DROUGHT RESISTANCE RESEARCH IN MALI

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By
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ICRISAT

International Crops Research Institute for the Semi-Arid Tropics
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NOTE TO READER

This is a pre-publication informal report for work conducted at the Cinzana Agricultural Experiment Station, Cinzana, Mali, West Africa during March and April, 1984. This report is designed to stimulate thinking and comments from professional colleagues and is not to be considered as a formal publication bearing the endorsement of the Institute.

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PREFACE

This report describes one experiment in drought resistance research with millet and sorghum at the Cinzana Agricultural Experiment Station, near Segou, Mali. The experiment was designed to investigate the effects during early development of these crops when subjected to high soil temperature and water stresses. The bulk of the report is a manuscript submitted to Experimental Agriculture, Cambridge University Pr[illegible] Additional tables and figures are included in the appendex which may be helpful and informative to breeders working in the area. Finally, data may be obtained from the Office of International Cooperation on tape GC Magtape by those interested in performing additional analysis.

File name	Subject
WATERMIL.DAT	Millet Line Source Water Application
WATERSOR.DAT	Sorghum Line Source Water Application
TEMP1.DAT	Millet Line Source Soil Temperature

File name	Subject
TEMP2.DAT	Sorghum Line Source Soil Temperature
POP1.DAT	Millet Line Source Field Emergence, Population after thinning and at harvest, Vigor at harvest, and Dry Weight of two plants.
POP2.DAT	Sorghum Line Source Field Emergence, Population after thinning and at harvest, Vigor at harvest, and Dry Weight of two plants.
PITTEMP.DAT	Millet and Sorghum Charcoal Pit Soil Temperature
PITVIG.DAT	Millet and Sorghum Lab. Germination; Emergence, Vigor at Emergence, Survival after 10 days, Vigor of survival at 11 days in the Charcoal Pits; and 1000 seed weight, Vitriosity, Density of Seed, and Root Hair Vigor measured in the lab.

Running Title :

HIGH TEMPERATURE AND WATER STRESSES IN MALI

EFFECTS OF HIGH SOIL TEMPERATURE AND WATER STRESSES ON MALIAN PEARL MILLET AND SORGHUM DURING SEEDLING STAGE

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SUMMARY

Pearl millet (*Pennisetum americanum* (L) Leeke) and sorghum (*Sorghum bicolor* (L) Moench) can suffer from poor stand establishment under conditions of high soil temperature and water stresses. A line source sprinkler irrigation system and a charcoal pit technique were used to evaluate stand establisnment and high correlations existed between the two methods. It may be possible to use the charcoal pit technique as a predictive tool in drought resistance breeding programs.

INTRODUCTION

Drought and crop establishment are the two major priorities for millet and sorghum improvement in the low rainfall zones of West Africa (House, 1982). This area is characterized by intermittent periods of moisture stress and high radiation loads which can have disastrous effects upon crop production, particularly when they occur during the seedling stage (GS-1). Yield reductions, caused by incomplete stand establishment due to high soil temperatures and moisture stress, are common (Peacock, 1982).

The line source sprinkler irrigation system (LS), as developed by Hanks et al., (1976), has been used extensively to investigate various aspects of moisture stress effects on such diverse crops as sugarbeets (Miller and Hang, 1980), grain legumes (Pandey et al., 1984), sorghum (O'Neill et al., 1983), rice (O'Toole and Namuco, 1983), and wheat (Hang and Miller, 1983). This technique provides the application of a continuously decreasing gradient of water from the LS to the extremities of the experimental plot, which enables researchers to better understand the development and effects of moisture stress.

The interactive effects of high soil temperature and moisture stresses upon germination and stand establishment are difficult to separate in the field. To investigate the effects of high soil temperatures during early growth, a technique has been developed at ICRISAT in which a thin layer of powdered charcoal or kaolin is spread evenly over the soil to modify soil temperatures (Wilson et al., 1982). They have demonstrated differential emergence of sorghum cultivars under high soil temperature stress.

The present study was conducted to test screening procedures used to evaluate the response of pearl millet and sorghum varieties to moisture and high soil temperature stresses during GS-1 in Mali. The LS system was chosen as a field screening method to subject Malian varieties of millet and sorghum to moisture stress and charcoal pits (CP) were used to subject the same varieties to high soil surface temperature stress. It was also proposed to investigate the correlation of high soil temperature stress results with those obtained in the field.

METHODS AND MATERIALS

The study was conducted at the Cinzana Agricultural Experiment Station (near Segou, Mali) during March and April, 1984, the period of the year with maximum solar radiation. The station, located between the Bani and Niger Rivers in the 700 mm mean annual rainfall zone (Virmani, Reddy, and Bose, 1980), was developed as the major research site for the Sahelian zone of Mali. There are five major soils on the station; that used in the present study was a loamy sand (83 % sand) of the Oxic Haplaustalf family with an average gravimetric water holding capacity of 13 % in the upper 30 cm. Cation exchange capacity was low (4.2 meq $100g^{-1}$) and pH averaged 5.6.

Two LS systems were installed, one each for millet and sorghum, after a uniform preplant irrigation of 13 mm. The systems were oriented in an east-west direction with eight replications of sixteen entries in a randomized block design. Rain gauges were located in each replication at 0, 1.5, 4.5, 7.5, 10.5, and 13.5 m from, and perpendicular to, the LS. These five positions represented the five water application treatments. Diammonium phosphate was banded at a rate of 42,46 N,P kg ha^{-1} four days before planting. Five seeds of millet and sorghum were hand planted in pockets spaced every 20 cm on March 11 and 12, respectively, and Furadan (Carbofuran; 2,3-dihydro-2, 2-dimethylbenzofuran-7-yl methylcarbamate) was incorporated for insect control. Single entries were planted per row in rows spaced at 75-cm intervals. Pockets were thinned to one plant per pocket between growth stage 1 and 2 (Vanderlip and Reeves, 1972).

Each LS system was run every third day during the evening when wind velocities were relatively low. The period of water application was sufficient to replace moisture lost through maximum evapotranspiration (Doorenbos and Kassam, 1979) in the high water application treatment during the previous three days. Soil temperatures were measured at depths of 1, 5, and 10 cm with an insertion probe thermocouple in each irrigation treatment and all replications between 1300 and 1500 h local time.

Measurements were taken in the seedbed prior to, and on the day following, an irrigation at similar distances from the LS as the rain gauges. Plant populations in each of the five water application treatments were determined after thinning and final population counts were taken one day prior to harvest. Two plants per treatment were harvested 37 days after planting (DAP), dried in the sun to constant weight and dry weights were determined.

Concurrently, four pits were dug and cement floors and block walls were constructed with an inside dimension of 240x240x40 cm. The inside walls and floor were lined with plastic to enable accurate water application and prevent moisture loss. Each pit was then filled to 30 cm with the same soil used in the field test to a bulk density of 1.65 g cm^{-3}. The resulting pit soil surface was even with that of the surrounding field surface. Millet and sorghum of the same varieties used in the LS test were planted in 1-m rows, 3 cm deep in four replications of a randomized block design at a rate of 50 seeds per meter on April 2, 1984. Each block was irrigated with 45 mm of water, sufficient to bring the upper 15 cm of soil to field capacity, and a 0.5-cm covering of powdered charcoal was spread evenly over the surface. Data were taken of seed germination and vitriosity (endosperm corneousness) in the laboratory (House, 1982), and of emergence, vigor (Maiti et al., 1981) at emergence, and survival at 10 DAP in the CP. There was 3.7 mm of rain during the evening of 10 DAP so vigor scores of recovered surviving plants were taken on 11 DAP (Maiti et al., 1981). Soil temperatures at 1, 5, and 10 cm were measured each day of the 11-day experiment between 1330 and 1430 h and maximum unshaded air temperature measured 10 cm above the soil surface was recorded at the agrometeorological station 0.5 km from the CP and LS test sites.

RESULTS AND DISCUSSION

Environment

Environmental conditions during the 37-day study were extreme with maximum temperatures averaging 39^{o} C (Table 1). Pan evaporation ranged from 8.2 to 19.6 mm day^{-1} with a mean of 14.0 mm day^{-1}, rather high due to advection. Potential evapotranspiration (ETP) was calculated by the Penman method (Gommes, 1983) and by using pan coefficients as suggested by Doorenbos and Kassam (1979). The two methods differed by only 0.1 mm day^{-1} when averaged over the total experimental period, with similar maximum and minimum rates. Maximum evapotranspiration (ETmax), that quantity of water required by crops during various stages of growth, was calculated using ETP and crop coefficients ranging from 0.4 at planting to 0.84 for millet and 0.77 for sorghum at 37 DAP (Doorenbos and Kassam, 1979). This period represented approximately 30 and 25 % of crop development for the millet and sorghum, respectively. Maximum evapotranspiration ranged from 1.9 mm day^{-1} at planting to 6.0 mm day^{-1}.

Line Source Test

Total water application, regressed against distance from the line source, showed a very linear pattern. Coefficients of determination were greater than 0.96, but because of continual winds from the north, regression slopes on that side of the LS were much steeper than on the south. Total water applications in the lowest treatment on the north side of the LS were 50 and 69 mm for millet and sorghum, respectively. Of this total, 25 and 32 % were delivered during the last two irrigations to the millet and sorghum, respectively. Because severe water deficits prior to these last two irrigations resulted in drastically different growing conditions on either side of the LS, only the results from the south four replications are presented.

Soil temperatures were very similar for both sorghum and millet. Figure 1 illustrates the soil temperatures for sorghum in the high (1.5 m from LS) and low (13.5 m from LS) water application treatments at 1 and 5-cm depths. Mean daily maximum unshaded air temperature was 44° C and surface soil temperatures in the low water treatment were similar. Soil temperatures were reduced following irrigation due to evaporative cooling, but rose on subsequent days (Fig. 1). Temperatures at the 5-cm depth remained about 5° C cooler than surface temperatures. Althougth the higher water application treatment received substantially more water than the low treatment, surface soil temperatures reached nearly similar values on several occasions.

Mean dry weight of two plants from each treatment was regressed against total water applied during the 37 days of the study (Fig. 2). An indication of the degree of moisture stress is given on the secondary abcissa as the ratio of total water applied to cumulated ETmax. Differences in plant populations, which could affect water utilization by individual plants, was initially included in the analysis. There was no significant improvement of the analysis when percent population was used so all calculations were done with dry plant weight. Two separate response groups for millet and four for sorghum were identified by combining entries with lines of similar slopes and intercepts

(Fig. 2). Growth of 14 of the 16 millet varieties was similar with respect to water application. The response of sorghum was more diverse; there was one superior sorghum variety, three others above average, and one below (Fig. 2). Millet generally produced more dry matter than sorghum at all levels of water application. At a water application rate of 50 % cumulative ETmax, millet dry matter was three times greater than that of the best sorghum entries. All entries were Malian varieties but millets have tended to do better in similar sandy soils whereas the reverse has been true on heavier soils (Serafini, 1983).

