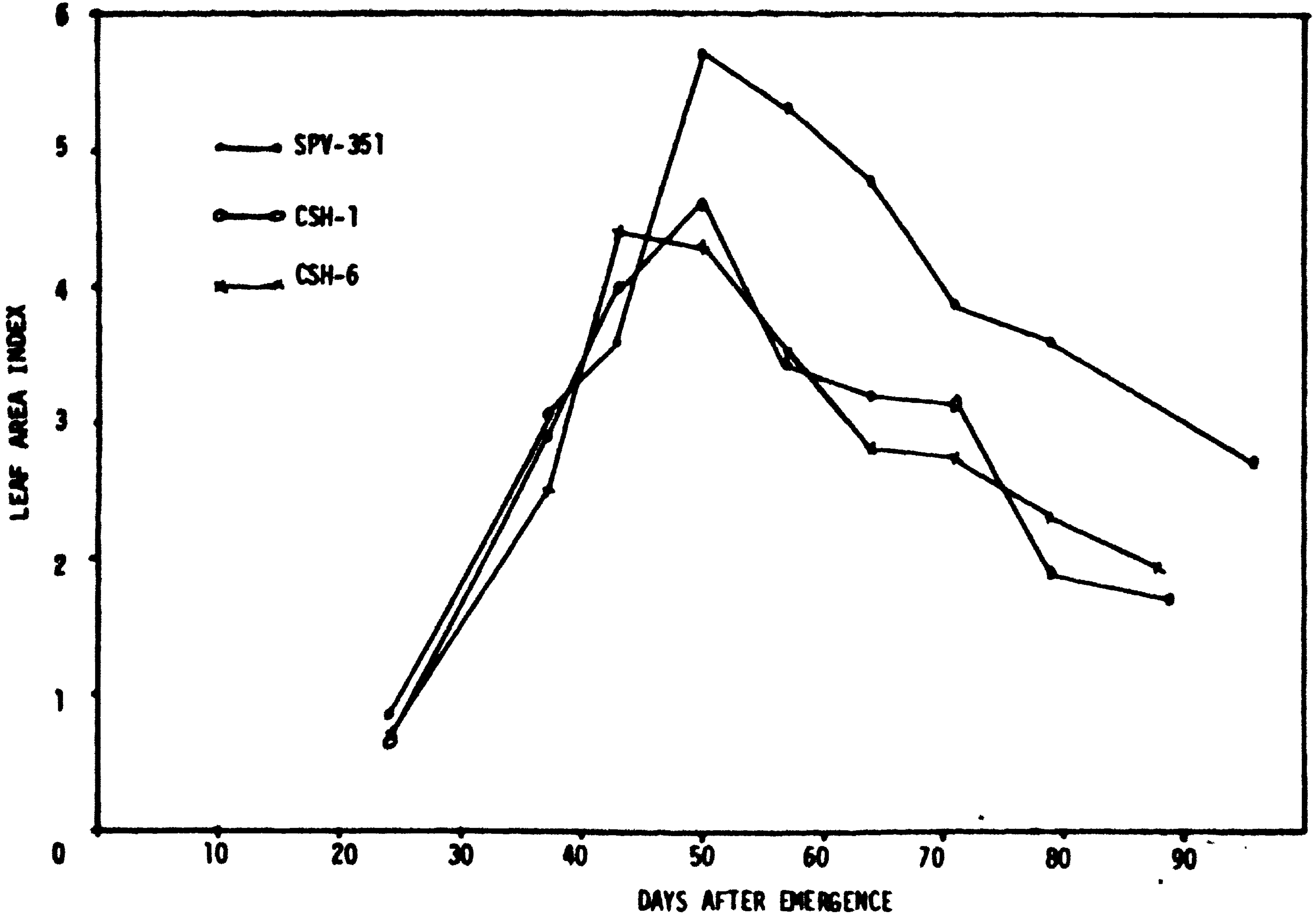

Figure 2. Comparison of LAI for three sorghum genotypes during the growing season (Field BP-12, 1981 rainy)

SPV-351 had higher LAI compared to CSH-1 and CSH-6 in both fields from 50 DAE till the maturity. This difference was more in medium deep Vertisol (BP-12). No significant difference in LAI was observed between CSH-1 and CSH-6 throughout the growing season. 1981 was above normal rainfall year; rainfall received between June to September was 917 mm against the normal of 624 mm. This helped in maintaining greater green leaf area for all genotypes till the maturity. SPV-351 maintained its LAI at nearly 3.0 at PM in both fields; however, CSH-1 and CSH-6 maintained higher LAI (2.5) at PM in Alfisol compared to medium deep Vertisol. It can be noticed from these figures that both CSH-1 and CSH-6 had higher leaf area duration during the grain filling period in Alfisol. This resulted in higher grain yield and total dry matter in Alfisol.

Comparison of sorghum total dry matter

All these trials were harvested approximately one week after reaching PM; samples were taken from 100 m^2 area to determine grain yield and total dry matter. Total dry matter (TDM) for all the genotypes was higher in Alfisol except the medium fertility treatment (Table 3.). The temporary waterlogging problem was observed frequently in the Vertisols due to heavy rain in 1981. This resulted in lower TDM and grain yield in Vertisol. Between the two Vertisol experiments, TDM was lower in medium deep Vertisol (BP-12); this difference of course was less than the 600 kg/ha. Between the two Alfisol experiments, 30-40% reduction in TDM was observed in medium fertility and pesticide free experiment.

Total dry matter and its partitioning to different plant parts (leaf, culm, head + grain, and grain) were monitored from destructive plant samples taken from 1 m^2 area at periodic time intervals throughout the growing season from two experiments; one in Alfisol (RP-4) and the other in medium deep Vertisol (BP-12). Distribution of TDM to different plant parts was computed on single plant basis for the three genotypes (CSH-1, CSH-6, and SPV-351) for both experiments by accounting for the plant population in unit area as given in Table 4. Such conversion was required to compare the results with SORGF model which simulates dry matter and its distribution on single average plant basis.

From these data (Figs. 3-8), it can be observed that harvest index was lower in SPV-351 (0.31-0.37) compared to CSH-1 and CSH-6 (0.42-0.47). During the later part of the grain filling period, the reduction in culm weight for both CSH-1 and CSH-6 indicates the translocation of dry matter from culm to grain. For SPV-351, no reduction in culm weight was observed. Leaf weight per plant reached maximum around 50 DAE; the value remained almost constant throughout the growing season except for CSH-1 in Alfisol where slight reduction was observed during later part of the growing season. The higher LAI in SPV-351 as discussed earlier resulted in comparatively higher leaf weight in both the fields.

Comparison of sorghum grain yield

Grain yields were higher in Alfisols for all the genotypes (Table 5.) For CSH-1 and CSH-6, a difference which ranged nearly 1000 kg/ha was obtained.

Table 3. Comparison of sorghum total dry matter.

Genotype	Experiment			
	Alfisol (RP-4)	Alfisol Medium fertility Pesticide free (RUS-3)	Medium deep Vertisol (BP-12)	Deep Vertisol (BW-3)
	kg/ha			
CSH-1	12467	8435	10572	11162
CSH-5	*	8752	*	129[illegible]
CSH-6	14024	8342	10600	11043
CSH-8	*	8228	*	12416
SPV-351	14852	8547	12055	12448

*Not included in the experiment.

Table 4. Comparison of sorghum population.

Genotype	Experiment			
	Alfisol (RP-4)	Alfisol Medium fertility Pesticide free (RUS-3)	Medium deep Vertisol (BP-12)	Deep Vertisol (BW-3)
	kg/ha			
CSH-1	17.8	15.3	18.4	11.7
CSH-5	*	19.1	*	11.0
CSH-6	17.8	16.1	17.8	11.9
CSH-8	*	16.6	*	11.5
SPV-351	15.9	11.5	16.9	13.2

*Not included in the experiment.

Table 5. Comparison of sorghum grain yield.

Genotype	Experiment			
	Alfisol (RP-4)	Alfisol Medium fertility Pesticide free (RUS-3)	Medium deep Vertisol (BP-12)	Deep Vertisol (BW-3)
	kg/ha			
CSH-1	5579	3521	4440	4828
CSH-5	*	1911	*	4370
CSH-6	6272	3409	5001	5042
CSH-8	*	1611	*	4016
SPV-351	4583	2420	4462	4388

*Not included in the experiment.

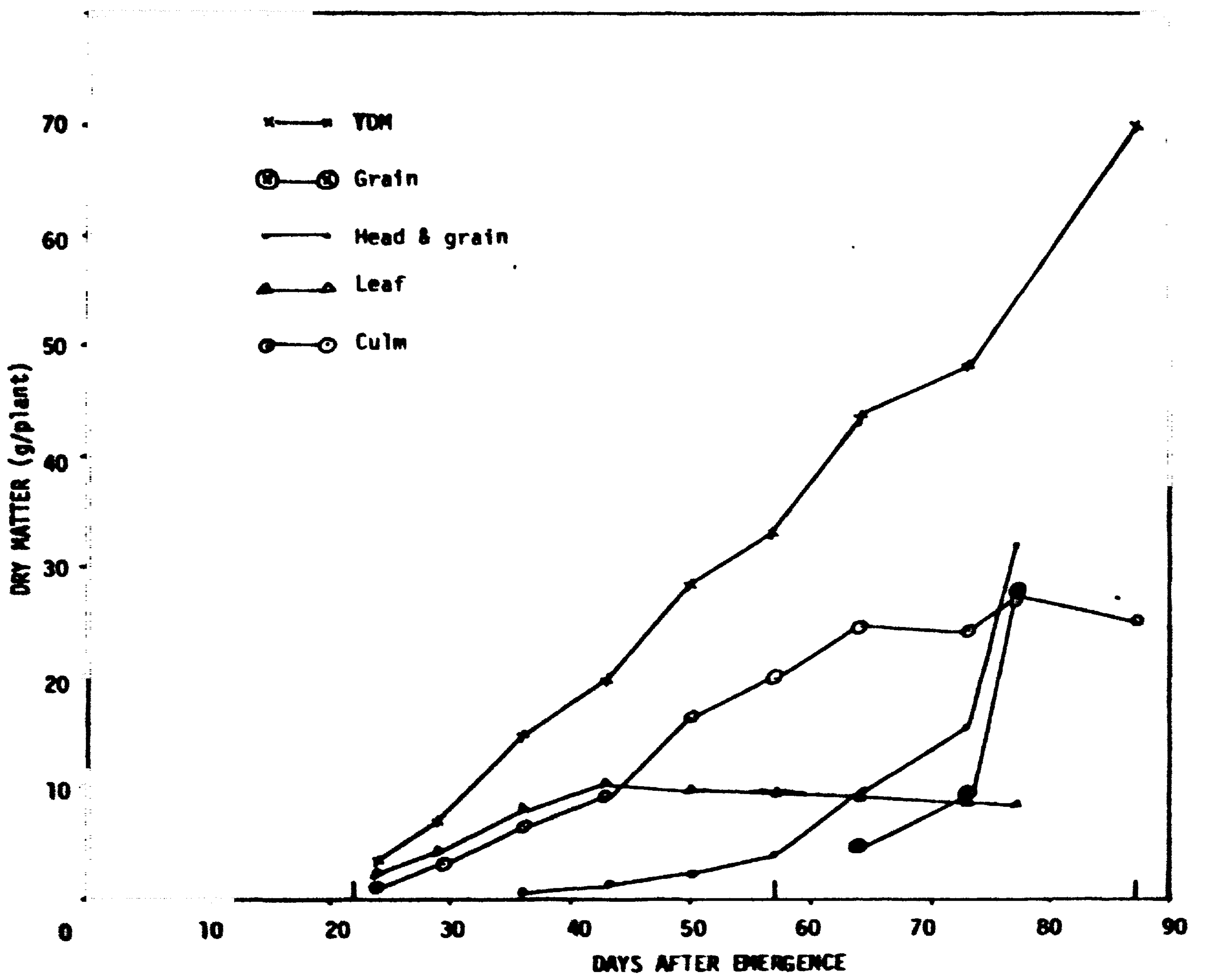

Fig. 3. Total drymatter of sorghum (CSH-1) and its partitioning to different plant parts during the growing season (Field RP-4, 1981 rainy)

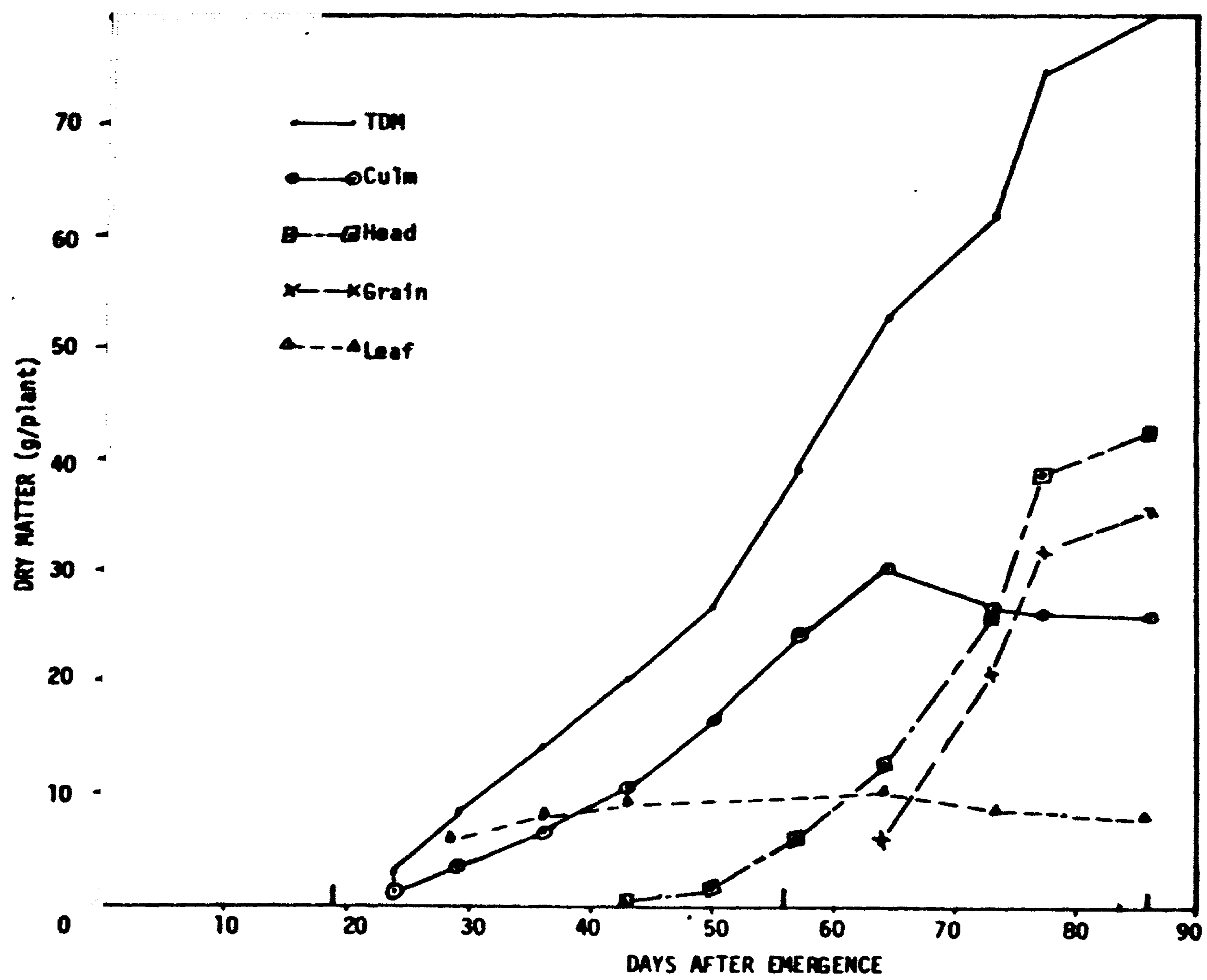

Fig. 4 . Total drymatter of sorghum (CSH-6) and its partitioning to different plant parts during the growing season (Field RP-4, 1981 rainy)