Charcoal Pit Test

Daily soil temperatures for millet at 1, 5, and 10 cm with charcoal applications are represented in Figure 3. Initial soil temperatures were lower than unshaded air temperatures because of evaporative cooling after irrigation. Surface temperatures rose to 60^{o} C at 7 DAP and remained near there until a rain occured at the end of the period (Fig. 3). Temperatures at 5 cm (2 cm deeper than planting depth) reached 47^{o} C at emergence and temperatures in the planting zone must have been around 50^{o} C at that time. Temperatures at 5 cm and maximum unscreened air temperature reached similar values at 3 DAP.

Maximum percent emergence for millet in the CP was 59 %, not significantly different from the local check (CMM 374) or the mean (Table 2). There was a 17 and 19 % loss of population between emergence and day 10 for the check and best millet entry, respectively. The stand of the poorest entry decreased by 36 % compared to the mean reduction of 22 %. Both the local check and the best entry recovered and appeared vigorous after 3.6 mm of rain during the evening of 10 DAP. The local sorghum check (CSM 205) and best entry had a very good percent emergence and vigor scores, both significantly better than the mean and worst entry (laboratory germination for worst sorghum entry : 59 %) but their stand was reduced 29 and 30 %, respectively. Their survival vigor score was good, especially when compared to the mean or the worst entry.

Charcoal Pits vs Line Source

Correlations of entry responses in the CP to those of the LS in the low water application treatment are presented in Table 3. Except for the highly significant correlation for vitriosity vs dry weight, there are no biologically significant relationships for the millet entries. This is not surprising given the lack of differences among millet varieties in the field (Fig. 1) and the high mean survival in the CP (Table 2). The millet varieties were selected from local material adapted to heat and moisture stresses. Sorghum, on the other hand, selected from a more diverse range of germplasm, demonstrated highly significant correlations ($p<0.01$) between the two tests for all responses except percent emergence vs dry weight, which was significant at the 5 % level, and vitrosity vs dry weight. Negative correlations for vigor and vitriosity were expected because they were ranked from 1 to 5 with 1 being superior.

There was a range of responses for sorghum in the field (Fig. 2) and when subjected to high temperature stress in the CP (Table 2). The mean values for % survival in the pits vs % survival in the field for the 16 sorghum varieties are plotted in figure 4. At low % percent survival, the field response was somewhat greater than the 1:1 line. Varieties which maintained high survival rates were below the 1:1 line indicating field conditions were more severe due to the longer period of the LS test. Responses were similar under both conditions as evidenced by the high correlations (Table 3); CP evaluations predicted LS performance under moisture stress although good vitrosity scores may not be indicative of field performance under drought conditions.

The very high correlation of sorghum survival in the CP verses field emergence, survival, and dry weight production suggest the CP may be used as a screening method for the combined effects of high soil temperature and moisture stress. The method is rapid; several runs can be made during the hot season from early March through late May. The method is easy; given the high temperatures during the hot season, no sophisticated equipment is needed to increase soil temperatures. And finally, the method reasonably evaluates the probable field performance during GS-1 of a range of material given an adequate potential range of responses to high soil temperature and moisture stress.

Acknowledgements : The author would like to express his thanks to Drs. O. Niongado, SRCVO/Mali Millet Breeder; J.F. Scheuring, ICRISAT/Mali Cereal Breeder; and K.V. Ramaiah, ICRISAT/Upper Volta Striga Physiologist for providing germplasm and to Messrs. Mamadi Diaby, Diby Diakite, and Makano Coulibaly, SRCVO/Mali Ingenieurs and Moniteur, respectively, without whose able work, this project would not have been completed. This research was made possible by a grant to ICRISAT/Mali by USAID.

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Table 1. Daily temperature, pan evaporation, estimates of potential evapotranspiration (ETP), and maximum evapotranspiration (ETMax) from March 12 - April 17, 1984.

	Maximum	Minimum	Mean
Temp. Max. (^{o}C)	42.9	26.9	39.3
Temp. Min. (^{o}C)	27.5	9.5	19.2
Pan Evap. (mm day^{-1})	19.6	8.2	14.0
ETP[+] (mm day^{-1})	8.9	4.4	6.6
ETP[‡] (mm day^{-1})	8.8	4.1	6.7
ETMax[@] (mm day^{-1})	6.0	1.9	4.2

[+] Penman equation (Gommes, 1983).
[‡] Penman equation (Doorenbos and Kassam, 1979).
[@] Penman equation and crop coefficients (Doorenbos and Kassam, 1979).

Table 2 Responses of various parameters of 16 millet and sorghum varieties to high temperature stress in charcoal pits.

Entry	Emergence (%)	Emergence vigor (1-5)[+]	Survival day 10 (%)	Survival vigor day 11	Vitri-osity (1-5)[‡]
Millets					
Check CMM 374	47.0	1.0	38.8	1.3	3.0
Maximum	59.0	1.0	48.8	1.0	2.3
Minimum	29.0	3.0	18.5	4.3	4.3
S.E.±	8.53	0.29	7.10	0.32	0.53
Mean	42.9	1.8	33.3	2.5	3.3
Sorghum					
Check CSM 205	71.0	1.0	50.8	1.3	2.3
Maximum	74.0[@]	1.0	51.8[@]	1.0	1.5
Minimum	6.5[@]	3.8	0.0[@]	5.0	4.8
S.E.±	7.90	0.32	5.73	0.37	0.43
Mean	46.3	2.3	26.4	3.2	3.1

[+] Ranking 1 to 5 with 1 being superior (Maiti, Raju, and Bidinger, 1981).

[‡] Ranking 1 to 5 with 1 being superior (House, 1982).

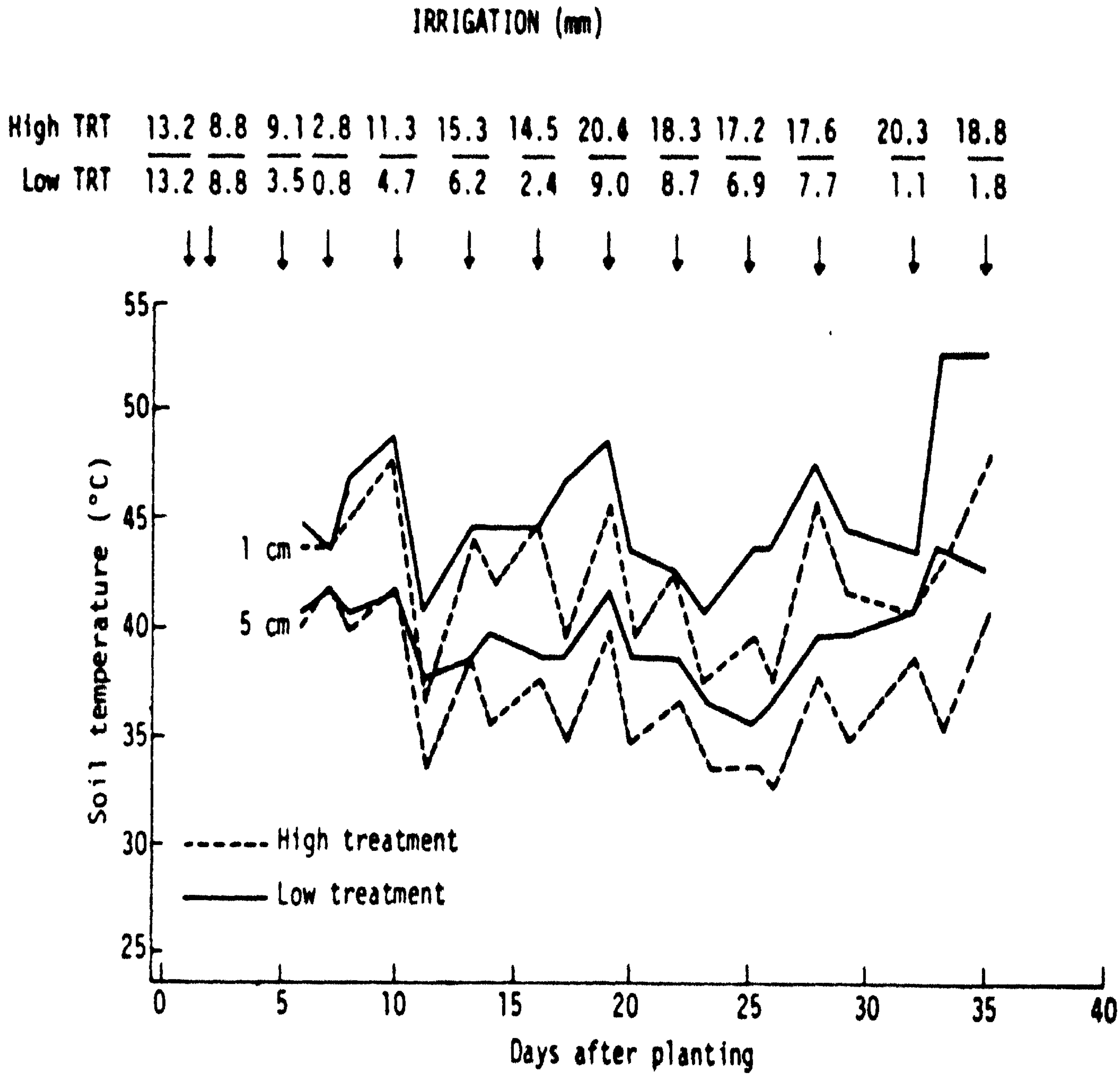
[@] S.E. does not refer to these values.

Table 3. Correlations for various parameters of 16 millet and sorghum varieties between responses in charcoal pits and in the low water application treatment of a field line source irrigation gradient.

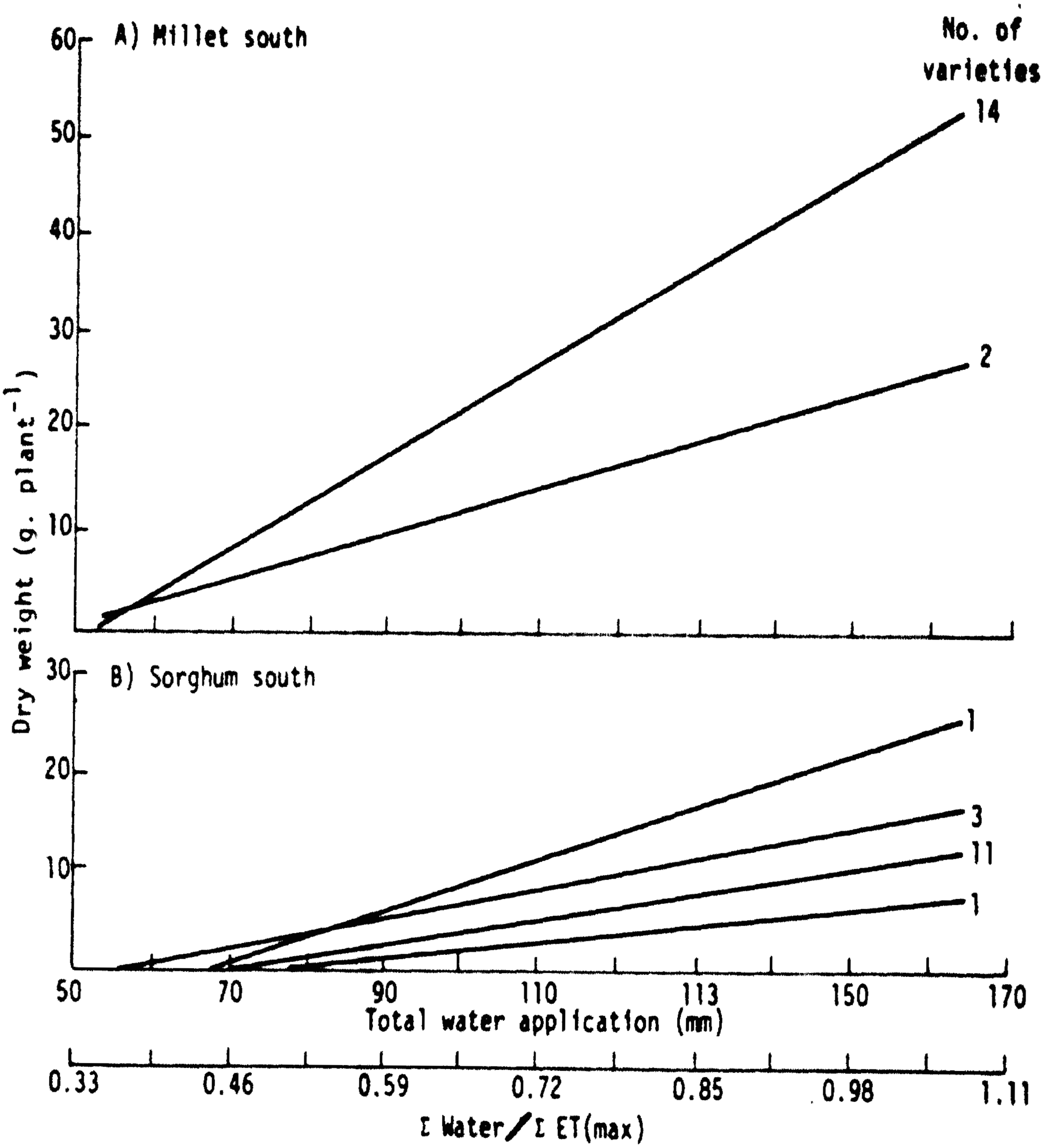
Field / Pits	Emergence (%)	Survival (%)	Dry Weight ($g\ plant^{-1}$)
Millet			
Emergence (%)	0.28*	-0.01	-0.29*
Emergence vigor	0.16	0.14	0.22
Survival (%)	0.27*	0.00	-0.27*
Survival vigor	0.12	0.14	0.18
Vitriosity	0.00	0.20	-0.67**
Sorghum			
Emergence (%)	0.81**	0.74**	0.32*
Emergence vigor	-0.70**	-0.66**	-0.45**
Survival (%)	0.87**	0.82**	0.46**
Survival vigor	-0.75**	-0.71**	-0.44**
Vitriosity	-0.44**	-0.41**	-0.12

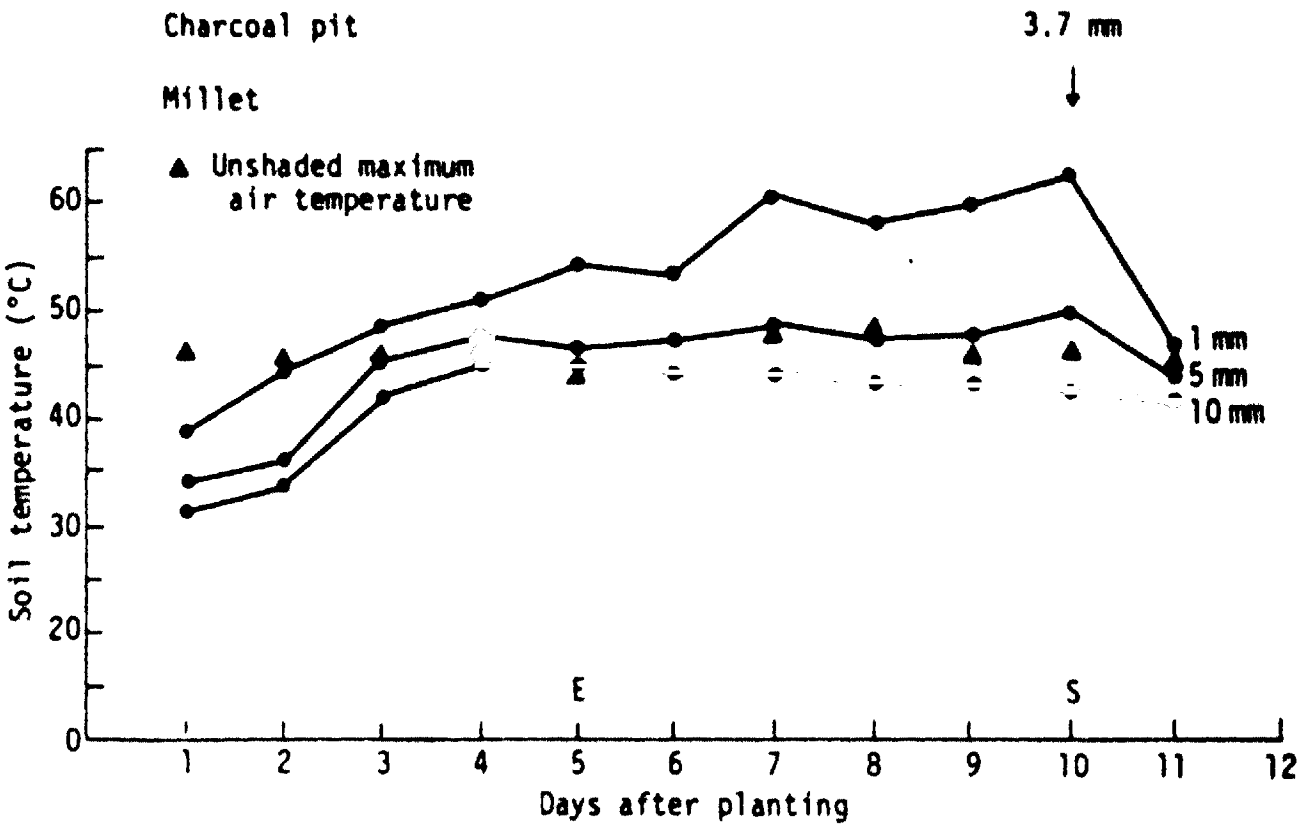
*, $0.01 < P < 0.05$; **, $P < 0.01$

LIST OF FIGURE CAPTIONS

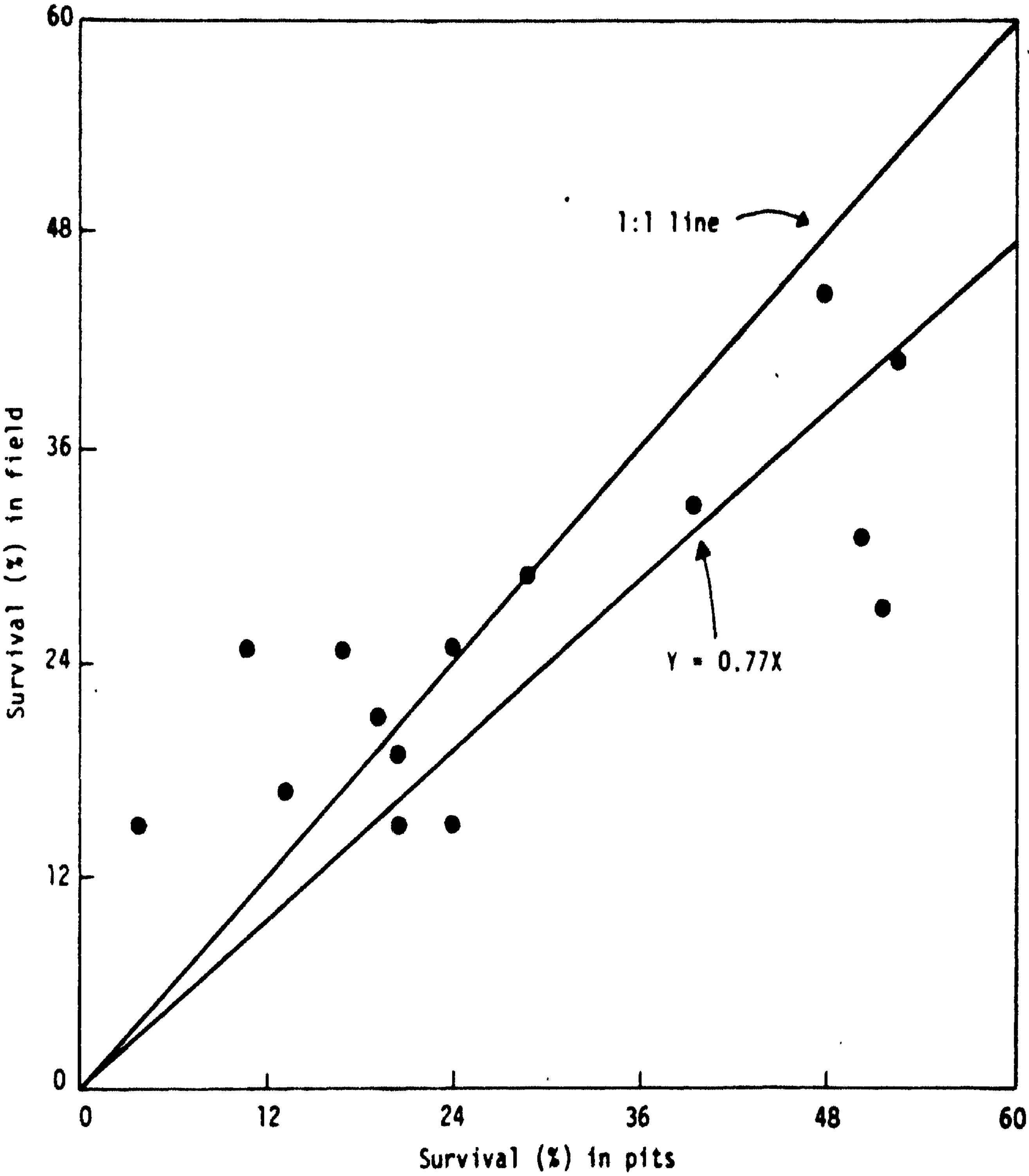


IRRIGATION (mm)
High TRT 13.2 8.8 9.1 2.8 11.3 15.3 14.5 20.4 18.3 17.2 17.6 20.3 18.8
Low TRT 13.2 8.8 3.5 0.8 4.7 6.2 2.4 9.0 8.7 6.9 7.7 1.1 1.8
55
50
45
40
35
30
25
Soil temperature (°C)
1 cm
5 cm
High treatment
Low treatment
0
5
10
15
20
25
30
35
40
Days after planting