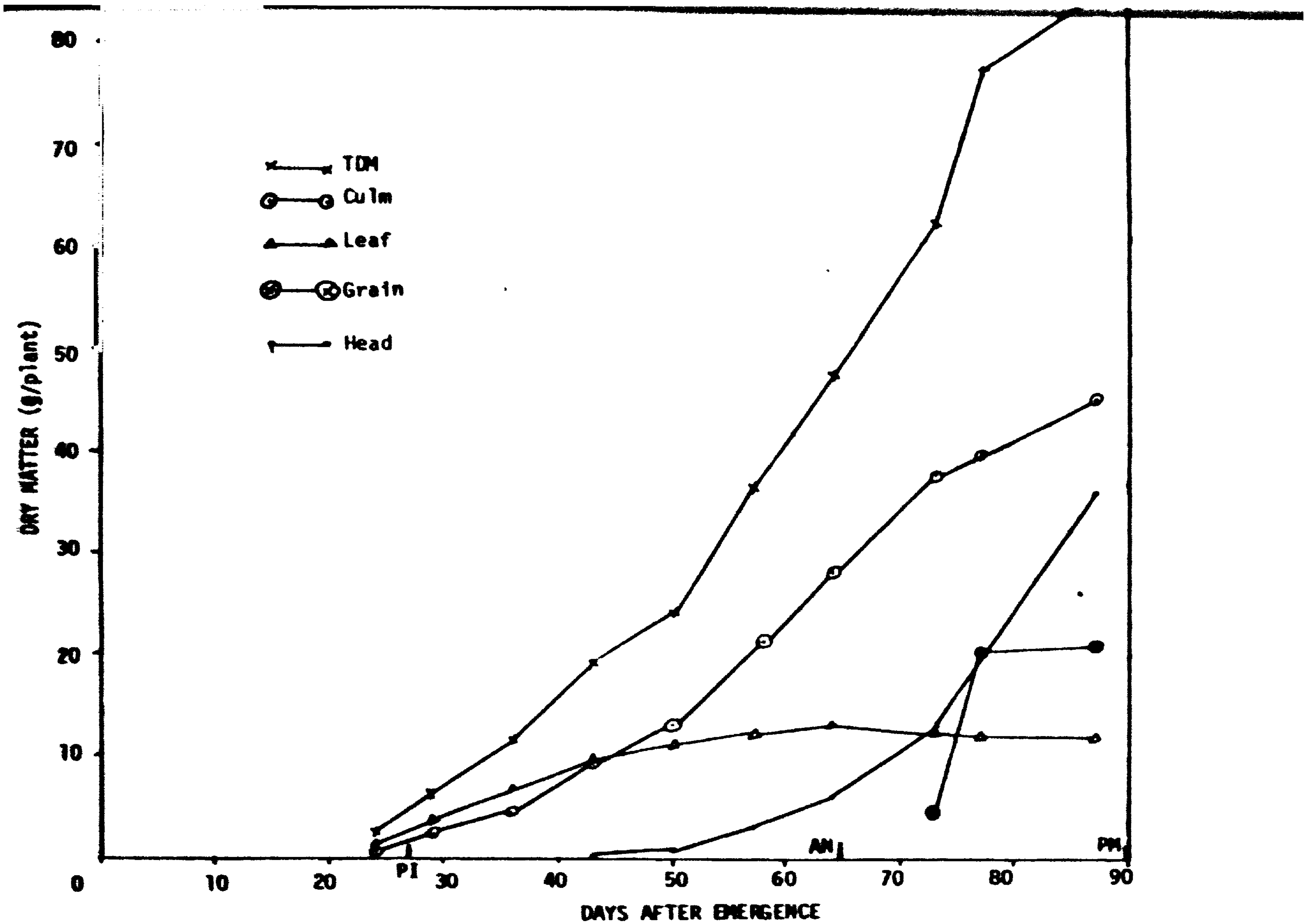

Figure 5. Total drymatter of sorghum (SPV-351) and its partitioning to different plant parts during the growing season (Field RP-4, 1981 rainy)

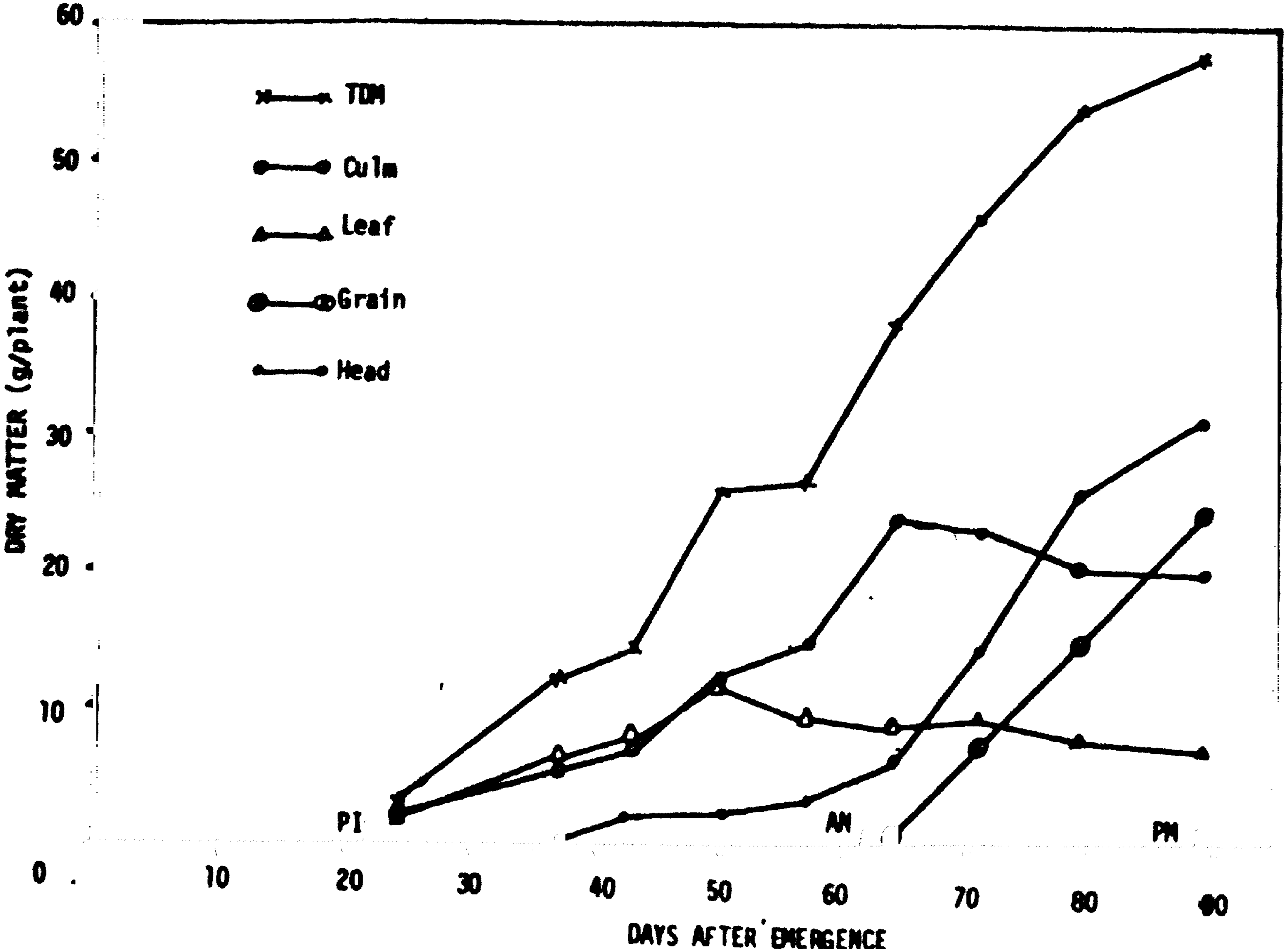

Figure 6. Total dry matter of sorghum (CSH-1) and its partitioning to different plant parts during the growing season (Field BP-12, 1981 rainy)

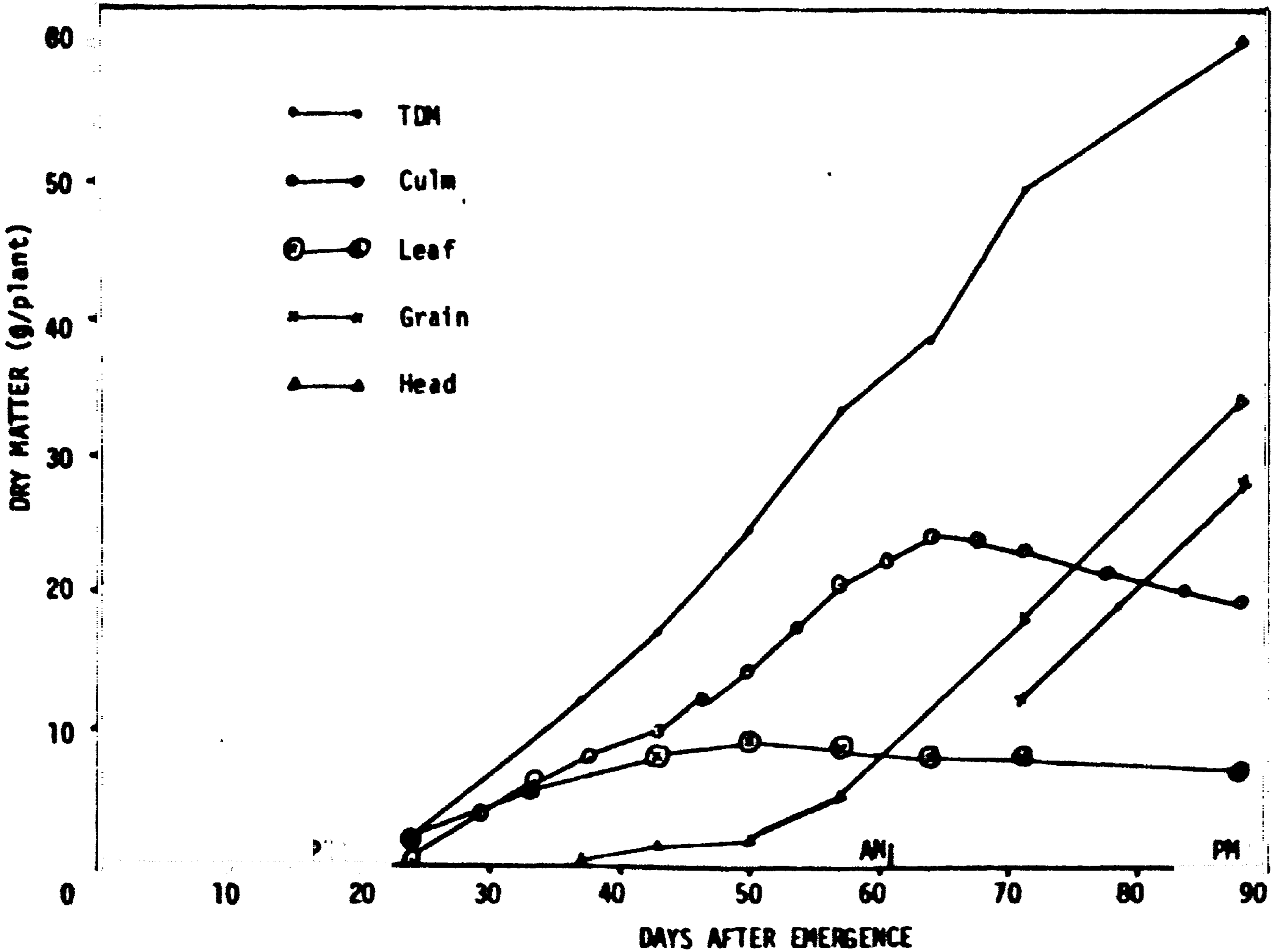

Figure 7. Total dry matter sorghum (CSH-6) and its partitioning to different plant parts during the growing season (Field BP-12, 1981 rainy)

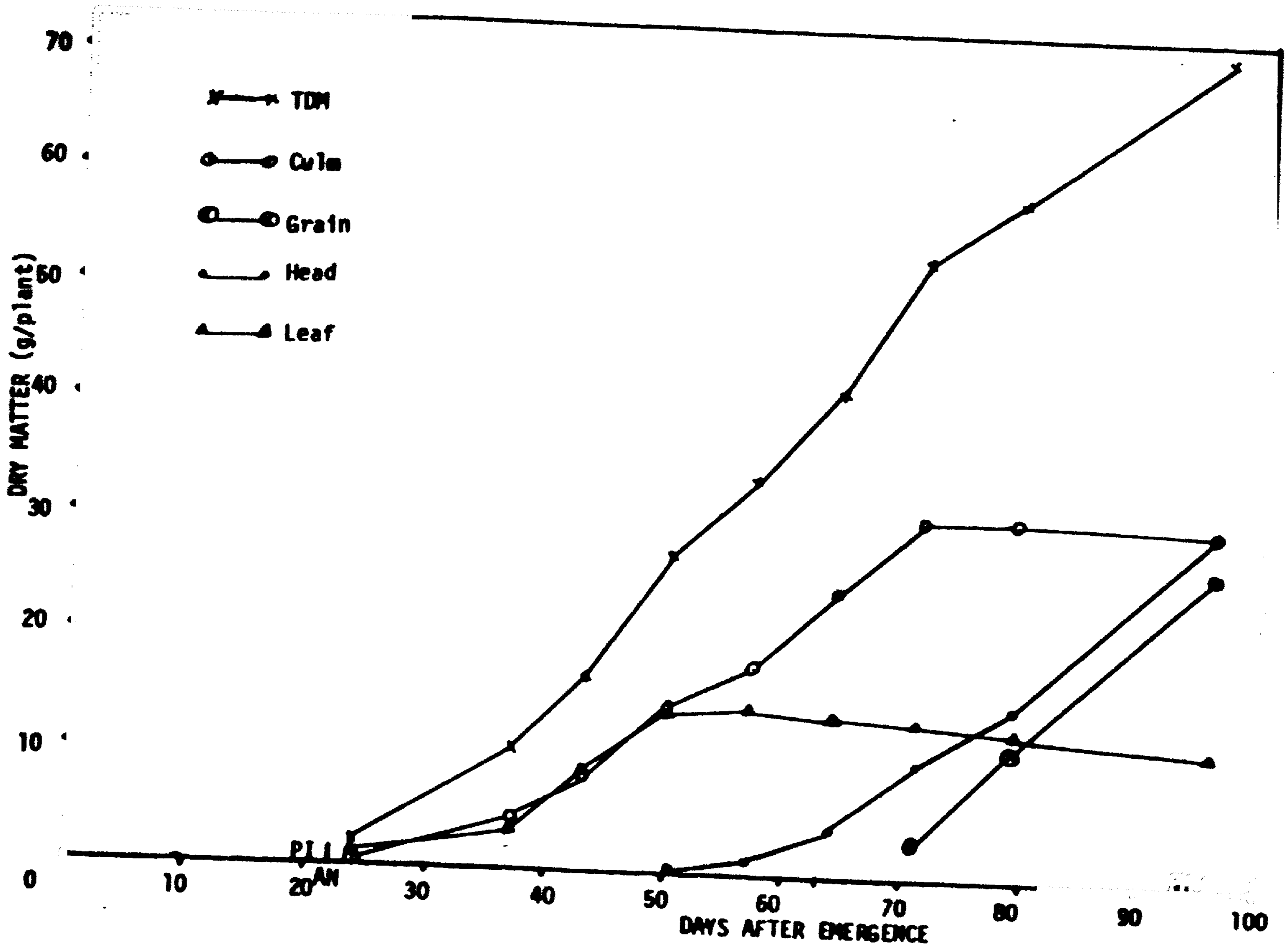

Figure 8. Total dry matter of sorghum (SPV-351) and its partitioning to different plant parts during the growing season (Field BP-12, 1981 rainy)

Even though, the TDM for SPV-351 was more than 2500 kg/ha in Alfisol, this was not reflected in grain yield due to its lower harvest index. Grain yields between medium deep and deep Vertisols were similar for all the genotypes. Between two Alfisol experiments, nearly 35-50% yield reduction was observed in the medium fertility and pesticide free experiment.

b) 1981-82 postrainy season

Quantification of moisture stress in sorghum

An experiment to examine the effect of moisture stress imposed at different phenological stages was sown on 23 November on an Alfisol (RP-4). Emergence occurred on 28 November after an irrigation of 4 cm was given on 24 November. There were five moisture treatments, two genotypes (CSH-8 and M-35-1) and three replications. The moisture treatments included adequate moisture supply throughout growing season (Mo), stress during growth stage 1 — from emergence to PI (M1), stress during growth stage 2 — from PI to anthesis (M2), and stress during growth stage 3 — from anthesis to PM (M3), and stress during later part of both growth stages 2 and 3 (M4). Grain yield, total dry matter, plant population and phenology for both genotypes under five treatments are given in Table 25.

Leaf area index

LAI for CSH-8 for five moisture treatments is given in Figure 9. Highest LAI, as expected, was obtained in Mo where no moisture stress was observed throughout the growing season. In growth stage 1, lower LAI was obtained in the M1 treatment. The treatment M2 had lowest LAI in both growth stages 2 and 3. Even after the release of stress in growth stage 3, there was no recovery in the leaf area due to stress in stage 2. This is expected since no more leaf initiation and expansion occur after the anthesis of sorghum. The stress in stage 3, caused marked reduction in leaf area index from > 2.0 to < 1.0.

Phenology

Moisture stress in GS1 hastened the days to panicle initiation, while stress in GS2 delayed flowering and thereby delayed maturity. Stress in GS3 reduced the grain filling period.