A) Millet south
B) Sorghum south
No. of varieties
14
2
1
3
11
1
Dry weight (g. plant^{-1})
60
50
40
30
20
10
30
20
10
50
70
90
110
113
150
170
Total water application (mm)
0.33
0.46
0.59
0.72
0.85
0.98
1.11
Σ Water/Σ ET(max)



Charcoal pit
Millet
3.7 mm
▲ Unshaded maximum air temperature
Soil temperature (°C)
0
20
30
40
50
60
1 mm
5 mm
10 mm
E
S
1
2
3
4
5
6
7
8
9
10
11
12
Days after planting



60
48
36
24
12
0
Survival (%) in field
1:1 line
Y = 0.77X
0
12
24
36
48
60
Survival (%) in pits

APPENDIX

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Table A1. Sixteen millet and sorghum varieties used under a line source irrigation gradient and subjected to high soil temperature stress in charcoal pits during the 1984 hot season at Cinzana, Mali.

Entry		Millet[+]	Sorghum[++]
1	Checks	CMM 374	CSM 205
2		CMM 388	CSM 205 with brown coat
3		CMM 389	A13120 from selfed parent
4		CMM 422	A13120 from lodged parent
5		CMM 424	A13120 from open pollinated parent
6		CMM 425	CE-90 (83-SA)
7		CMM 433	CSM 228 (83-SA)
8		CMM 390	82-S-50[@]
9		CMM 420	82-S-79[@]
10		CMM 404	83-CZ-F6-171
11		CMM 396	83-CZ-F6-173 (bulked)
12		CMM 419	83-CZ-F6-225
13		CMM 455	83-SB-F6-173
14		CMM 466	83-SB-F6-226
15		CMM 468	83-SB-Base Population, Hard Grain
16		CMM 479	E-35-1

Material supplied by O. Niongado, Millet Breeder, SRCVO/Mali

Material supplied by J.P. Scheuring, Cereal Breeded, ICRISAT/Mali

@ Material supplied by K.V. Ramaiha, Striga Physiologist, ICRISAT/Upper Volta

Table A2. Characteristics of soil used under a line source irrigation gradient and in charcoal pits during the 1984 hot season at Cinzana, Mali.

	0-10 cm	20-30 cm
pH	6.1	5.0
CEC (meq $100g^{-1}$)	3.3	4.0
Clay (%)	7.3	10.4
Silt (%)	9.8	10.1
Sand (%)	82.9	79.1

Loamy Sand - Oxic Haplaustalf

Table A3. Equations of dry weight (g plant^{-1}) regressed against total water applied (mm) for 16 millet varieties on the north and south side of a line source irrigation gradient during the 1984 hot season at Cinzana, Mali.

	NORTH SIDE			SOUTH SIDE		
Entry	Intercept	Slope	r2	Intercept	Slope	r2
1	-22.5	0.324	0.52	-26.2	0.540	0.34
2	-22.6	0.376	0.76	-22.2	0.434	0.75
3	-44.2	0.523	0.85	-14.3	0.367	0.33
4	-33.8	0.469	0.77	-22.2	0.438	0.48
5	-34.1	0.453	0.59	-30.6	0.544	0.39
6	-26.1	0.340	0.68	-19.0	0.317	0.41
7	-28.6	0.402	0.70	-39.9	0.600	0.74
8	-29.2	0.407	0.70	-23.3	0.469	0.54
9	-33.8	0.444	0.83	-20.4	0.401	0.34
10	-39.5	0.489	0.66	- 3.6	0.138	0.11
11	-28.1	0.364	0.67	-29.0	0.454	0.84
12	-44.9	0.602	0.80	-15.3	0.385	0.45
13	-35.4	0.464	0.78	-29.4	0.547	0.39
14	-39.9	0.505	0.77	-23.6	0.443	0.66
15	-44.0	0.622	0.69	-17.5	0.374	0.79
16	-27.2	0.350	0.82	-31.1	0.507	0.81

Table A4. Equations of dry weight (g $plant^{-1}$) regressed against total water applied (mm) for 16 sorghum varieties on the north and south side of a line source irrigation gradient during the 1984 hot season at Cinzana, Mali.

	NORTH SIDE			SOUTH SIDE		
Entry	Intercept	Slope	r2	Intercept	Slope	r2
1	13.1	0.005	-[+]	- 7.5	0.122	0.66
2	10.8	0.020	-	-10.5	0.165	0.67
3	9.9	0.031	-	-14.5	0.182	0.63
4	17.9	-0.024	-	- 9.3	0.131	0.66
5	2.1	0.102	0.11	-12.1	0.146	0.48
6	16.0	0.010	-	- 8.8	0.136	0.52
7	6.3	0.043	-	- 7.5	0.105	0.44
8	24.3	0.040	-	-18.7	0.227	0.69
9	9.1	0.001	-	- 9.1	0.126	0.46
10	5.1	0.023	-	- 6.6	0.085	0.19
11	23.5	-0.083	0.06	- 8.4	0.118	0.49
12	7.1	0.013	-	- 7.1	0.099	0.52
13	17.4	-0.014	-	- 9.7	0.145	0.45
14	30.6	-0.084	0.01	- 5.3	0.135	0.29
15	12.9	-0.004	-	-10.5	0.137	0.69
16	27.8	-.078	-	-10.8	0.170	0.50

[+] Bar (-) indicates residual variance exceeds that of the Y-variate.

Table A5. Equations, grouped by ANOVA, of dry weight (g $plant^{-1}$) regressed against total water applied (mm) for 16 millet varieties on the south side of a line source irrigation gradient during the 1984 hot season at Cinzana, Mali.

Line	Entries	Intercept	Slope
1	1, 2, 3, 4, 5, 7, 8, 9, 11, 12, 13, 14, 15, 16	-24.6	0.465
2	6, 10	-11.3	0.228

% of variance accounted for = 53.3

Table A6. Equations, grouped by ANOVA, of dry weight (g plant^{-1}) regressed against total water applied (mm) for 16 sorghum varieties on the south side of a line source irrigation gradient during the 1984 hot season at Cinzana, Mali.

Line	Entries	Intercept	Slope
1	8	-18.7	0.277
2	2,14,16	- 8.8	0.157
3	1,3,4,5,6,7,9, 11,12,13,15	- 9.5	0.132
4	10	- 6.6	0.085

% of variance account for = 58.2

Table A7. of various parameters of 16 millet and sorghum measured in the lab without replication during the 1984 hot season at Cinzana, Mali.

Entry	Millet			Sorghum		
	Germination (%)	Density (%)	Root Hair Vigor+	Germination (%)	Density (%)	Root Hair Vigor
1	92	60	4	92	70	2
2	84	70	4.5	85	20	2
3	85	70	2	83	60	3
4	93	80	2	95	20	5
5	80	100	2	89	30	2
6	66	100	3	80	90	3
7	78	80	3	98	100	1
8	80	50	4	93	70	1
9	56	80	2	75	0	3
10	76	90	3	59	0	3
11	80	70	3	69	40	2
12	85	60	2	64	40	2
13	80	70	4	73	10	2
14	98	90	3	72	50	2
15	100	100	4	80	60	4
16	94	100	3	55	0	2

+ Ranking 1 to 5 with 1 being superior (Maiti et al., 1981)

Table A8. Response of various parameters of 16 millet varieties subjected to high soil temperature stress in charcoal pits during the 1984 hot season at Cinzana, Mali.

Entry	Emergence (%)	Emergence vigor (1-5)[+]	Survival day 10 (%)	Survival vigor day 11	Vitri-osity (1-5)[+]
1	47.0	1.0	38.8	1.3	3.0
2	40.5	1.5	33.3	2.0	3.0
3	51.5	1.3	41.5	2.0	2.5
4	40.0	2.3	31.0	2.8	3.5
5	49.0	1.0	43.8	1.3	3.5
6	40.5	1.8	28.8	2.8	3.8
7	53.0	1.0	43.5	1.0	4.0
8	29.0	3.0	18.5	3.3	3.3
9	34.5	2.0	29.5	3.0	3.0
10	33.0	1.8	20.5	2.8	3.0
11	47.5	1.8	41.0	2.8	4.0
12	33.0	2.5	20.3	4.3	2.3
13	42.0	2.0	32.0	3.0	3.5
14	38.5	1.5	28.0	2.3	3.0
15	48.5	2.3	34.8	3.3	2.5
16	59.0	2.0	48.0	2.8	4.3
Mean	42.9	1.8	33.3	2.5	3.3
S.E.	8.53	0.29	7.10	0.32	0.53

d.f. = 62

[+] Ranking 1 to 5 with 1 being superior (Maiti, et al., 1981)

Ranking 1 to 5 with 1 being superior (House, 1982)

Table A9. Response of various parameters of 16 sorghum varieties subjected to high soil temperature stress in charcoal pits during the 1984 hot season at Cinzana, Mali.

Entry (1-5)++	Emergence (%)	Emergence vigor (1-5)+	Survival day 10 (%)	Survival vigor day 11	Vitri-osity
1	71.0	1.0	50.8	1.3	2.3
2	69.5	1.3	52.5	1.3	4.8
3	65.5	1.3	39.8	2.3	2.3
4	34.5	2.0	16.3	2.8	2.5
5	42.5	2.8	19.0	4.3	3.3
6	52.5	2.0	29.3	2.8	3.5
7	72.5	2.3	47.8	2.8	2.0
8	74.0	1.0	51.8	1.0	2.8
9	58.4	2.8	23.5	3.5	4.5
10	6.5	3.3	0.0	5.0	4.8
11	37.5	3.8	3.0	4.5	3.9
12	37.0	3.0	20.0	4.8	2.5
13	36.8	3.3	20.5	4.3	4.3
14	32.5	1.3	24.3	2.3	1.5
15	25.0	3.5	10.3	4.8	2.3
16	26.0	3.0	13.3	4.0	3.5
Mean	46.3	2.3	26.4	3.2	3.1
S.E.	7.90	0.32	5.73	0.37	0.46

d.f. = 62

+ Ranking 1 to 5 with 1 being superior (Maiti, et al., 1981)

++ Ranking 1 to 5 with 1 being superior (House, 1982)

Table A10. Correlations for various parameters of 16 millet and sorghum varieties subjected to high soil temperature stress in charcoal pits during the 1984 hot season at Cinzana, Mali.

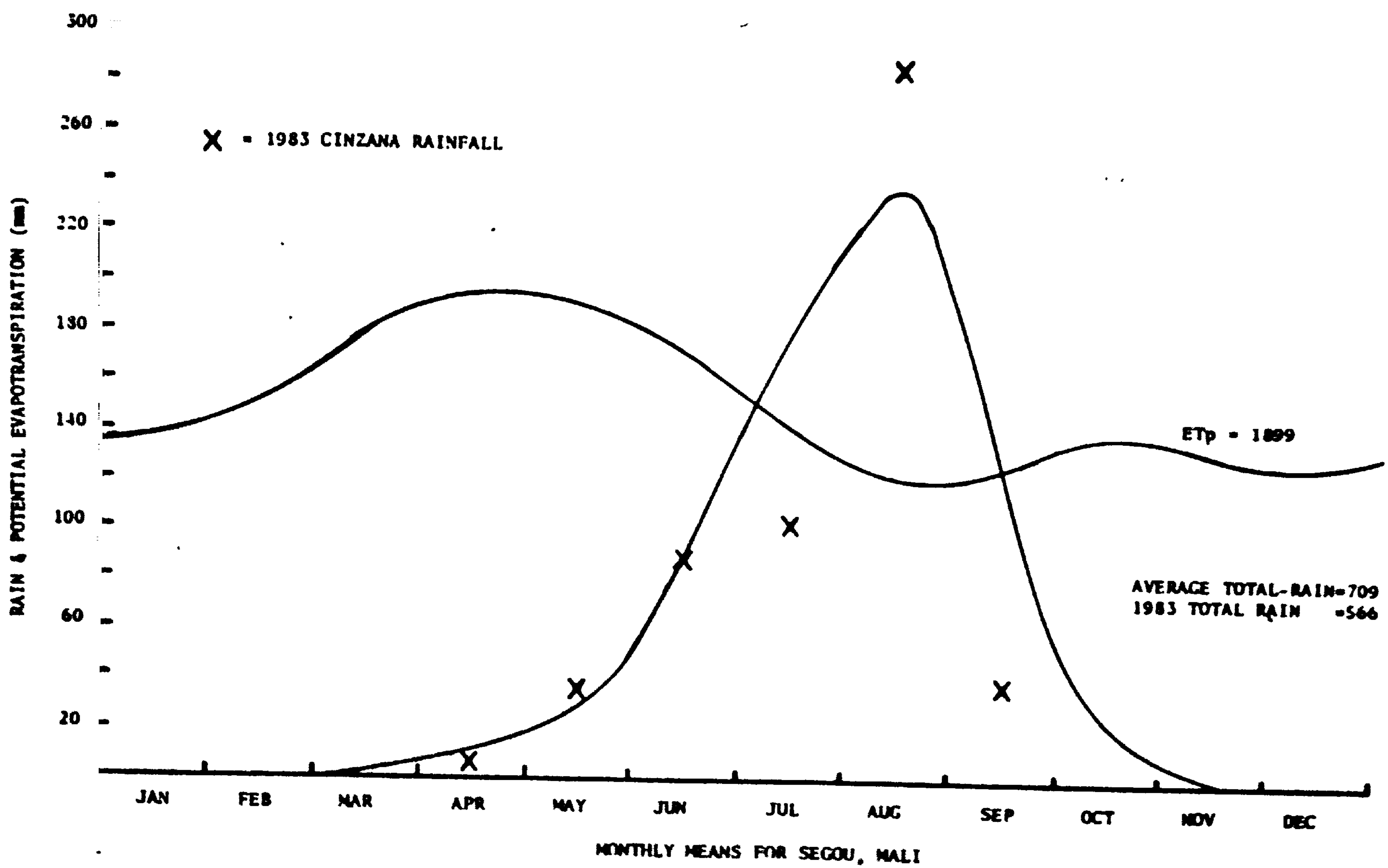
	Emergence (%)	Emergence vigor (1-5)+	Survival day 10 (%)	Survival vigor day 11	Vitri-osity (1-5)++
Millet					
Emerg. (%)	1.000				
Emerg Vig	-0.556**	1.000			
Surv (%)	0.958**	-0.634**	1.000		
Surv Vig	0.640**	0.841**	-0.721**	1.000	
Vitrosity	0.430**	0.168	0.482	-0.419	1.000
Sorghum					
Emerg (%)	1.0000				
Emerg Vig	-0.687**	1.000			
Surv (%)	0.923**	-0.830**	1.000		
Surv Vig	-0.787**	0.953**	-0.881**	1.000	
Vitrosity	-0.180	0.379**	-0.256*	-0.274*	1.000

+ Ranking 1 to 5 with 1 being superior (Maiti, et al., 1981)

++ Ranking 1 to 5 with 1 being superior (House, 1982)

* $0.01 < P < 0.05$

** $P < 0.01$



(after Virmani, Reddy & Bose, 1980)

Figure 1. Mean monthly rainfall and potential evapotranspiration (mm) as a function of time for Segou, Mali (50 km from Cinzana). Data points (X) refer to the 1983 rainfall at Cinzana, Mali.

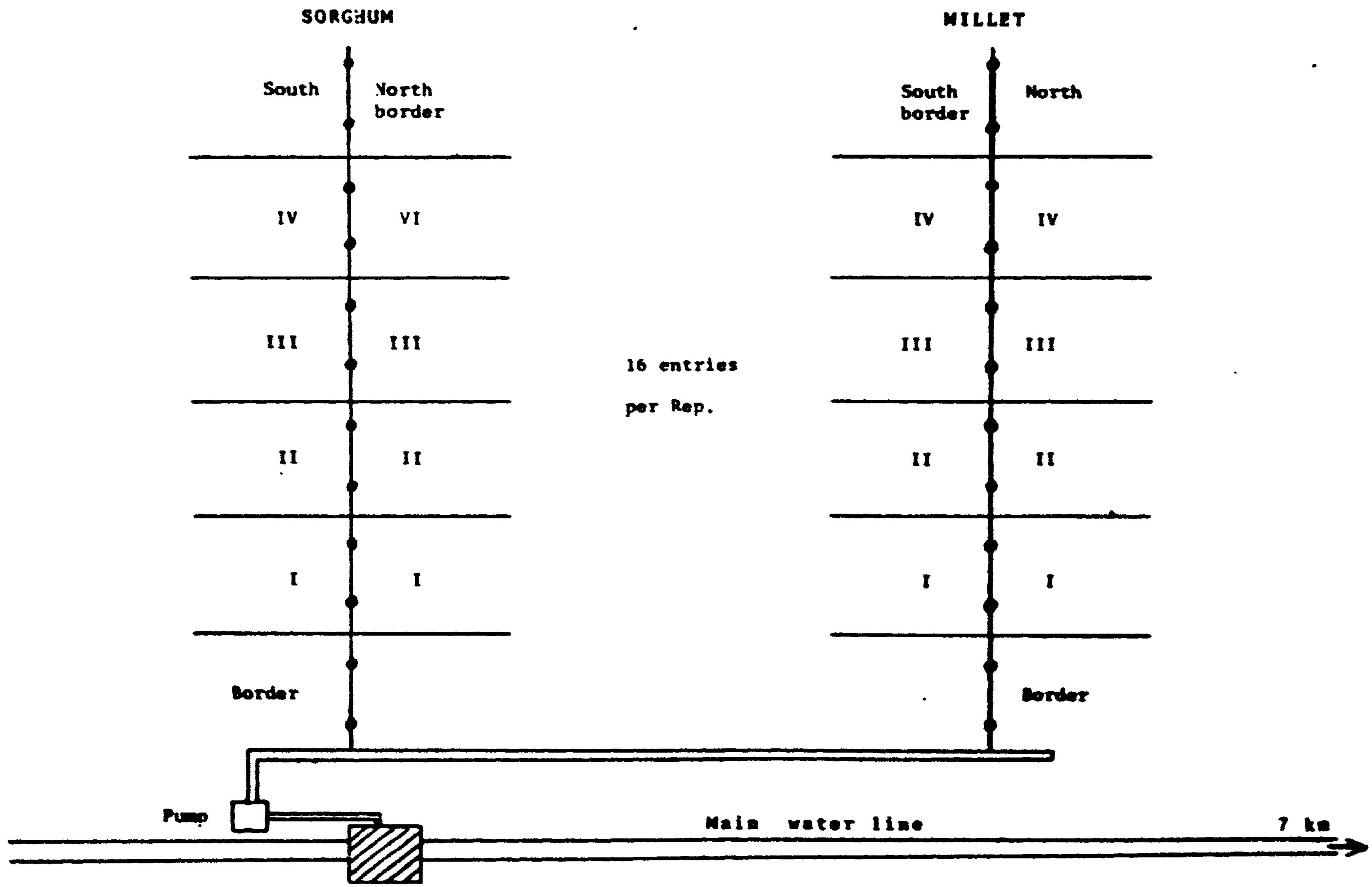


Figure 2. Field plan for 16 millet and sorghum varieties grown under a line source irrigation gradient during the 1984 hot season at Cinzana, Mali.