Dry matter and grain yield

The treatment M2 had lowest LAI almost throughout the growing season. However it had shorter grain filling period. The treatment M3 caused rapid declination of LAI in growth stage 3 and shorter grain filling period (36 days). As a result the stress in growth stage 3 (anthesis to PM) caused maximum reduction in total dry matter and grain yield for both the genotypes tested (Table 6). Grain yield and TDM for CSH-8

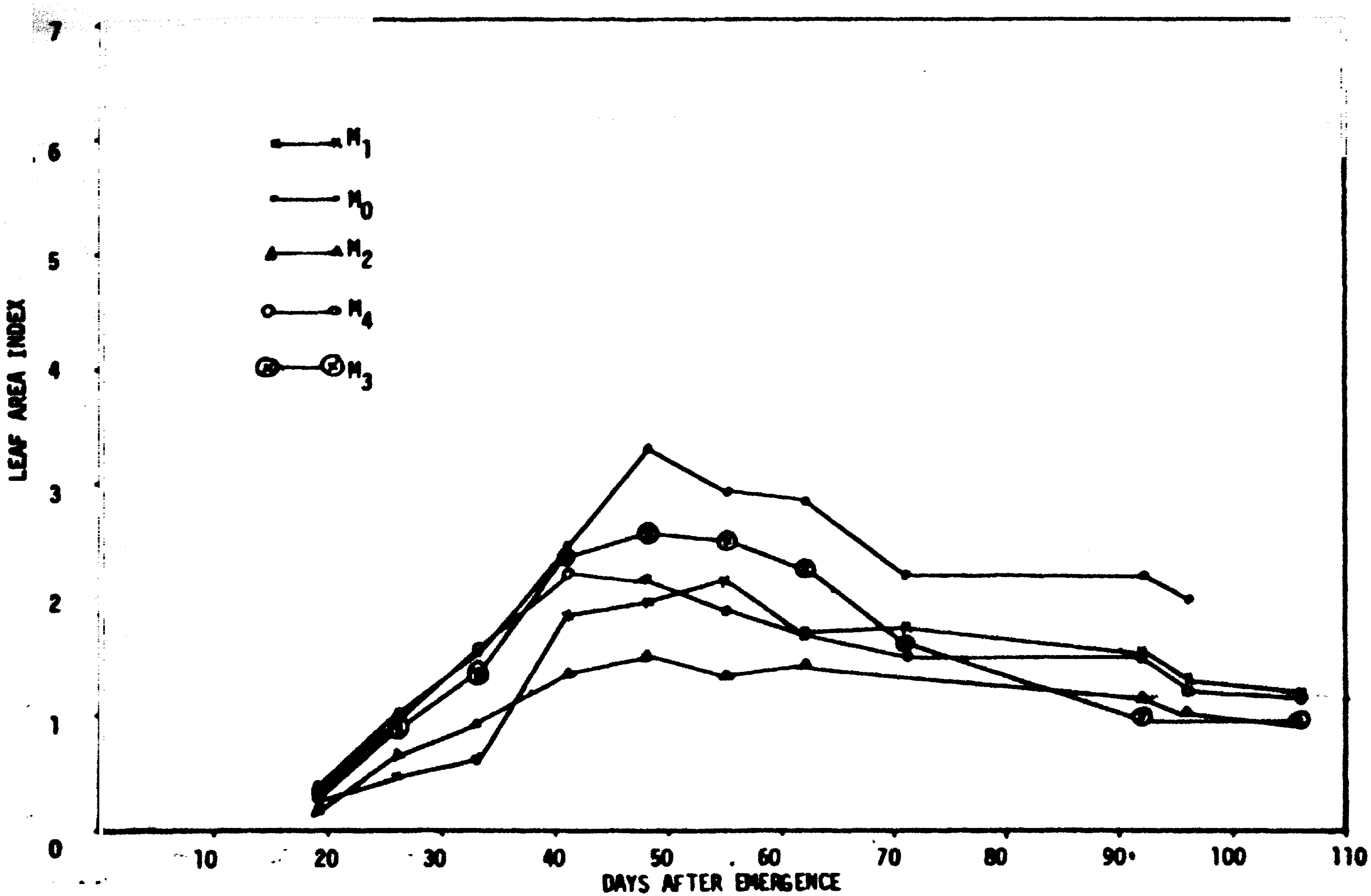

Figure 9. Comparison of LAI for sorghum (CSH-8) during the growing season under five moisture treatments imposed at different phenological stages (Field RP-4, 1981-82 postrainy)

Table 6. Sorghum population, phenology, grain yield and total dry matter under five moisture treatments imposed at different phenological stages (Field RP-4, 1981-82 postrainy).

Genotype	Moisture treatment	Population (pl/m²)	Growth stage: PI	Growth stage: AN	Growth stage: PM	Grain yield	TDM
			Days after emergence			kg/ha	
CSH-8	Mo[a]	15.5	23	66	106	5663	12529
	M1	16.2	21	64	104	4546	9619
	M2	13.0	23	68	108	3296	6687
	M3	13.5	23	68	104	2913	5806
	M4	14.3	23	68	106	3296	6966
M-35-1	Mo	11.4	27	72	112	3828	10832
	M1	10.7	25	68	110	3524	8710
	M2	10.7	27	72	110	1908	6101
	M3	9.0	27	72	109	1976	5246
	M4	9.1	27	72	108	2437	6001

[a] Mo = No stress throughout the growing season; M1 = Stress at GS1; M2 = Stress at GS2; M3 = Stress at GS3; M4 = Stress during later part of both GS2 and GS3.

were highest in Mo following M1, M4, M2, and M3. Grain yield and TDM were lower in M-35-1 compared to CSH-8 under all treatments. However, the response of moisture stress in M-35-1 was similar to that of CSH-8. Total dry matter of CSH-8 and its distribution to different plant parts for Mo treatment are given in Figure 10.

Grain yield component

The effect of water stress imposed at different phenological stages on components of sorghum grain yield is shown in Table 7. The following four points are noteworthy.

1. The component which was growing most rapidly at the time of occurrence of stress was most severely affected

   - In M1 greatest reduction in primary and secondary branches of the panicle was found. The formation of both these components are the first morphogenetic event during panicle development and this stress at that stage (M1) had the greatest effect.

   - Reduction of tertiary branches and spikelet per primary branch in M2 and M4 was the result of stress occurring during later part of panicle development.

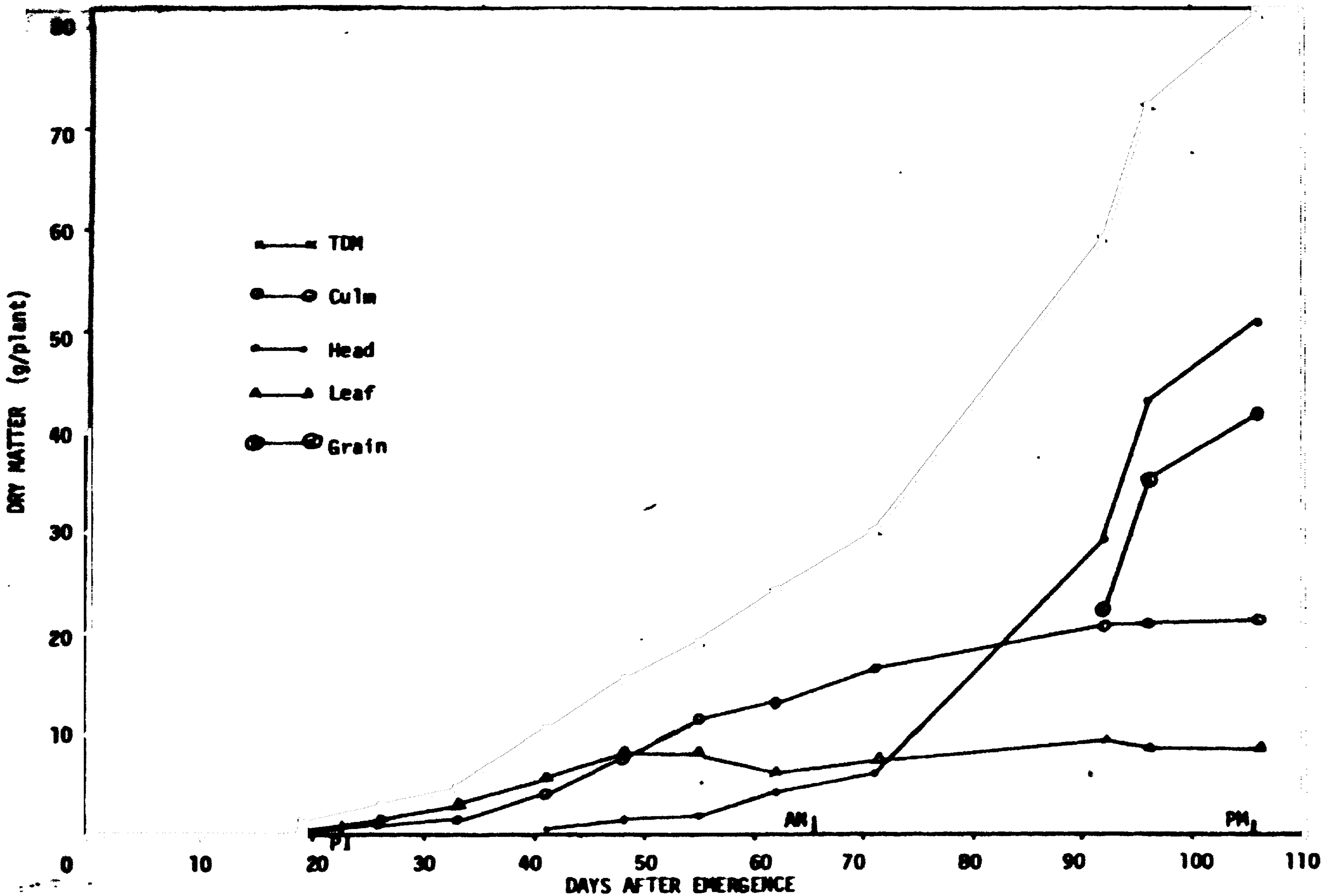

Figure 10. Total dry matter of sorghum (CSH-8) and its partitioning to different plant parts under the treatment of no moisture stress throughout the growing season (Field RP-4, 1981-82 postrainy).

- Seed set (No. of seeds/No. of sessils (fertile) florets) and seed size were most affected in M3, in which stress started at anthesis and continued throughout grain filling period.

2. Compensation for the stress induced loss in a component formed earlier in the development occurred by increasing the number or size of later developing component when the water stress was released in time.

   - In M1, the number of spikelets per tertiary branch increased even over controls (Mo) since stress was terminated before the formation of tertiary branches.

   - Marginal increase in seed size was seen in M1 and M2 over Mo. The increase would have been greater if the stress had less effect on source (leaf area) development.

   - The seed size in M4, inspite of terminal stress, was unaffected for the following two reasons: (i) the stress started much later during grain filling than in M3 and (ii) the seed number itself was reduced considerably (unlike in M3), thus reducing the sink demand.

3. Phenological changes can alter the yield components by either postponing or terminating the development of a particular component.

   - The cessation of grain filling period by 4 days earlier in M3 was also partly responsible for the reduced seed size in this treatment.

4. Genotypes showed considerable differences in their number or size of yield components. The response of yield components to stress pattern were also genotype specific.

   - M-35-1 had 2184 spikelets (sessile) per panicle. CSH-8 had only 1899.

   - In M3, the terminal stress reduced seed size by only 13% in M-35-1, but the same was 18% in CSH-8.

   - In CSH-8, the reduction in secondary, branches in the panicle due to stress in M1 treatment was much less than in M-35-1.

Source sink relationship and natural incidence of stalk rot

Stalk rot is caused by a pathogen [*Macrophomina phaseolina (Tassi) Goid*] in sorghum plants predisposed by carbon stress and translocation imbalance (Dodd 1980). The correspondence between source sink relationship (as altered by different moisture stress treatments) and the incidence of stalk rot was observed in this experiment.

Table 7. Grain yield of sorghum (N-35-1) under five moisture treatments imposed at different phenological stages (all data are shown as percentage of control, for which the absolute values are shown in parenthesis. All figures are numbers per specified unit except for seed size (g/100 seed)).

Field RP-4, 1981-82 postrainy season.

Components	Irrigation treatments				
	Mo	M1	M2	M3	M4
# of Pr.Br/panicle	100(63.2)	77	95	96	96
# of Sec.Br/Pr.Br.	100(5.8)	87	95	58	52
# Ter.of Br/Pr.Br.	100(10.7)	83	82	98	78
# of spikelets/Pr.Br.	100(34.8)	94	72	99	73
Grain yield/panicle (g)	100(72.6)	71	70	72	65
Seed size (g/100 seeds)	100(4.12)	103	102	87	102
Seeds/panicle	100(1758)	83	69	83	64
Sec.Br./panicle	100(363.8)	68	90	97	87
Ter.Br./panicle	100(667.0)	64	77	96	76
Spikelets/panicle	100(2184)	73	78	96	71
Seeds/spikelet	100(0.84)	93	89	86	88
Spikelets/Ter.Br.	100(3.27)	115	101	100	94

Pr. = Primary, Sec. = Secondary; Ter. = Tertiary; Br. = Branch.
Mo = No moisture stress throughout the growing season; M1 = Stress at GS1; M2 = Stresss at GS2; M3 = Stress at GS3; M4 = Stress at total part of both GS2 and GS3.

The relationship between grain yield and total dry matter for CSH-8 under five moisture treatments is given in Figure 11. Reduction in grain yield in M3 treatment is due to stress in grain filling period; in M1 and M2, due to stress during early and late panicle development stages respectively, which determines the number of grain per panicle. Grain yield reduction in M4 is because of stress during later part of both panicle development and grain filling periods.

Three random sets consisting of 10 consecutive plants in each plot of CSH-8 were tagged during hard dough stage to examine the stalk rot incidence. If 3-4 internodes immediately above ground were found solid (not hallow) when pressed between fingers, the plant was considered free of disease. Disease counts were taken on three dates at one week interval around PM. Severity of stalk rot was expressed as percentage of plants with soft stems.

The effect of the moisture stress treatments on stalk rot incidence is given in Figure 12. Treatment M3, which experienced terminal stress for the longest time had highest stalk rot followed by M4 in which part of the seed number (sink demand) was lost due to stress at boot stage. Mo, M2, and M3 had the last irrigation at soft dough stage, but took 2-4

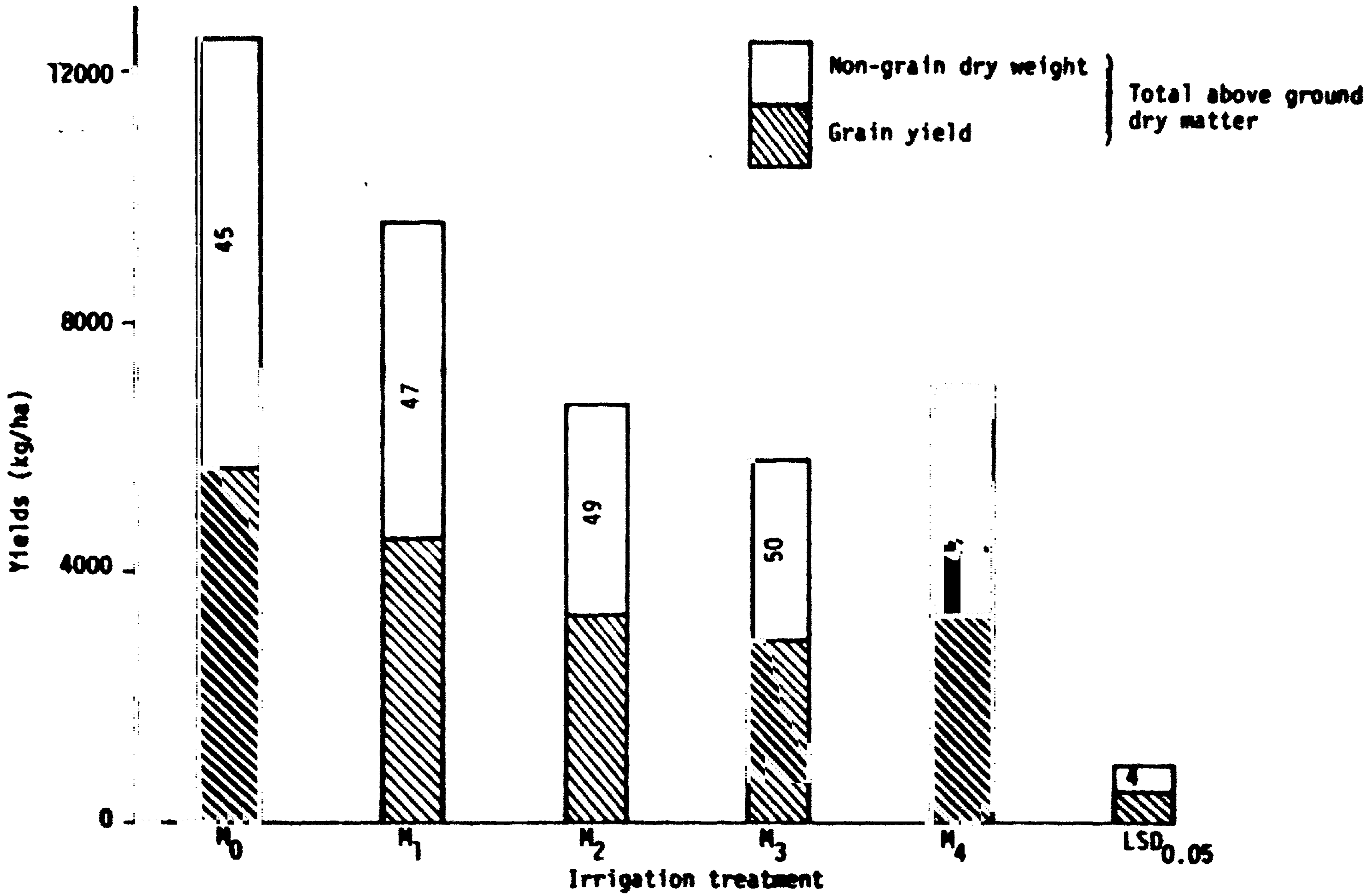

Figure 11. Effect of five moisture treatments imposed at different phenological stages on sorghum (CSH-8) grain yield and total dry matter (Field RP-4, 1981-82 postrainy).