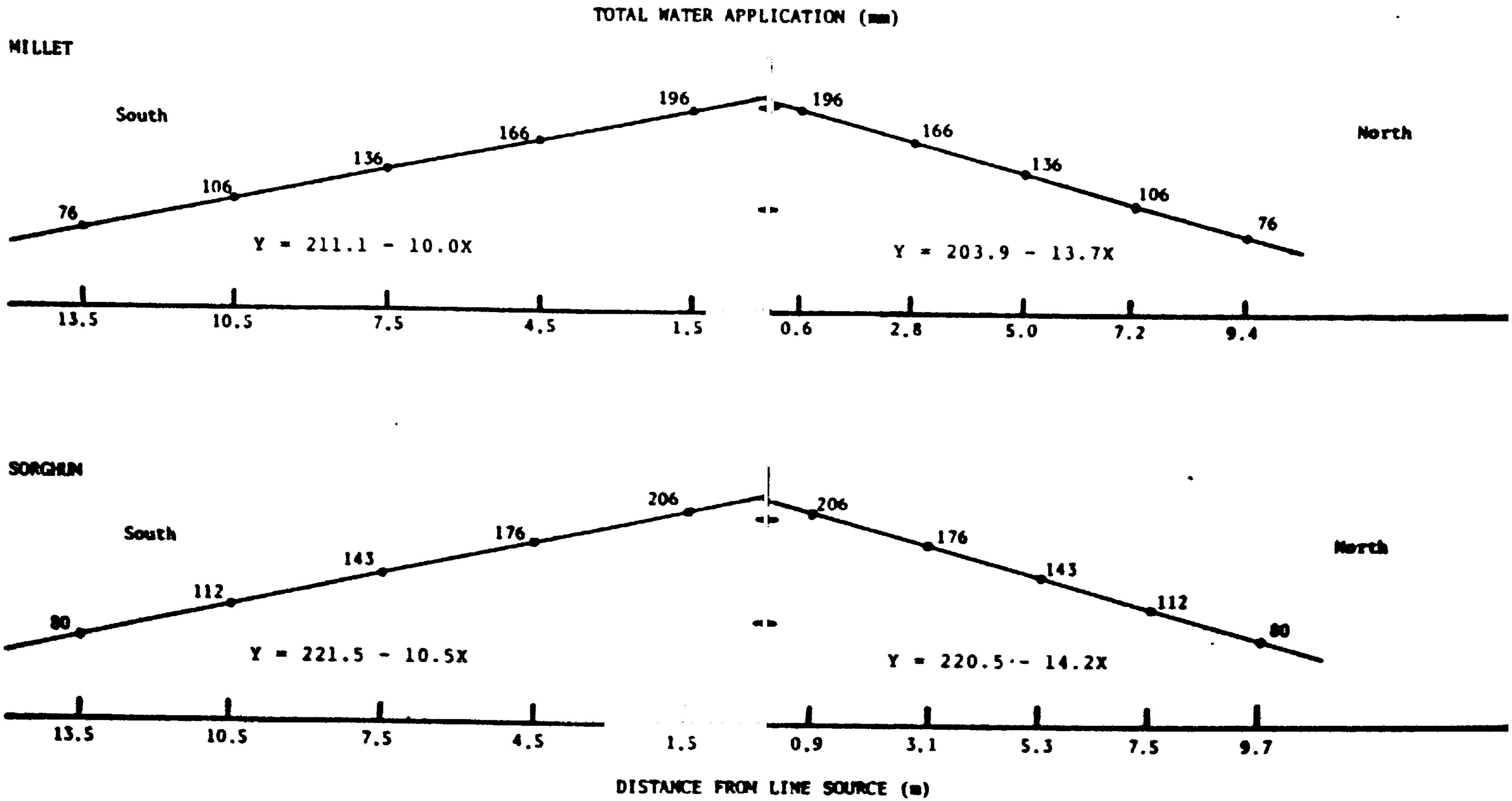


Figure 3. Total water applied to 16 millet and sorghum varieties on the north and south side of a line source irrigation gradient during the 1984 hot season at Cinzana, Mali.

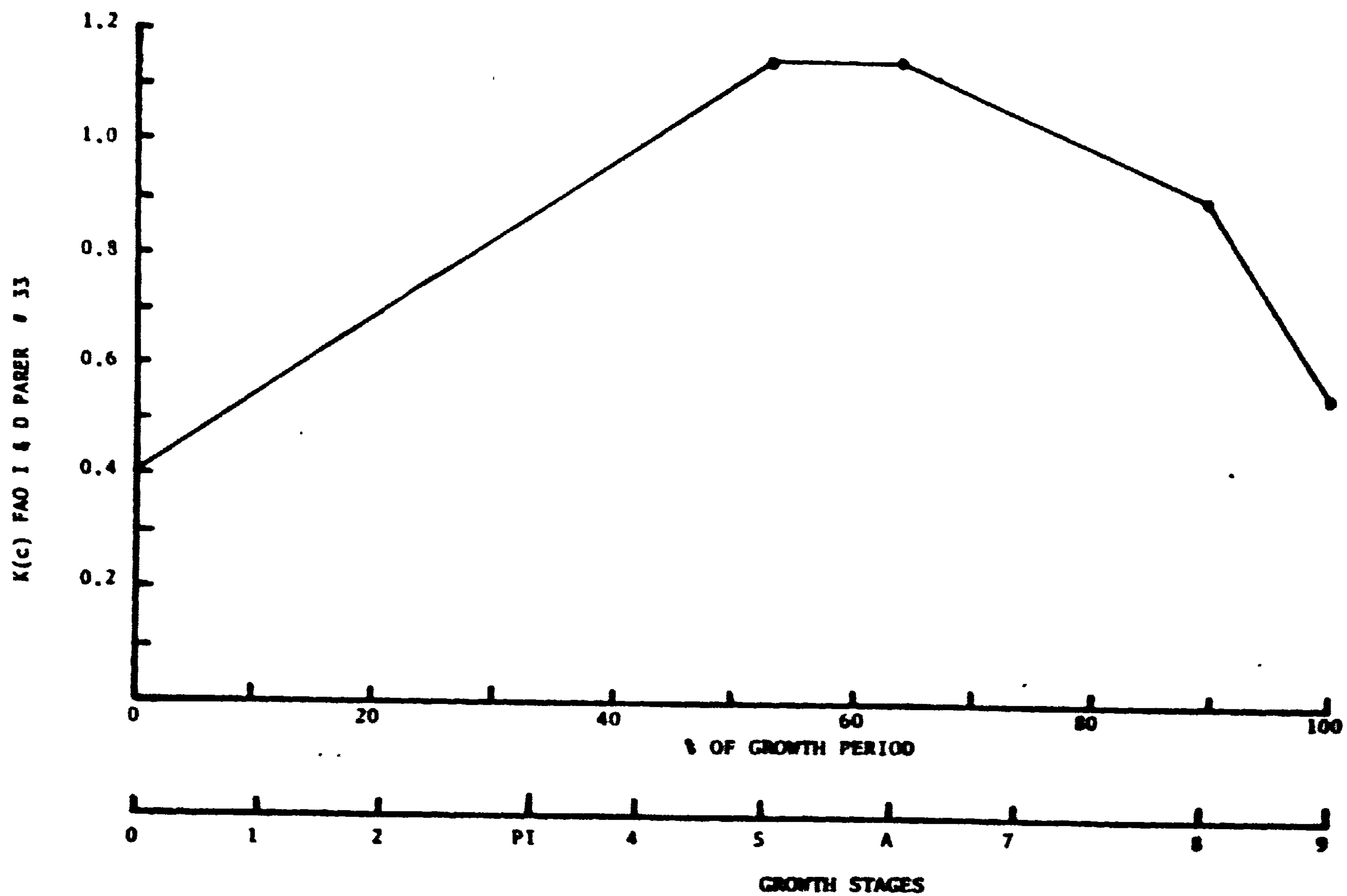


Figure 4. Sorghum crop coefficients (Doorenbos and Kassam, 1979) as a function of estimated percent of growth period and growth stages (Vanderlip and Reeves, 1972).

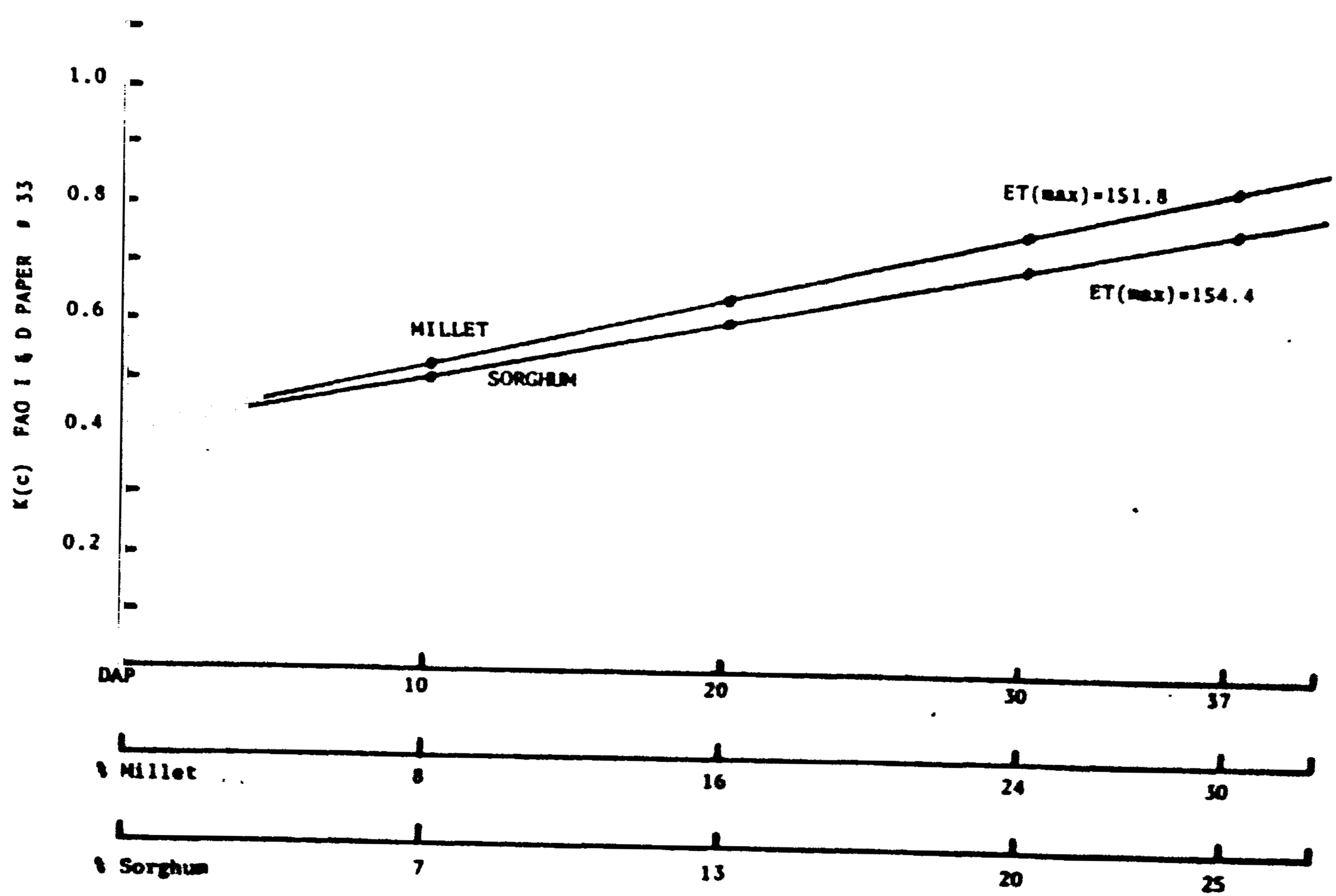


Figure 5. Crop coefficients for millet and sorghum as a function of days after planting (DAP) and percent of growth period assuming 30 and 25 % of growth period finished for millet and sorghum, respectively.

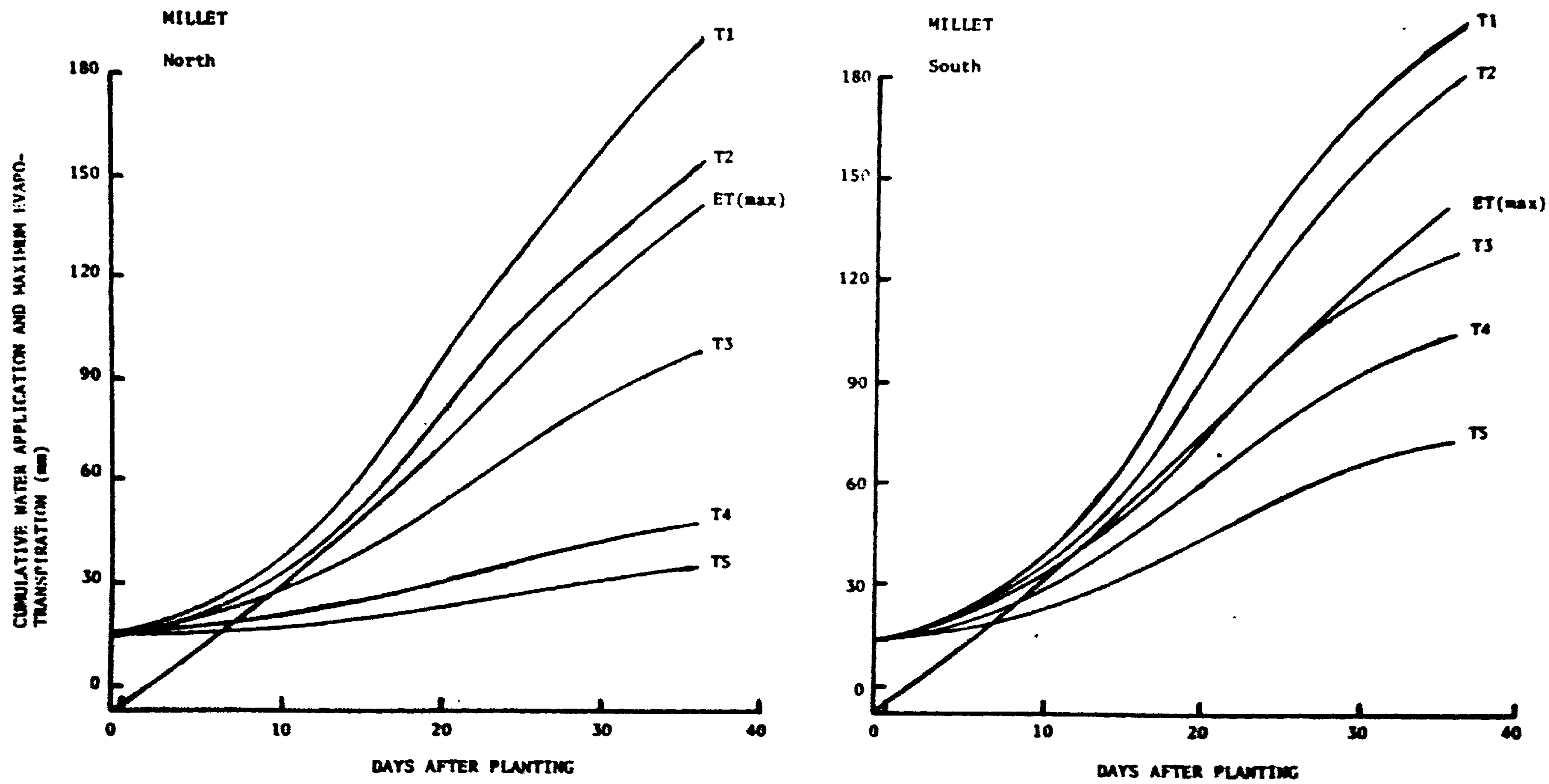


Figure 6. Cumulative water application (mm) to five water treatments (T1-T5) and ET(max) (Doorenbos and Kassam, 1979) as a function time for 16 millet varieties on the north and south side of a line source irrigation gradient during the 1984 hot season at Cinzana, Mali.

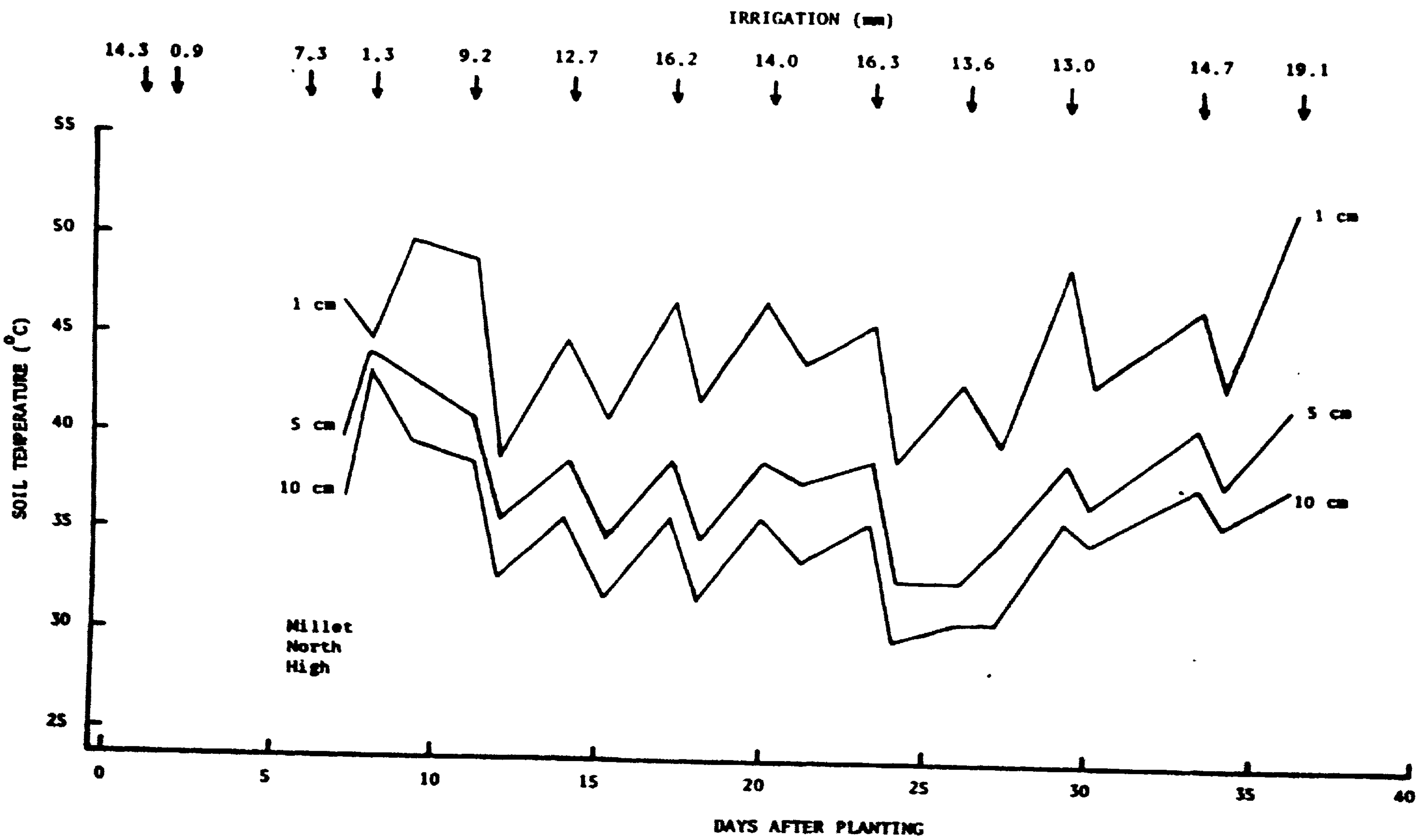


Figure 7. Mean soil temperature (°C) at 1, 5, and 10 cm as a function of time for the high water applcation treatment in the millet on the north side of a line source irrigation gradient during the 1984 hot season at Cinzana, Mali. Arrows at the top of the graph represent irrigation