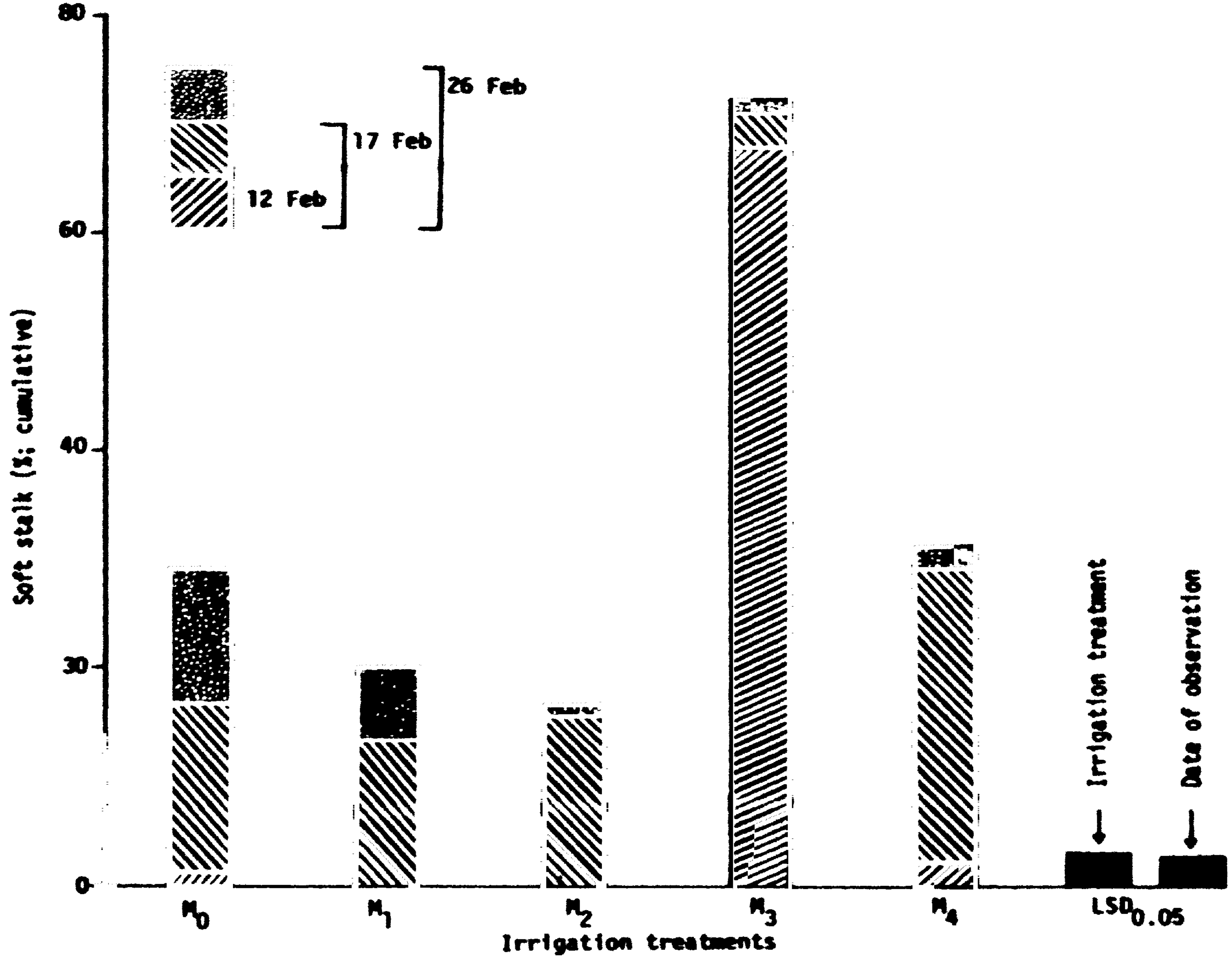

Figure 12. Effect of five moisture treatments imposed at different phenological stages on sorghum (CSH-8) stalk rot incidence as counted over three dates (Field RP-4, 1981-82 postrainy).

more days to maturity (total 108) compared to M3. Hence they might have experienced some terminal stress (though at much later stages of grain filling and much less than M3), and showed some soft stalk incidence. M1 and M2, which had smaller sink because of stress during reproductive growth, had both lower yields and stalk rot incidence than Mo.

The amount of stalk rot incidence on each of the three different dates (Fig. 12.) indicated that interactions between disease and time during maturity exist ($P > 0.05$). In M3, the disease developed rapidly on the first date of count itself, while other showed significant only on second date. The further increase in disease was significant only for the Mo (control) and M1 which underwent least amount of stress during the life cycle. Intensity of stress during seedling stage in M1 was less, since both the transpirational as well as the atmospheric demand for water during this stage was small enough to be reasonably met by the stored moisture in the profile which is also reflected in least reduction of yield (Fig. 11). Hence Mo and M1 showed significant increase in disease only at the very late stage of maturity.

In M3 the grain filling period was also shortened by 4 days (40 days in all other treatments); thus the earlier termination of demand for assimilates would have prevented further disease development during later dates.

c) Ratoon sorghum

After the harvest of five sorghum genotypes on 14 October, ratoon sorghum was grown under the residual moisture in Vertisol (BW3). Three nitrogen treatments (0, 20, and 40 kg N/ha) were superimposed on 16 October. Only 12 mm rainfall was received in October/November after the fertilizer was added. Thus nitrogen was not made available to plant and no significant difference in yield was obtained due to nitrogen treatments. No significant differences among the genotypes were also observed for grain yield and dry matter production. Grain yields, total dry matter and the plant population for the genotype treatments are given in Table 8.

COLLABORATIVE CENTERS

Delhi

Sorghum hybrid CSH-6 was sown on 3 July and emergence occurred on 8 July. There were two treatments: one is rainfed and the other one included irrigation at anthesis. Rainfall during the crop growing season (28 June-15 Oct) was 542 mm against the normal of 617 mm. The open pan evaporation was 617 mm during this period. Thus one irrigation at anthesis almost doubled the grain yield from 2700 kg/ha in rainfed to 5100 kg/ha in irrigated treatment. Plant population, phenology, and grain yield data are given in Table 9. Daylength in July is longer in Delhi compared to Patancheru and results in longer duration of growth stage 1. LAI data in Figure 13 show that one irrigation at anthesis helped maintain high LAI for longer period.

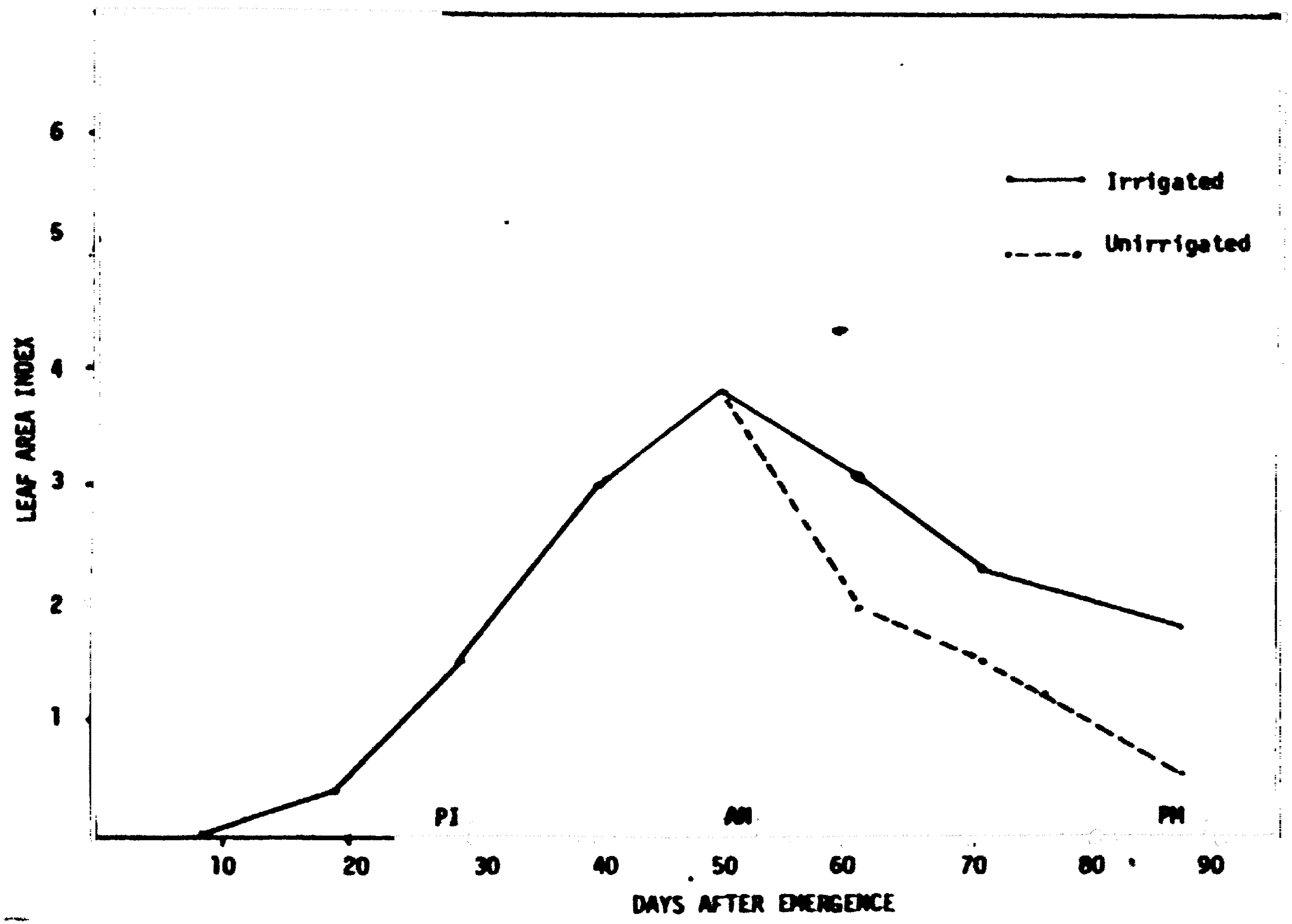

Figure 13. Comparisons of LAI for sorghum (CSH-6) during the growing season between two moisture treatments (Delhi, 1981 rainy).

Table 8. Ratoon sorghum population, grain yield and total dry matter under three nitrogen treatments. (Field BW-3, 1981-82 postrainy)

Genotype	Nitrogen treatments	Population pl/m^2	Grain yield kg/ha	TDM kg/ha
CSH-1	No	6.7	896	2530
	N1	6.9	951	2728
	N2	5.8	900	2617
CSH-6	No	8.2	668	2011
	N1	9.3	882	2504
	N2	7.7	766	2336
SPV-351	No	5.9	748	2399
	N1	6.6	792	2507
	N2	7.0	807	2641
CSH-5	No	8.4	1061	3002
	N1	8.7	1071	3228
	N2	8.9	1220	3440
CSH-8	No	6.8	845	2671
	N1	6.4	1216	3331
	N2	6.1	1099	3177

No = 0 N; N1 = 20 N; N2 = 40 N.

Table 9. Sorghum population, phenology, grain yield and total dry matter (Delhi, 1981 rainy)

Genotype	Population pl/m^2	Growth stage (Days after emergence)			Grain yield kg/ha	TDM kg/ha
		PI	AN	PM		
CSH-6 A	15.0	30	53	89	5100	11000
CSH-6 B	15.0	30	53	89	2700	8900

A = Irrigated B = Rainfed

Ludhiana

Sorghum hybrids CSH-1 and CSH-6 were sown on 18 June and emergence occurred on 23 June. CSH-1 took 107 DAE to reach PM which is 12 days longer than that of CSH-6. Both these genotypes particularly CSH-1 took longer period to reach anthesis and maturity at this high latitude location (31°N) compared to other low latitude centers. No significant difference in grain yield was observed between the genotypes. Plant population, grain, yield, and phenology data are given in Table 10.

Table 10. Sorghum population, phenology and grain yield. (Ludhiana, 1981 rainy)

Genotype	Population pl/m²	Growth stage [redacted] Days after emergence		Grain yield kg/ha
CSH-1	10.0	75	107	2150
CSH-6	10.0	65	95	2010

Parbhani

Sorghum hybrids CSH-1 and CSH-6 were sown on 21 June and emergence occurred on 29 June. Rainfall during the growing season was 718 mm; this was 112 mm below the normal rainfall for the season. Open pan evaporation was 844 mm. Grain yields for both CSH-1 and CSH-6 were nearly 3 tons/ha. LAI for CSH-1 was higher compared to CSH-6 (Fig. 14). Grain yields, TDM, plant population, and phenology are given in Table 11.

Table 11. Sorghum population, phenology, grain yield and total dry matter. (Parbhani, 1981 rainy)

Genotype	Population pl/m²	Growth stage			Grain yield kg/ha	TDM kg/ha
		PI	AN	PM		
		Days after emergence				
CSH-1	10.5	20	62	94	3031	10330
CSH-6	11.3	23	65	97	2894	10272

Rahuri

The experiment was not conducted in the rainy season. However, CSH-8 and M-35-1 were sown on 22 September and emergence occured on 26 September. An irrigation of 5 cm was given after anthesis. Grain yields for CSH-8 and M-35-1 were 3000 and 1440 kg/ha. Days after emergence to panicle initiation was not properly recorded. Anthesis and physiological maturity occurred 5 days earlier in CSH-8 compared to M-35-1. Population, grain yield, and phenological data are given in Table 12.

Table 12. Sorghum population, phenology and grain yield. (Rahuri, 1981-82 postrainy)

Genotype	Population pl/m²	Growth stage			Grain yield kg/ha
		PI	AN	PM	
		Days after emergence			
CSH-8	16.2	14	59	96	3000
M-35-1	17.5	20	64	101	1440

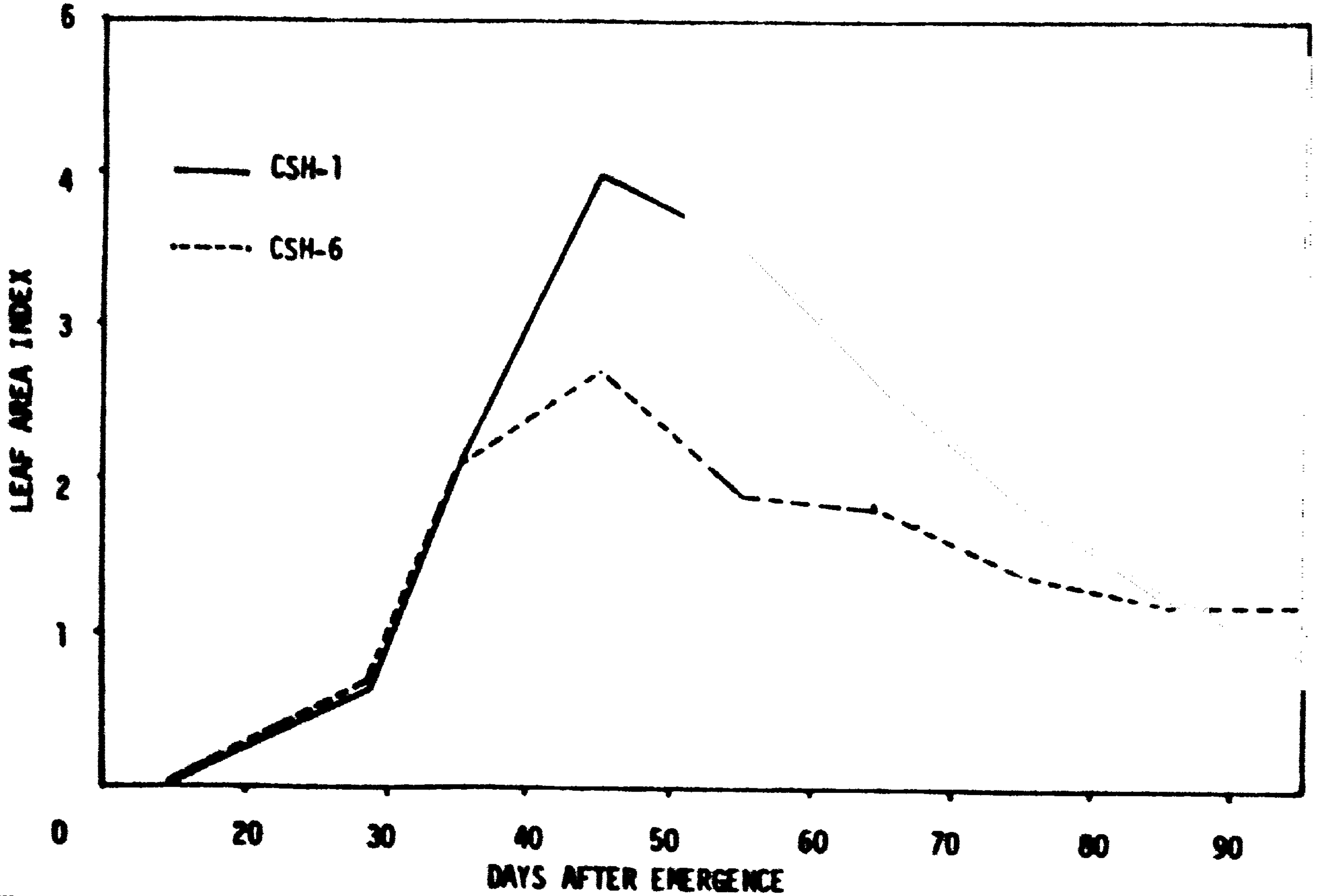

Figure 14. Comparison of LAI between two sorghum genotypes during the growing season (Parbhani, 1981 rainy).

IMPROVEMENTS MADE IN SORGHUM

Several subroutines of SORGF were identified that needed modification for the validation of the model in the SAT (Huda et al 1980). The algorithms of SORGF model dealing with light interception, phenology, total dry matter accumulation and its partitioning to grain, and leaf senescence have been revised. The improvements resulting from the revisions made are compared in each case e.g., light interception and phenological estimates etc. with the original SORGF model. Simulated dry matter and grain yield are compared with the field data. A detailed account of the revisions made in the model is discussed by Huda et al (1982b).

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 solar radiation and by accounting for the number of hours of sunlight for any day which is calculated as a sine function of the local solar time and daylength. Examination of our data showed that model computation of solar declination and daylength are accurate resulting in sufficiently accurate estimation of hourly solar radiation. The quantum flux density (PAR) in Einsteins m^{-2} day^{-1} is estimated in SORGF from the energy flux density (RS) in cal cm^{-2} day^{-1} as

$$PAR = RS\ (0.121)$$

However, our results using measured data on PAR and RS for extended periods of time indicated that the constant relating PAR to solar radiation (RS) should be altered. In the revised version, PAR is thus calculated as 0.09 times RS.

Light transmission is calculated from the relationship of extinction coefficient and maximum light transmission using information on row spacing and LAI. An examination of the computed and measured light transmission for different row spacings showed that the model was overestimating light-transmission, especially at low levels of canopy light transmission. The model breaks down for row spacings greater than 137 cm because the computed light transmission exceeds 100 percent. Thus the functions for estimating extinction coefficient and maximum light transmission were revised.

Comparisons of predicted and measured light transmission for 45 cm sorghum rows using the data sets collected at ICRISAT Center are shown in Figure 15. Data points show that the revised equations predict light transmission within 15 percent limit of the measured PAR interception.

PHENOLOGY

Accurate simulation of phenological events is important because the stage of development determines the daily dry matter partitioning to various

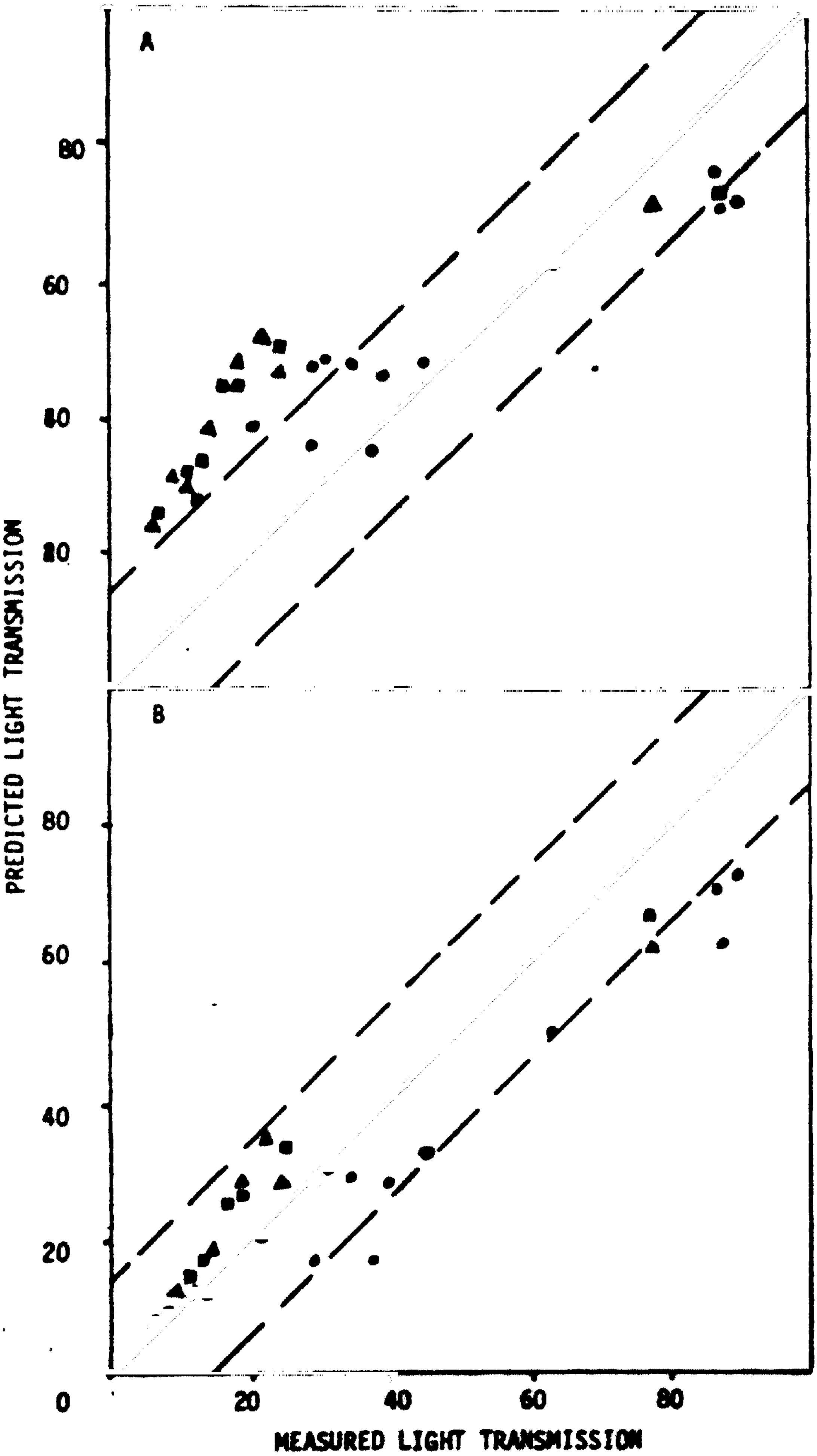

Figure 15. Relationship between measured and predicted light transmission under 45 cm sorghum rows according to (A) SORGF and (B) Revised equations (Symbols represent data from different growing seasons).

DRY MATTER ACCUMULATION AND PARTITIONING

In SORGF potential photosynthate is calculated from intercepted photosynthetically active radiation (PAR). Net photosynthate is computed after accounting for the water and temperature stress as well as for respiration. Using the approach of Gallagher and Biscoe (1978) and Stapper and Arkin (1980), a simpler relationship for calculating daily dry matter production from intercepted PAR was developed. From measured data over several growing seasons it was computed that potentially a total dry matter of 3.0 gm can be produced per each Mega Joule of PAR absorbed when water and temperature stress do not occur (Sivakumar 1981). From the daily potential dry matter, actual dry matter increase is estimated as a function of temperature and water stress.

Partitioning of total dry matter (TDM) to leaf, culm, head + grain and grain was studied by using data collected at weekly intervals from 27 field studies conducted at ICRISAT. TDM at anthesis and maturity was not significantly different between hybrids and varieties (Table 15). The percent of TDM partitioned to leaf was not significantly different between hybrids and varieties. The proportion of TDM accumulated in the culm was significantly higher in the varieties at both anthesis and maturity. Dry matter partitioned to grain as percent of TDM was higher in hybrids (0.45) compared to varieties (0.32). These data confirm that hybrids are more efficient than varieties in translocating dry matter to grain.

Table 15. Total dry matter and percent partitioned to leaf, culm, head + 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	[redacted]	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	1.3 b	2.5 a	32.0 a	43.0 a	65.0 a	73.0 a

Means with different letters are significantly different.

SOIL WATER

In SORGF daily available water for the entire soil profile (single layered) is computed after Ritchie (1972) using information on initial available soil water, available water holding capacity, rainfall/irrigation, and evaporative demand. Potential evaporation below a plant canopy (Eos) is calculated after computing potential evaporation from bare soil (Eo) and using LAI values. Eo is calculated in the model using the Priestley-Taylor (1972) equation which requires net radiation as input data. Net radiation is computed from albedo, maximum solar radiation reaching the soil surface (Ro), and sky emissivity. Ro in the SORGF model was calculated using a site-specific sine function. This function was revised to enable the computation of Ro for any latitude. Open pan evaporation and Eo estimated are compared in Figure 16. This change resulted in improved estimates of Eo as can be seen in Figure 16.

LEAF AREA

Leaf area is overestimated by SORGF, particularly in the grain filling period. Revisions were made in the leaf senescence algorithms. Senescence is now accounted for after the expansion of 7th leaf instead of the 11th leaf as suggested in SORGF. Leaf area at maturity is estimated as 50 percent of the total leaf area per plant obtained at anthesis.

SIMULATION COMPARISON

The revised algorithms discussed earlier have been incorporated in SORGF. Simulation results of total dry matter and grain yield are compared with observed data pooled from ICRISAT field studies and field studies from different cooperating centers (Figs. 17 and 18). The correlation coefficient (r) and the RMSE values for grain yield and total dry matter are given in Table 16.

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).

	Data	No. of observations	(r)	RMSE
Grain yield	Pooled	59	.87	561
	ICRISAT	42	.89	572
Total dry matter	Pooled	54	.87	1348
	ICRISAT	41	.87	1261

PEARL MILLET MODELING EXPERIMENTS

a) 1981 rainy season

Three pearl millet genotypes (BJ-104, WC-C75, and ICMS-7703) were grown in both Alfisols (RP-4) and Vertisols (BP-12) under high fertility condition (100 N, 60 P). Pearl millet was sown dry on 10 June in Vertisol, emergence occurred on 22 June with the receipt of 35 mm rainfall on 18 June. These crops were sown in Alfisol on 3 July after the profile was fully recharged, emergence occurred on 7 July. Phenology, leaf area index, total dry matter, and its distribution to different plant parts were monitored regularly. Results of these genotypes between Alfisols and Vertisols are compared.

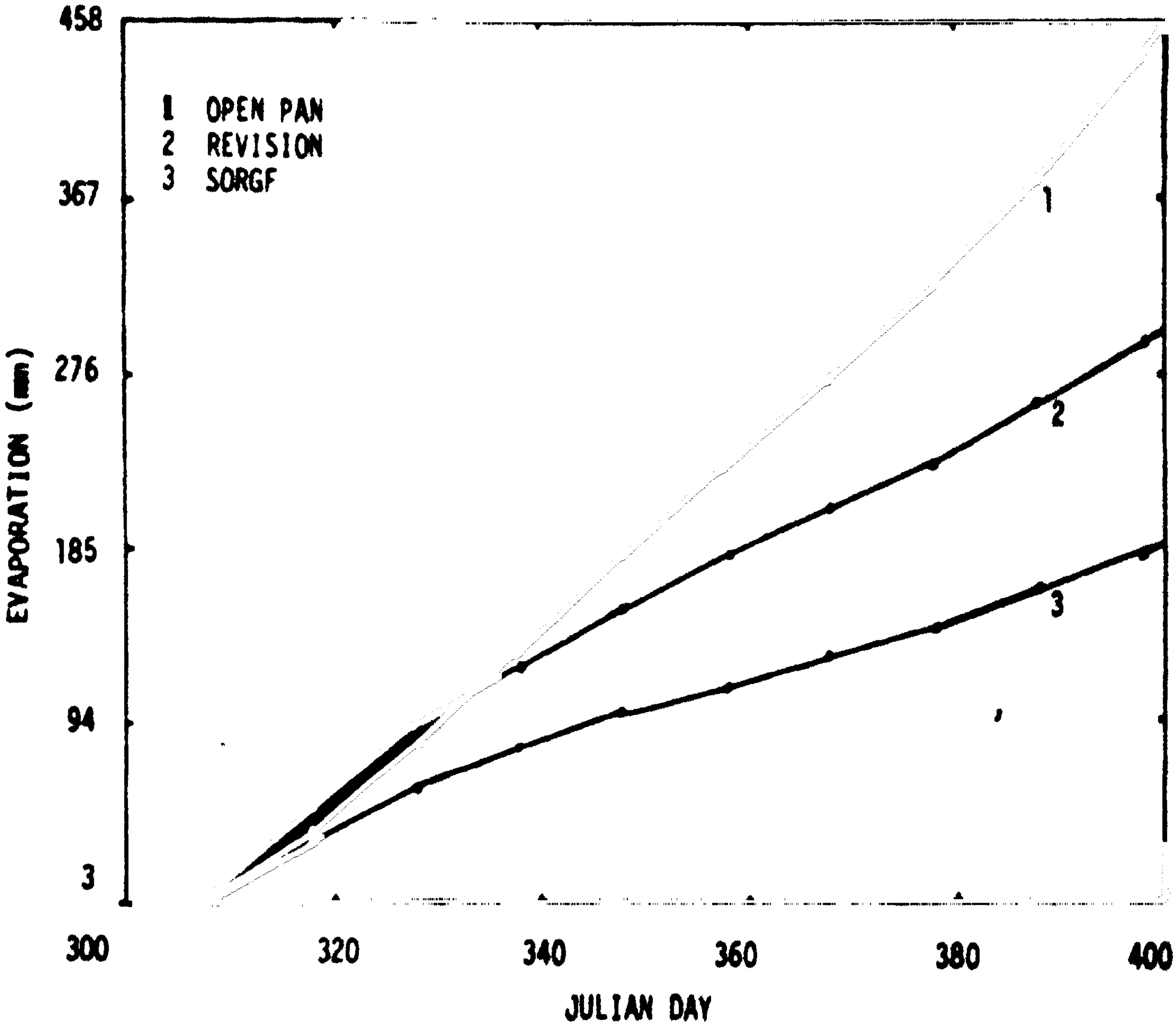

Figure 16. Plot of cumulative evaporation from the bare soil (E_0) during 1978 at ICRISAT research center according to SORGF and the revised equation. Open pan evaporation is presented for comparison.

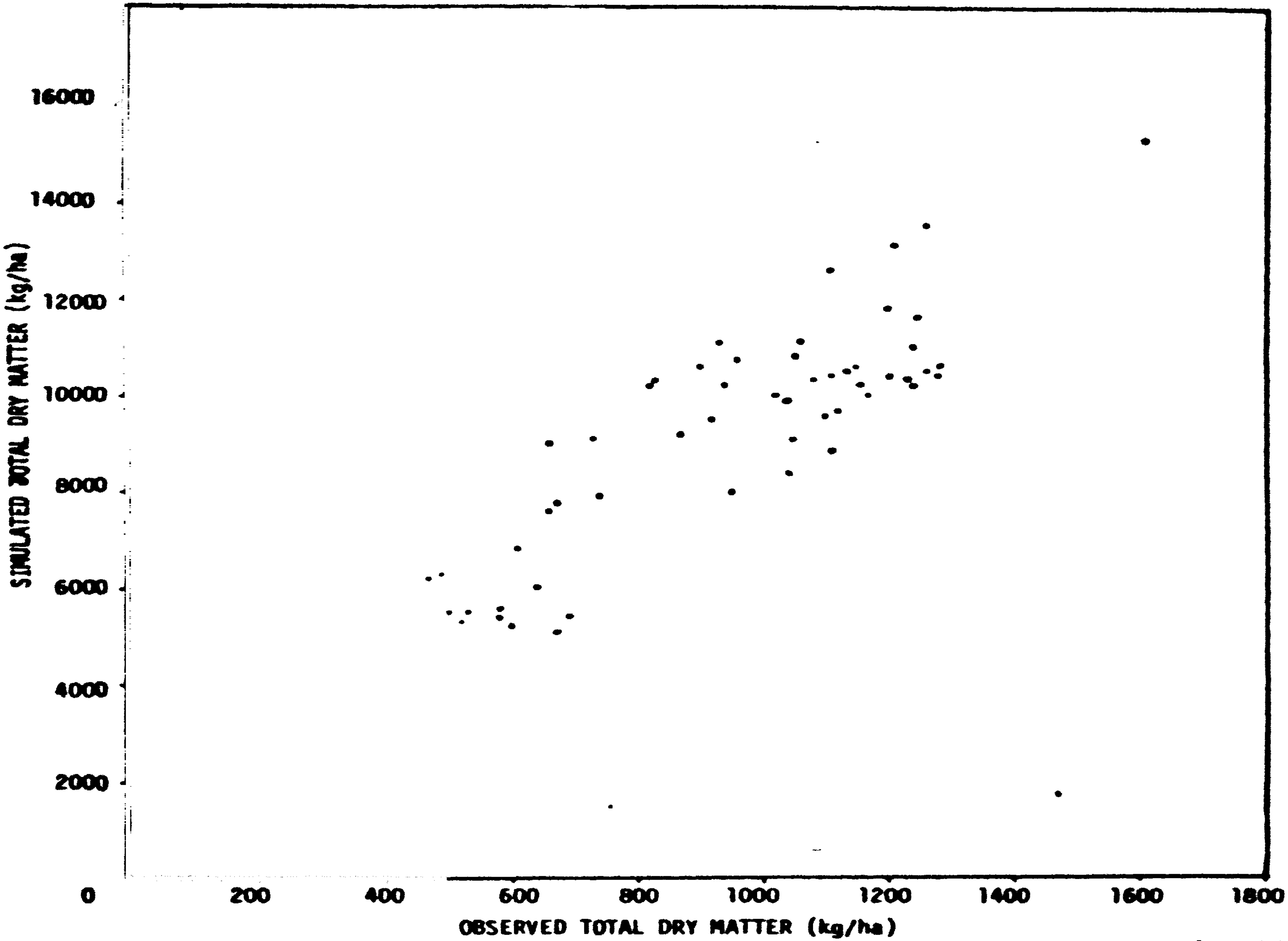

Figure 17. Relationship between observed and simulated total dry matter for pooled data (n = 54

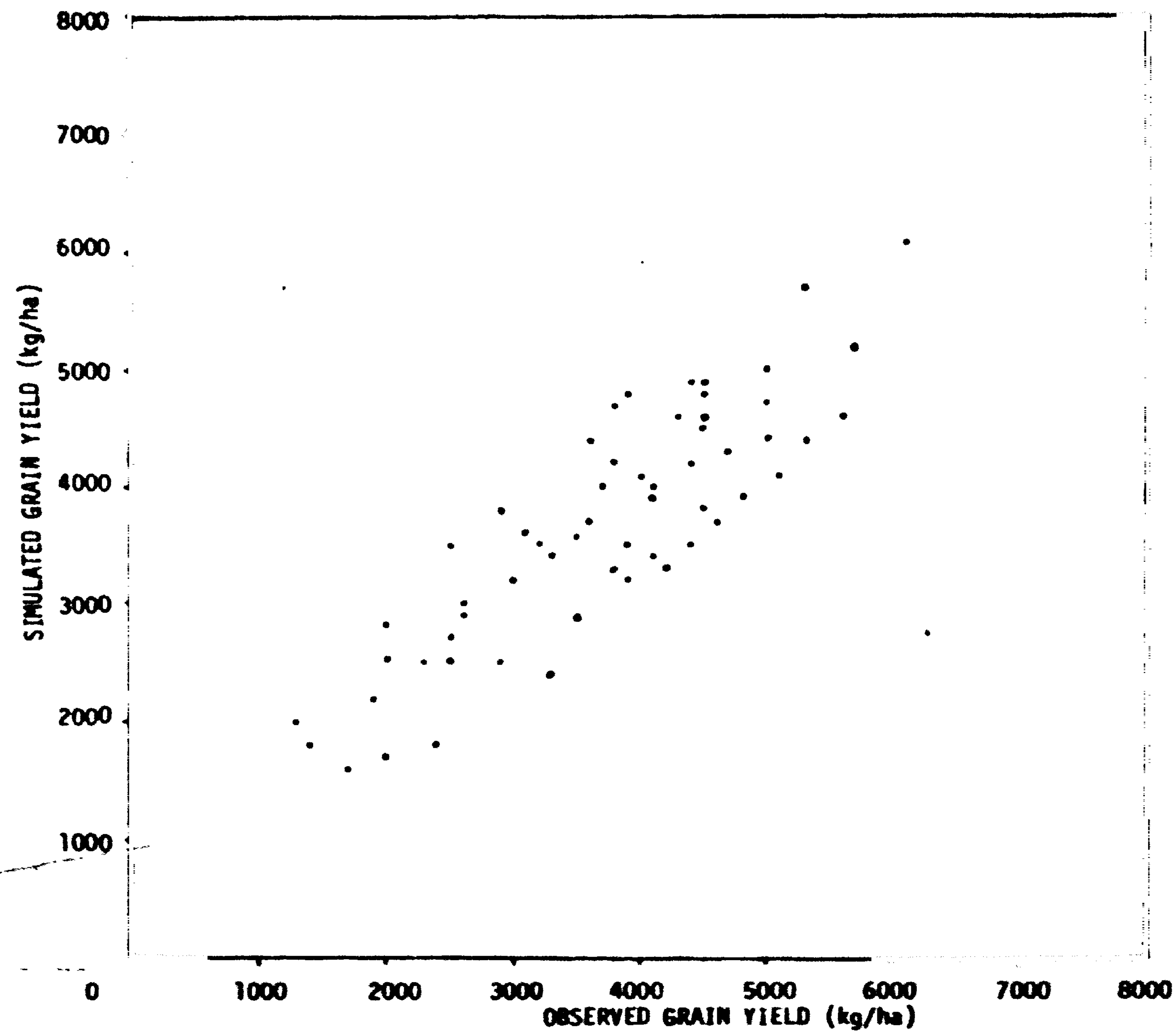

Figure [illegible]. Relationship between observed and simulated grain yield for pooled data (n = 59).

Comparison of pearl millet phenology

Days after emergence to PI, AN, and PM are given in Table 17. No major difference in growth stages was observed for any particular genotype between two fields. However, the total duration (emergence to PM) was 6-8 days longer for WC-C75 on ICMS-7703 compared to BJ-104.

Table 17. Comparison of pearl millet phenology.

Genotype	Growth stages	Alfisol (RP-4)	Vertisol (BP-12)
		Days after emergence------	
BJ-104	PI	16	15
	AN	42	44
	PM	70	73
WC-C75	PI	17	15
	AN	48	47
	PM	76	78
ICMS-7703	PI	19	17
	AN	49	46
	PM	78	78

Comparison of leaf area index

Destructive samples from 1 m^2 area were taken at periodic intervals from both trials for all the three genotypes to determine leaf area of main plants and tillers. However, the LAI (main + tiller) is compared for these genotypes in Figs. 19 and 20. LAI was highest for WC-C75 followed by ICMS-7703 and BJ-104 in both soils.

Comparison of dry matter partitioning

Total dry matter and its partitioning to different plant parts were recorded periodically throughout the growing season from destructive plant samples of 1 m^2 area. Dry matter partitioning of main plants and tillers were noted separately. However, combined TDM of main and tillers and their partitioning are compared for each genotype between soils at three critical growth stages i.e., PI, anthesis, and maturity (table 18). No major difference between soils was observed at any growth stage for all genotypes under study.

The harvest index in BJ-104 was nearly 10% higher compared to other two genotypes.

Comparison of grain yield and total dry matter

Grain yield and total dry matter for three genotypes are given in Tables 19 and 20. Contribution of main plants and tillers to grain yield are also compared for three genotypes between soils in these tables. For the sake of convenience to interpret the data, plant population data are also given in table 20.

Table 18. Total dry matter and percent dry matter partitioned to different plant components at the three growth stages for three pearl millet genotypes.

BJ-104 (1981 rainy)

Plant components	Growth stages					
	PI		AN		PM	
	Alfisol (RP-4)	Vertisol (BP-12)	Alfisol (RP-4)	Vertisol (BP-12)	Alfisol (RP-4)	Vertisol (BP-12)
Leaf	0.69		0.34	0.30	0.11	0.11
Culm	0.31		0.55	0.58	0.34	0.32
Head+grain			0.11	0.12	0.55	0.57
Grain			-	-	0.43	0.44
TDM (g/plant)	0.29		9.26	29.35	54.80	70.80

WC-C75 (1981 rainy)

Leaf	0.71		0.31	0.37	0.14	0.16
Culm	0.29		0.51	0.53	0.40	0.34
Head+grain			0.18	0.10	0.46	0.50
Grain			-	-	0.35	0.37
TDM (g/plant	0.28		7.66	30.90	59.60	59.50

IOMS-7703

Leaf	0.71		0.31	0.35	0.17	0.14
Culm	0.29		0.59	0.53	0.37	0.41
Head+grain			0.10	0.12	0.46	0.45
Grain			-	-	0.34	0.35
TDM (g/plant)	0.56		9.94	37.30	57.90	68.00

Table 19. Comparison of pearl millet grain yield (kg/ha) (1981 rainy season)

Genotype	Experiment					
	Alfisol (RP-4)			Vertisol (BP-12)		
	Main	Tillers	Main + tillers	Main	Tillers	Main + tillers
BJ-104	1600	1759	3359	1563	2308	3871
WC-C75	2306	572	2878	1889	984	2873
IOMS-7703	2462	469	2931	1609	1281	2[illegible]0

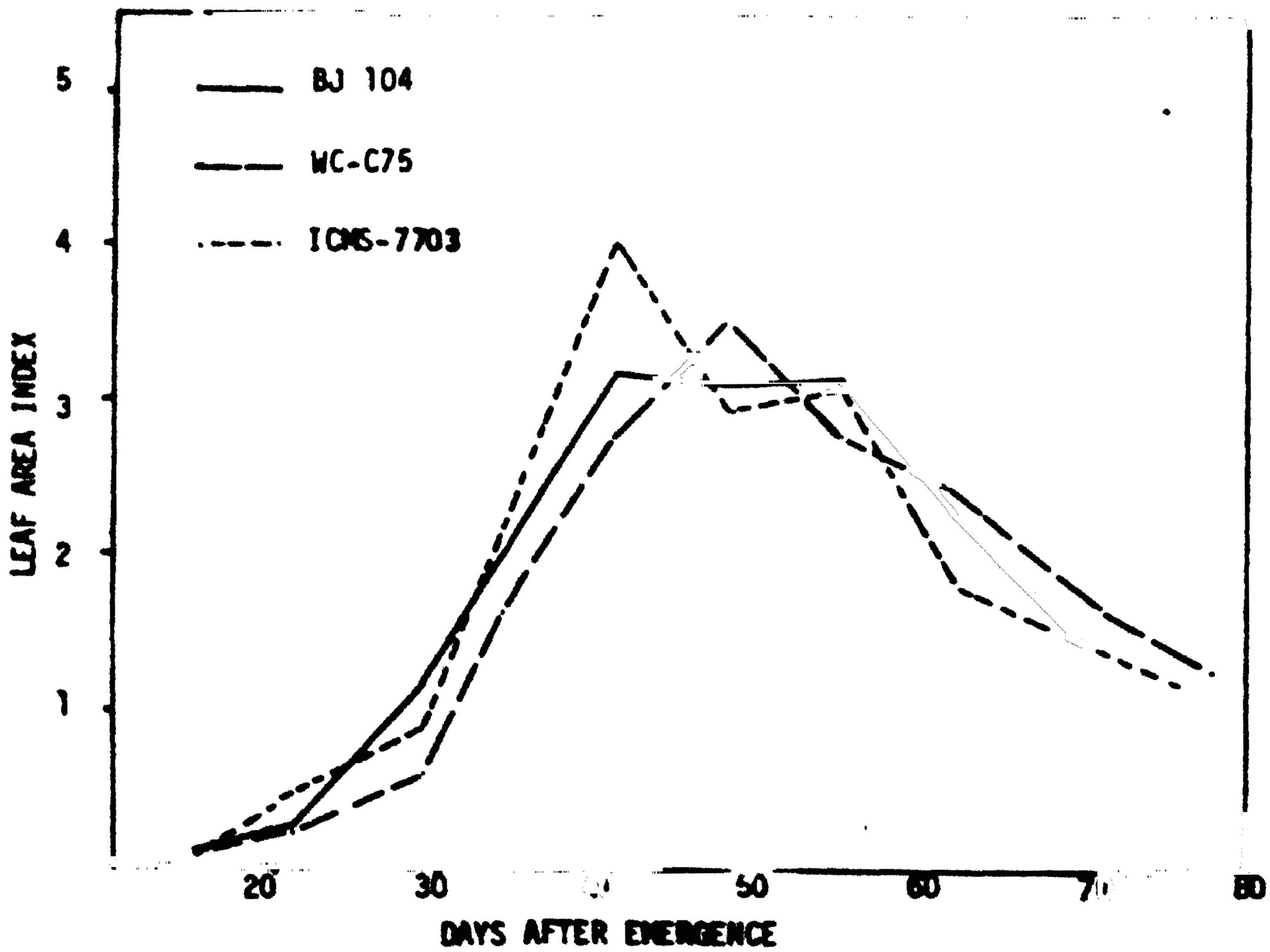

Figure 19. Comparison of LAI for three pearl millet genotypes during the growing season (Field RP-4, 1981 rainy).

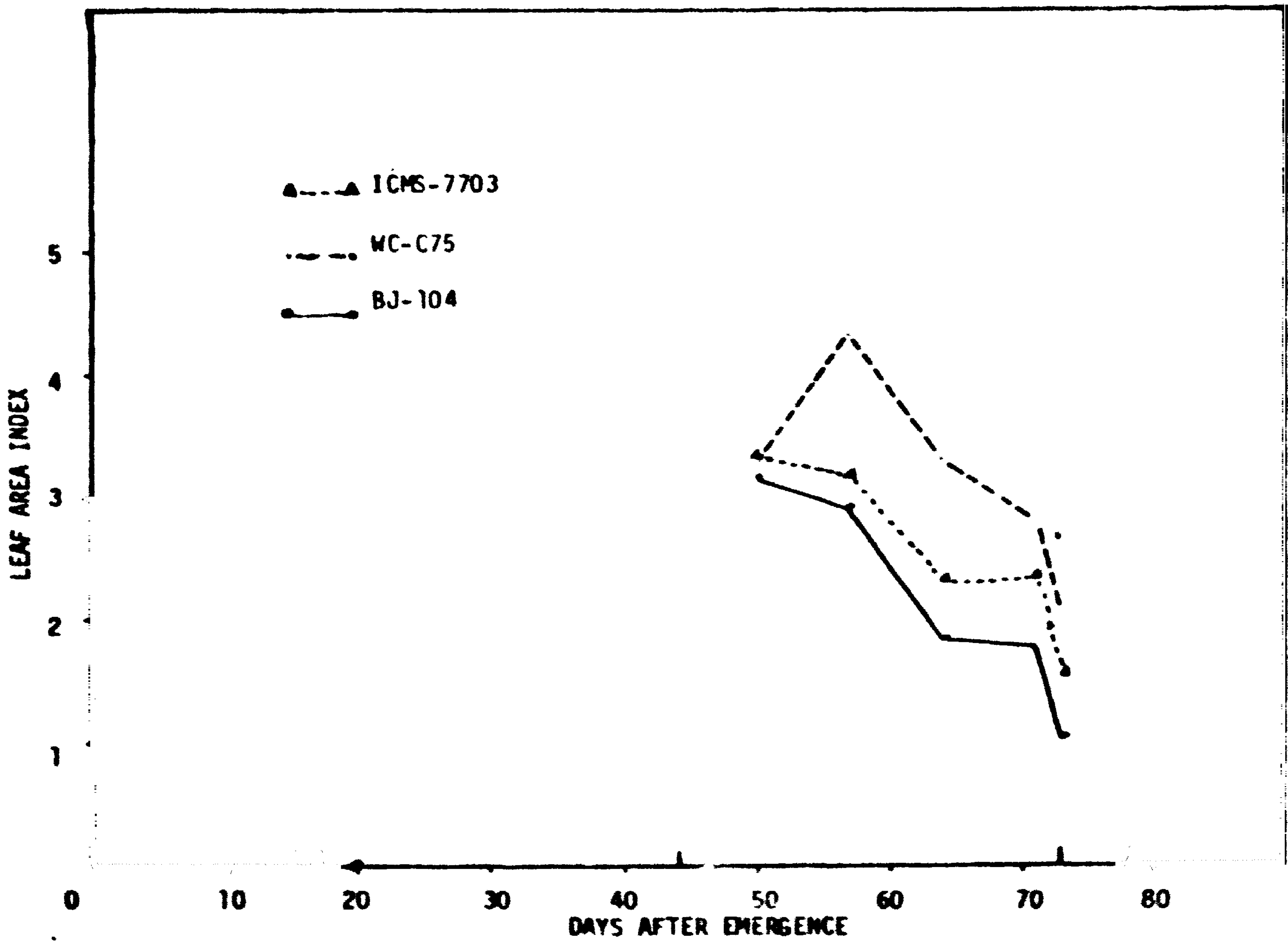

Figure 20. Comparison of LAI for three pearl millet genotypes during the growing season (Field RP-12, 1981 rainy).

Table 20. Comparison of pearl millet population and total dry matter. (1981 rainy)

Genotype	Population		Experiment					
			Alfisol			Vertisol		
	Alfisol (RP-4)	Vertisol (BP-12)	Main	Tiller	Main + tiller	Main	Tiller	Main + tiller
	-----pl/m² -----		----------------		kg/ha	----------------		
BJ-104	14.4	12.3	3414	4465	7879	3030	5659	8689
WC-C75	13.9	13.0	6312	197[illegible]	8282	4941	2772	7713
ICMS-7703	14.8	12.2	6264	2307	8571	4633	3624	8257

WC-C75 and ICMS-7703 had higher TDM in Alfisols but no difference in grain yield was observed between Alfisols or Vertisols for these genotypes. Even though ICMS-7703 had higher TDM in both soils, grain yield for both WC-C75 and ICMS-7703 was similar in both soils.

BJ-104 produced more effective tillers compared to other two genotypes. It had higher TDM and grain yield in Vertisols. Contribution of tillers to grain yield was higher in Vertisols. In fact, in Vertisol tillers contributed more than the main plants. The lower grain yield and TDM in Alfisol can be explained by the reduction in . effective tillers. This was probably due to late planting in Alfisol. It may be recalled that there was 15 days difference in emergence date between Alfisols and Vertisols.

1982 s r season

Response of pearl millet to moisture stress

An experiment was conducted in Alfisol to study the effect of moisture stress on pearl millet. Three pearl millet genotypes (BJ-104, WC-C75, and ICMS-7703) were planted in a medium deep Vertisol (BP-12) on 15 January 1982. An irrigation of 100 mm was given on 16 January, emergence occurred on 19 January. Two moisture treatments were imposed in the experiment. Treatment A included additional four irrigations at 14, 29, 43, and 58 DAE. Treatment B included additional two irrigations on 14 and 29 DAE.

Leaf area

Leaf area index was measured at periodic intervals and LAI was higher in treatment A.

Dry matter partitioning

Total dry matter and its partitioning to different plant parts are given in Figures 21 to 26. However, partition of TDM at three critical growth stages PI, AN, and PM are given Table 21. Harvest index was higher in treatment A for all genotypes. BJ-104 had higher harvest index.

Table 21. Total dry matter and percent of dry matter partitioned to different plant components at three growth stages of pearl millet genotypes under two moisture treatments. (Vertisol - BP-12, 1982 summer).

Plant components	Growth stage PI A	PI B	AN A	AN B	PM A	PM B
BJ-104						
Leaf	0.63	0.63	0.25	0.32	0.10	0.10
Culm	0.37	0.37	0.51	0.48	0.25	0.30
Head + grain	-	-	0.24	0.20	0.65	0.60
Grain	-	-	-	-	0.46	0.42
TDM (g/plant)			8.40	4.40	35.60	25.10
WC-C75						
Leaf	0.71	0.71	0.29	0.33	0.16	0.15
Culm	0.29	0.29	0.42	0.46	0.34	0.34
Head + grain	-	-	0.29	0.20	0.50	0.51
Grain	-	-	-	-	0.36	0.32
TDM (g/plant)			9.90	9.30	25.00	18.80
ICMS-7703						
Leaf	0.67	0.67	0.32	0.31	0.23	0.11
Culm	0.33	0.33	0.53	0.53	0.33	0.34
Head + grain	-	-	0.15	0.16	0.44	0.56
Grain	-	-	-	-	0.34	0.33
TDM (g/plant)			10.80	10.00	29.50	20.30

A = 5 irrigations B = 3 irrigations

Phenology

Phenology, plant population, final dry matter and grain yield at harvest are given in Table 22. ICMS-7703 and WC-C75 took 6-8 days more compared to BJ-104 to reach maturity. However, no difference in any growth stage was observed between treatments under study. Therefore, an experiment is being planned for 1983 summer to study the effect of moisture stress imposed at different phenological stages.

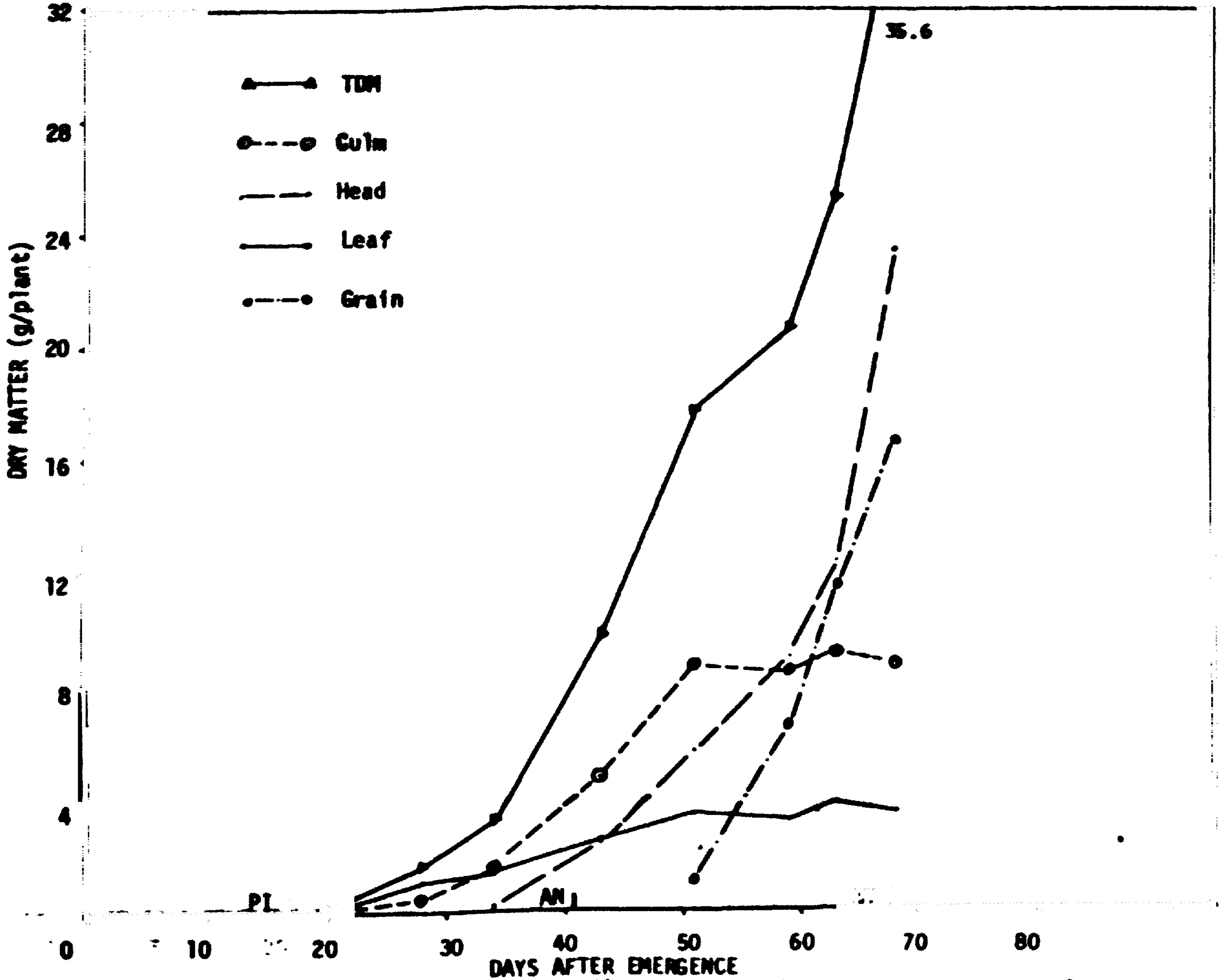

Figure 21. Total dry matter of pearl millet (BJ-104) and its partitioning to different plant parts during the growing season under adequately irrigated treatment (Field BP-12, 1982 summer).

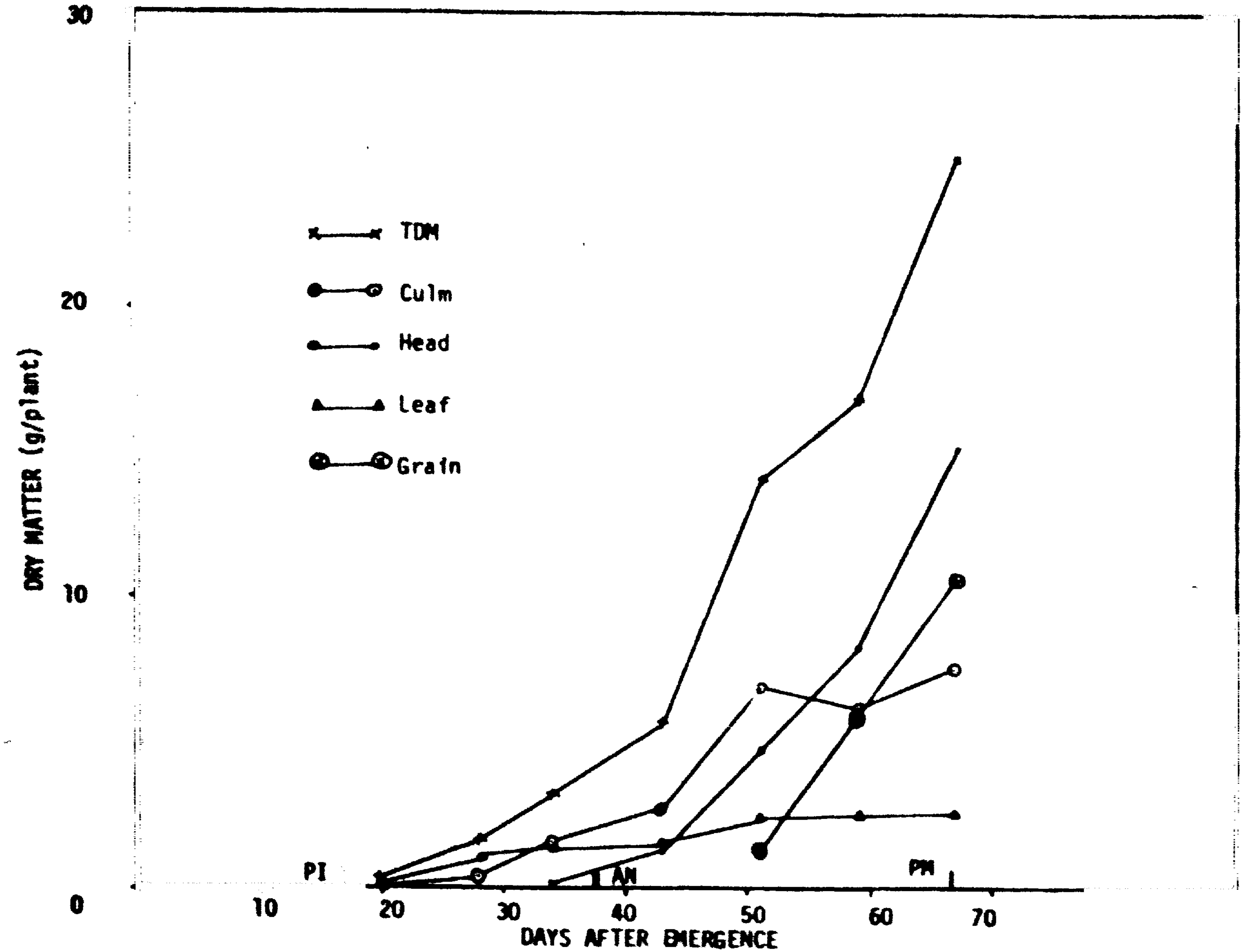

Figure 22. Total dry matter of pearl millet (BJ-104) and its partitioning to different plant parts during growing season under limited irrigation treatment (Field BP-12, 1982 summer).

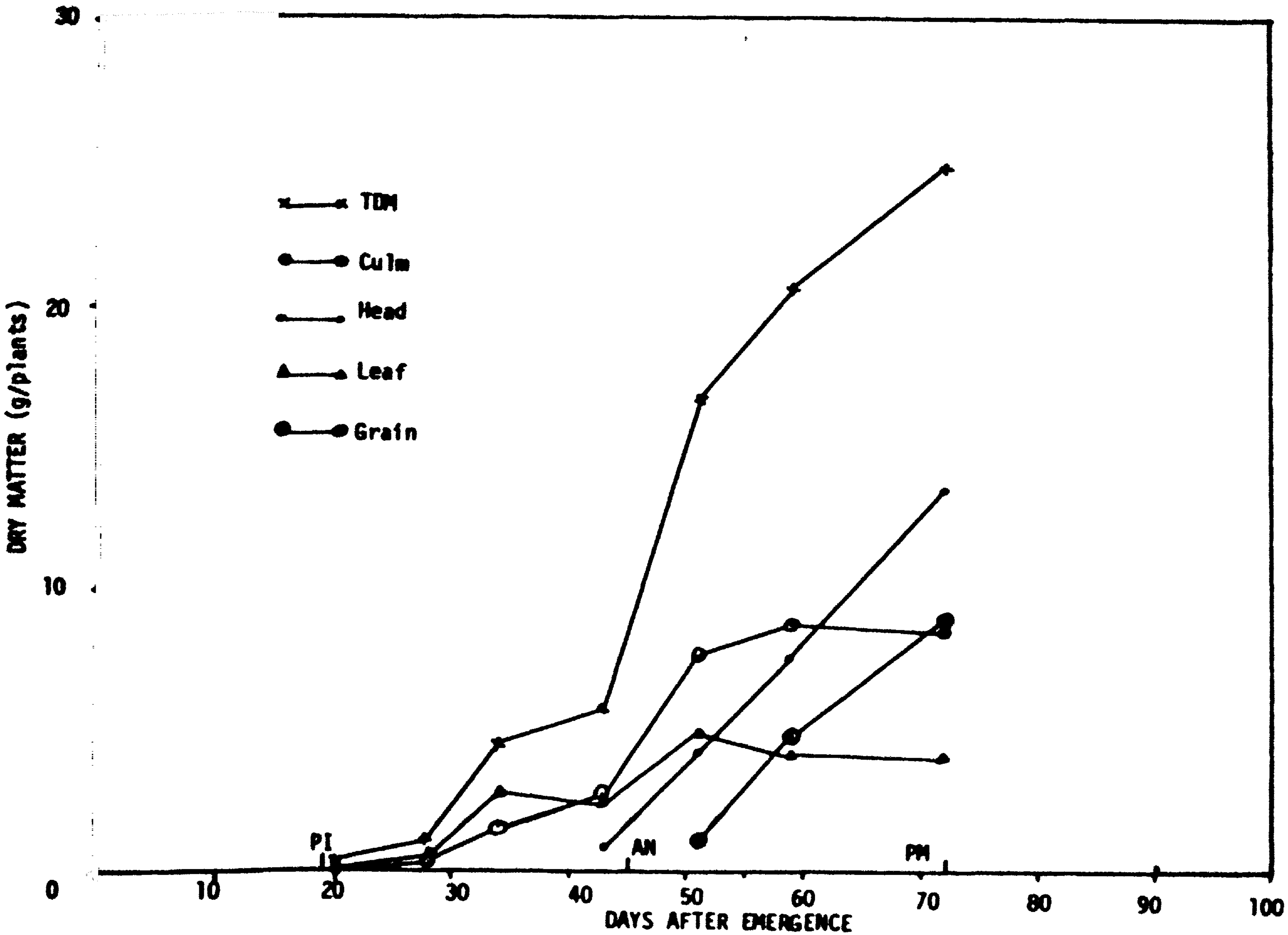

Figure 23. Total dry matter of pearl millet (WC-C75) and its partitioning to different plant parts during the growing season under adequately irrigated treatment (Field BP-12, 1982 summer).

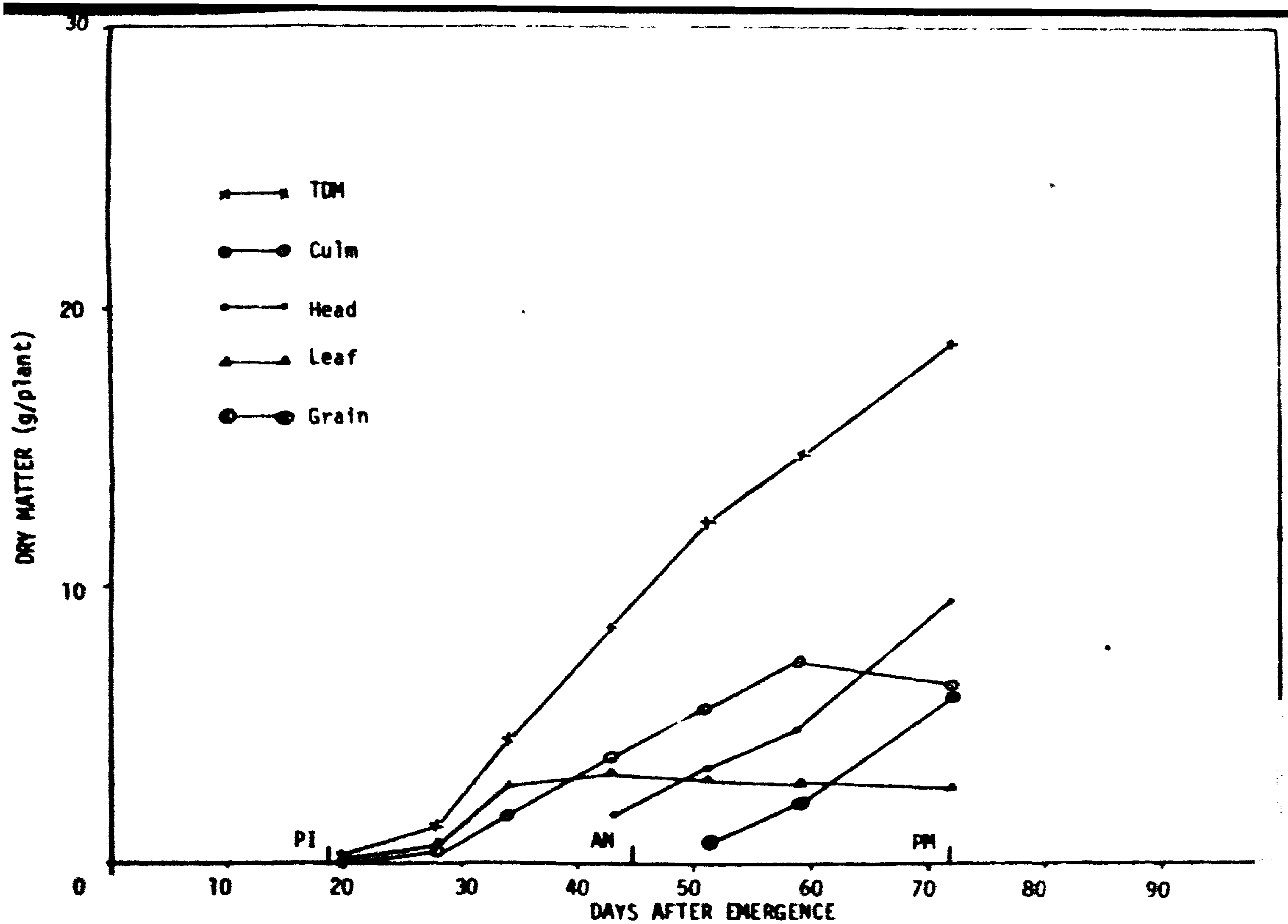

Figure 24. Total dry matter of pearl millet (WC-C75) and its partitioning to different plant parts during the growing season under limited irrigation treatment (Field BP-12, 1982 summer).

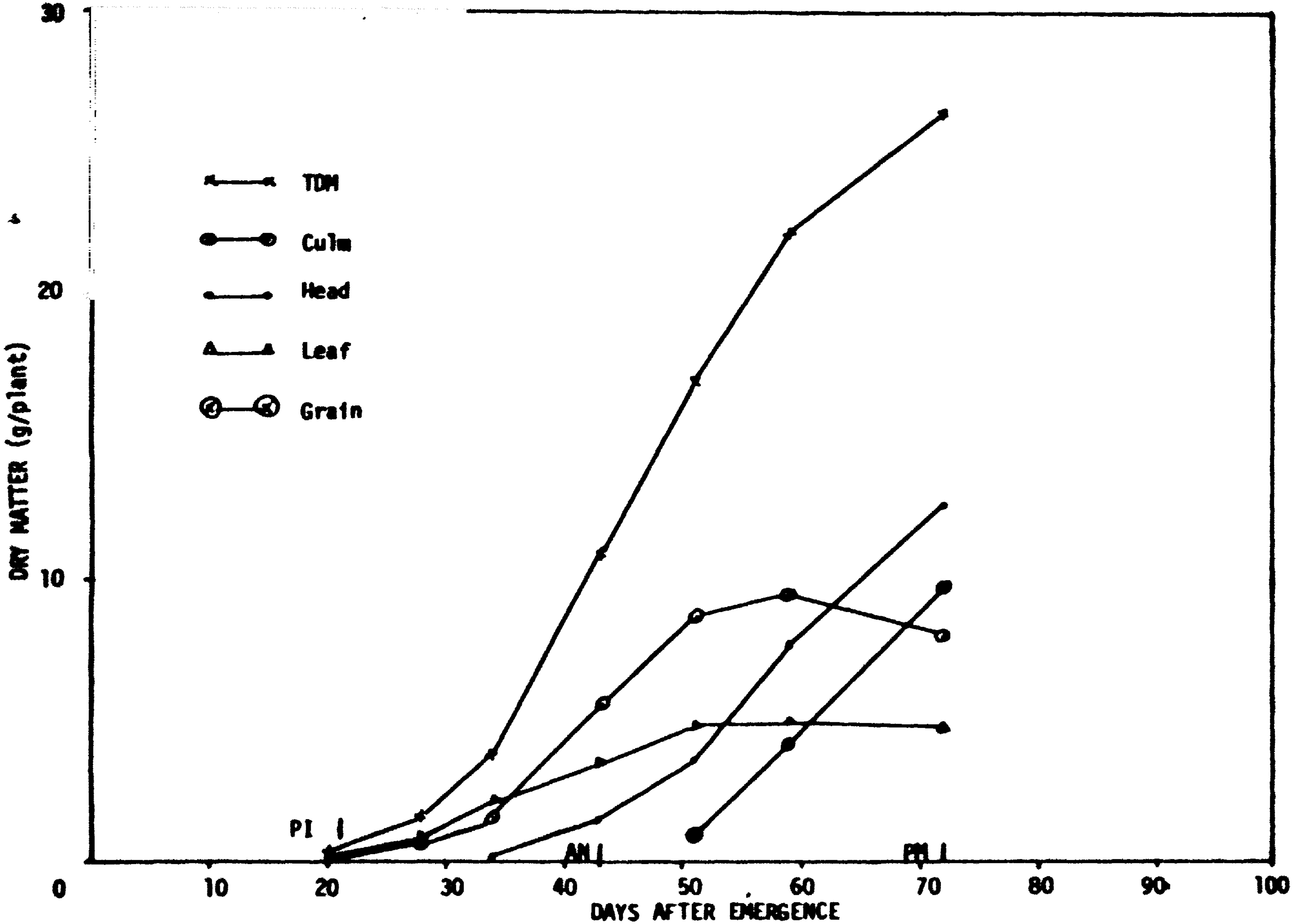

Figure 25. Total dry matter of pearl millet (ICMS-7703) and its partitioning to different plant parts during the growing season under adequately irrigated treatment (Field BP-12, 1982 summer).

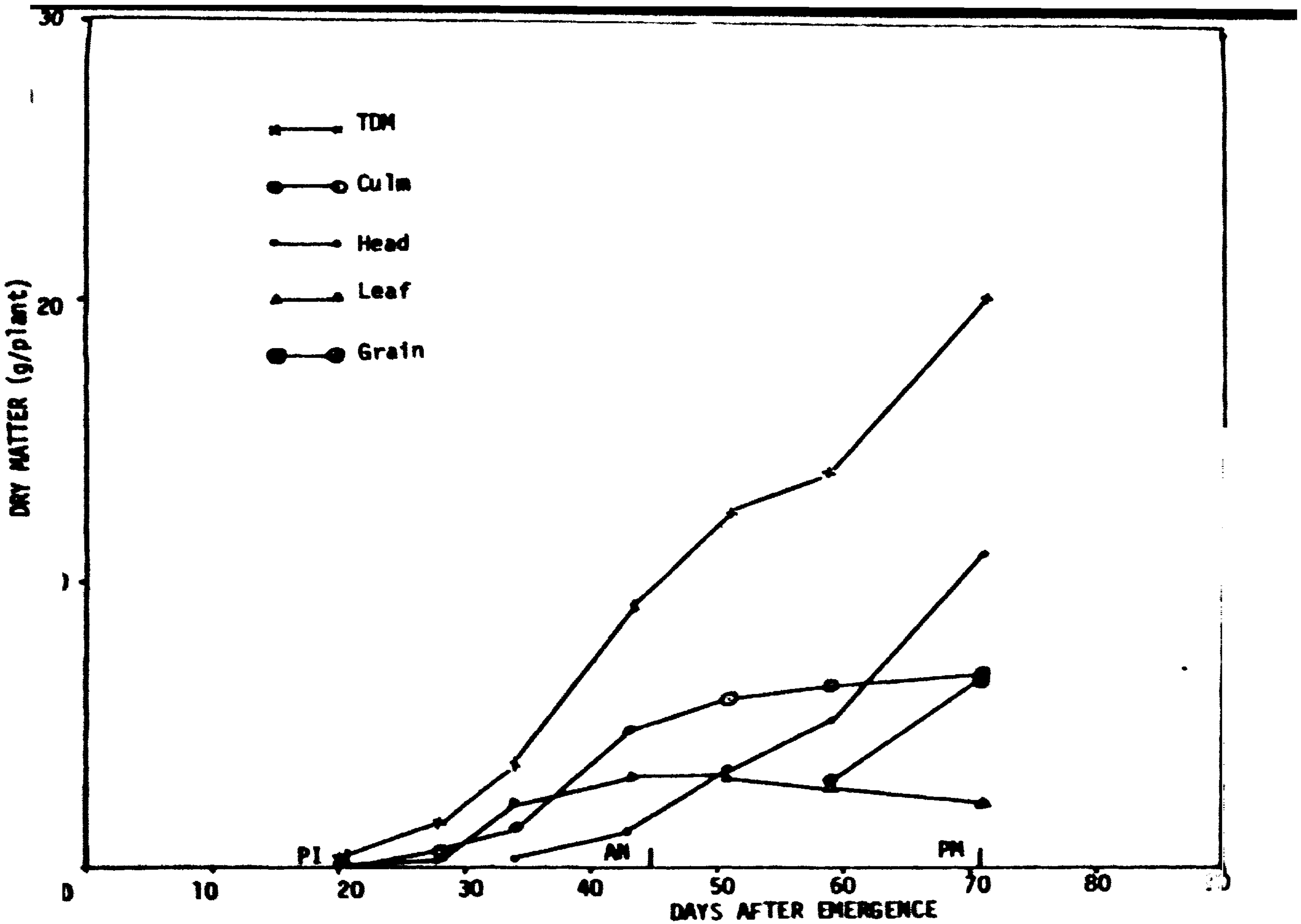

Figure 26. Total dry matter of pearl millet (ICMS-7703) and its partitioning to different plant parts during the growing season under limited irrigation treatment (Field BP-12, 1982 summer).

Table 22. Comparison of pearl millet population, phenology, grain yield and total dry matter under two moisture treatments. (Vertisol - BP12, 1982 summer).

Genotype	Population pl/m²	Growth stages PI	AN		Grain yield Main	Tiller	Main+ tiller	TDM
		Days after emergence			----------kg/ha	--------		
BJ-104 A	8.3	17	41	68	510	864	1374	2964
BJ-104 B	8.7	17	38	67	476	442	918	2240
WC-C75 A	10.1	19	45	72	899	0	899	2517
WC-C75 B	8.7	19	45	72	530	0	530	1630
ICMS-7703 A	10.7	21	43	72	1055	0	1055	2837
ICMS-7703 B	8.8	21	45	71	589	0	589	1746

Grain yield and total dry matter

In both moisture treatments, BJ-104 yielded highest, though the yield was 60% lower even in treatment A compared to that obtained in rainy season. No grain yield difference was obtained between WC-C75 and ICMS-7703 in both A and B treatments. However, the grain yield for both these two genotypes was less than 40% (even in treatment A) compared to those obtained in the rainy season. There was no contributions to grain yield from tillers in WC-C75 and ICMS-7703 in both moisture treatments. Moisture stress in BJ-104 reduced the contribution from tillers.

Effect of temperature on phenology in millet

The phenological data for three pearl millet genotypes (BJ-104, WC-C75, and ICMS-7703) grown in 1981 rainy and 1982 summer are given in tables 17 and 22. The relationship between mean temperature and the duration of growth stage 1 (emergence to panicle initiation) is given in Figure 27. The duration of GS1 decreases with the increase in temperature up to 26.6°C. There is an indication from the limited data that duration increases with the further increase in temperature beyond 26.6°C. No clear relationship between temperature and the duration of GS2 and GS3 was observed with the present data. More data points are however required to study the effect of temperature and daylength on phenology.

FUTURE PLANS

Our experience with the sorghum simulation model over the past five years gave us useful leads to examine alternative management strategies and extend the knowledge to other crops. We will continue our efforts:

- To extend knowledge in developing growth models for other crops of ICRISAT mandate. Pearl millet which is the second cereal crop of our mandate was obviously next choice. Efforts

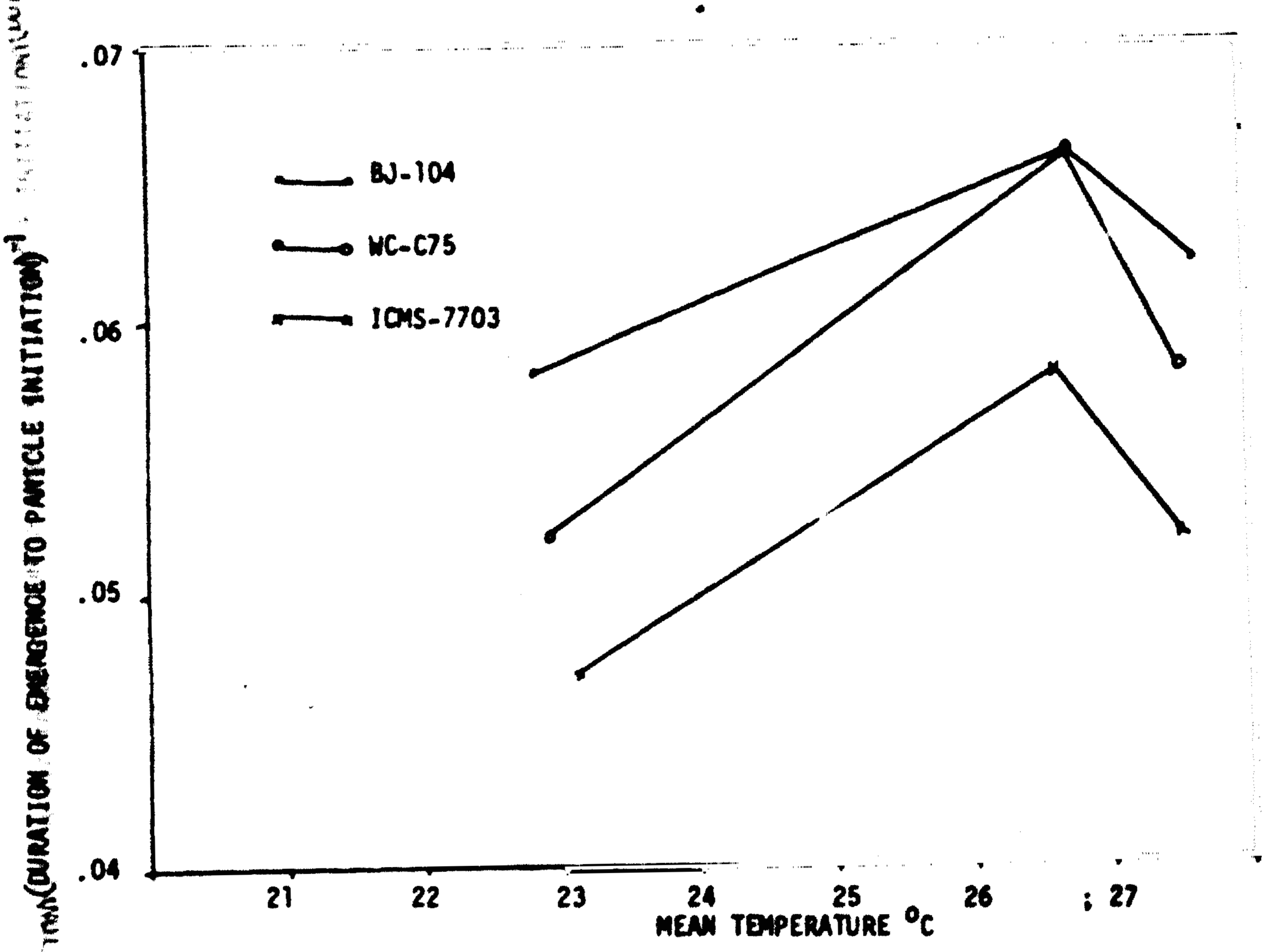

Figure 27. Effect of temperature on the duration of growth stage 1 (emergence to panicle initiation) for three pearl millet genotypes.

have been initiated in cooperation with the pearl millet improvement program at ICRISAT to develop a growth and development model for pearl millet. Experiments are being conducted from the 1981 rainy season to collect standard data sets on crop, soil and weather to achieve this objective.

The framework of the sorghum model with some modifications can be utilized to produce a pearl millet growth model. The modifications include the change of individual leaf concept as is done in SORGF to leaf area index. The development and incorporation of a tillering subroutine is very important. A suggested flow chart for pearl millet growth and development is given in Figure 28.

Collaborative experiments are being conducted to study light interception, water use, phenology, tillering habit, dry matter accumulation, and partitioning of pearl millet under both Indian and West African conditions. Experiments are also planned to study the effects of method of planting e.g. row (practised in India) versus hill (practised in West Africa) on the growth and development of pearl millet.

- To use the revised sorghum model in developing a methodology for first order screeing of different environments for their crop production potential.

- Sorghum yield simulations are presently made assuming that crops are raised under adequate nutrient supply, weed free, insect/disease free conditions. Algorithms addressing these questions should be developed and incorporated in the models for yield simulation under the real world situations. Thus collaborative experiments need to be planned for quantifying the stress factors (moisture, nutrient, biotic, etc.).