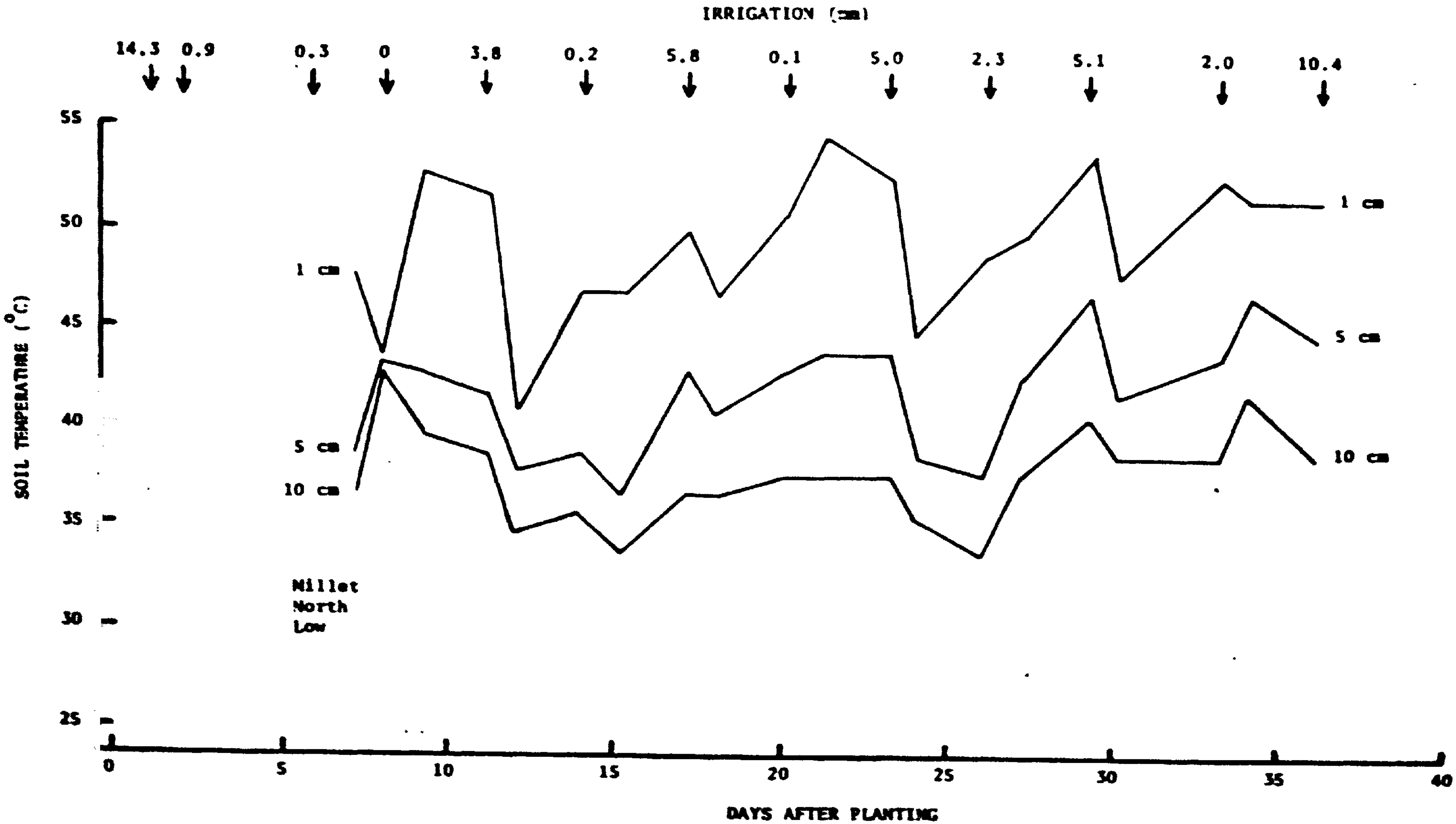


Figure 8. Mean soil temperature (°C) at 1, 5, and 10 cm as a function of time for the low water applcation treatment in the millet on the north side of a line source irrigation gradient during the 1984 hot season at Cinzana, Mali. Arrows at the top of the graph represent irrigation events and quantities applied are given above the arrows.

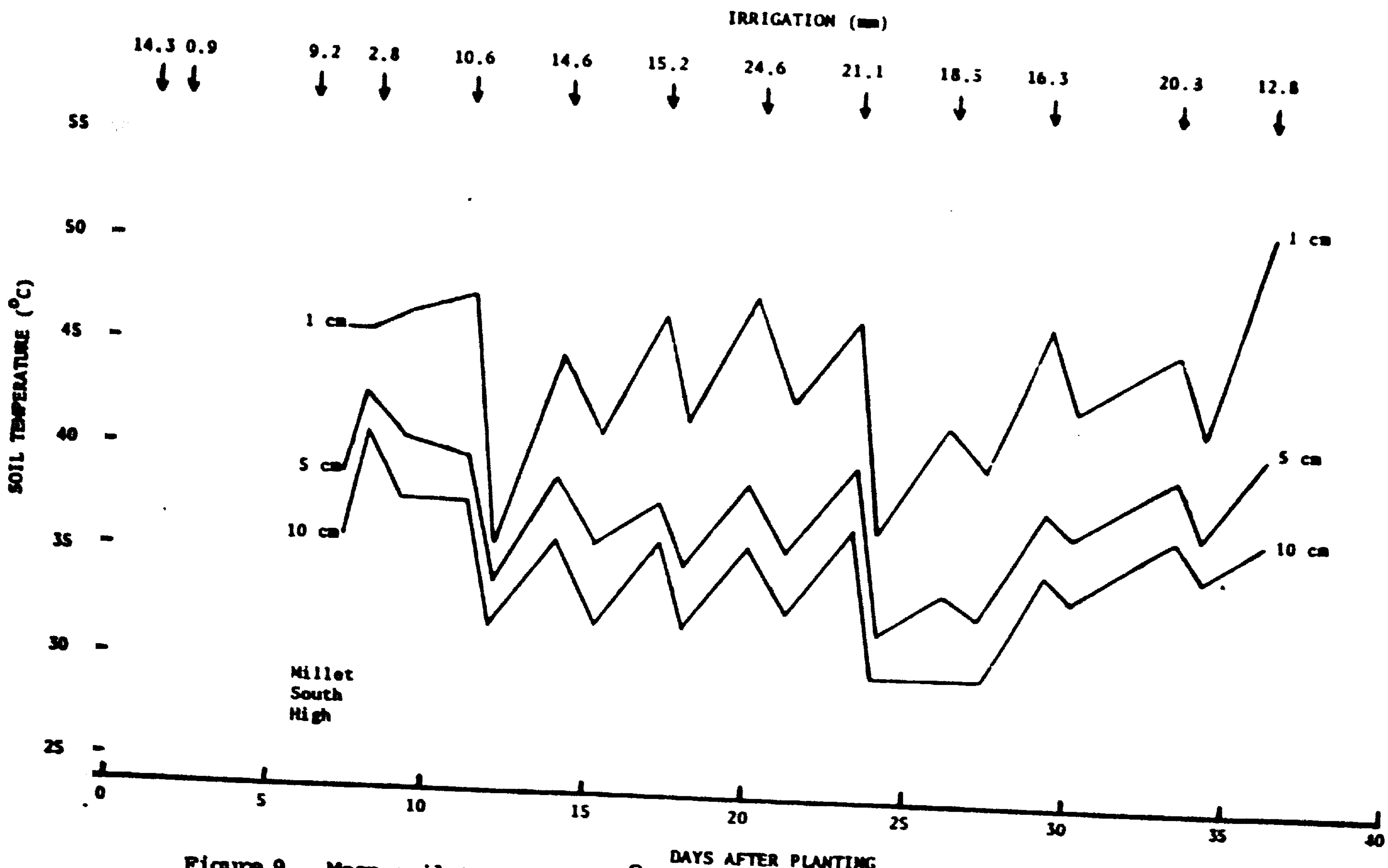


Figure 9. Mean soil temperature (°C) at 1, 5, and 10 cm as a function of time for the high water application treatment in the millet on the south side of a line source irrigation gradient during the 1984 hot season at Cinzana, Mali. Arrows at the top of the graph represent irrigation events and quantities applied are given above the arrows.

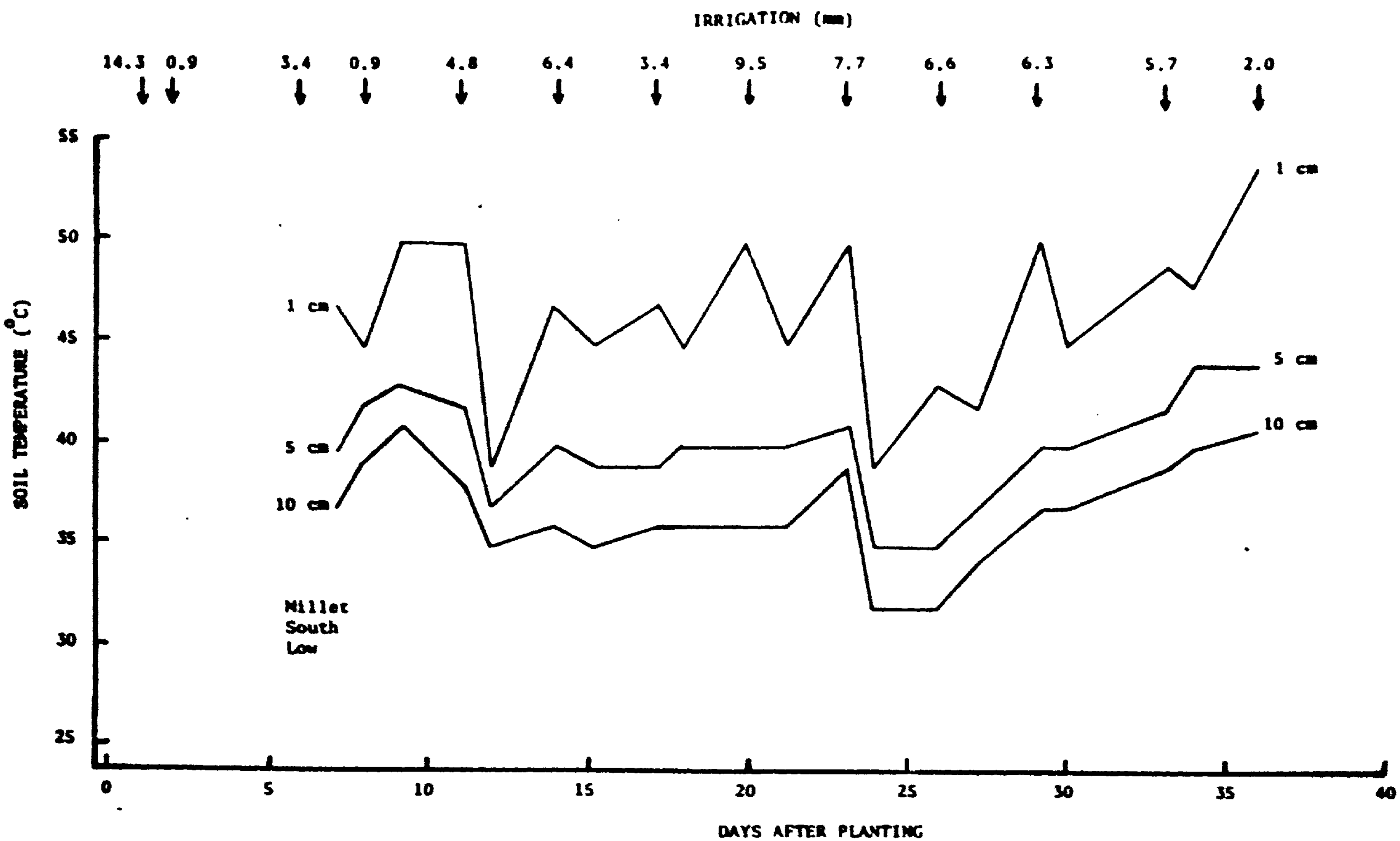


Figure 10. Mean soil temperature (°C) at 1, 5, and 10 cm as a function of time for the low water applcation treatment in the millet on the south side of a line source irrigation gradient during the 1984 hot season at Cinzana, Mali. Arrows at the top of the graph represent irrigation events and quantities applied are given above the arrows.

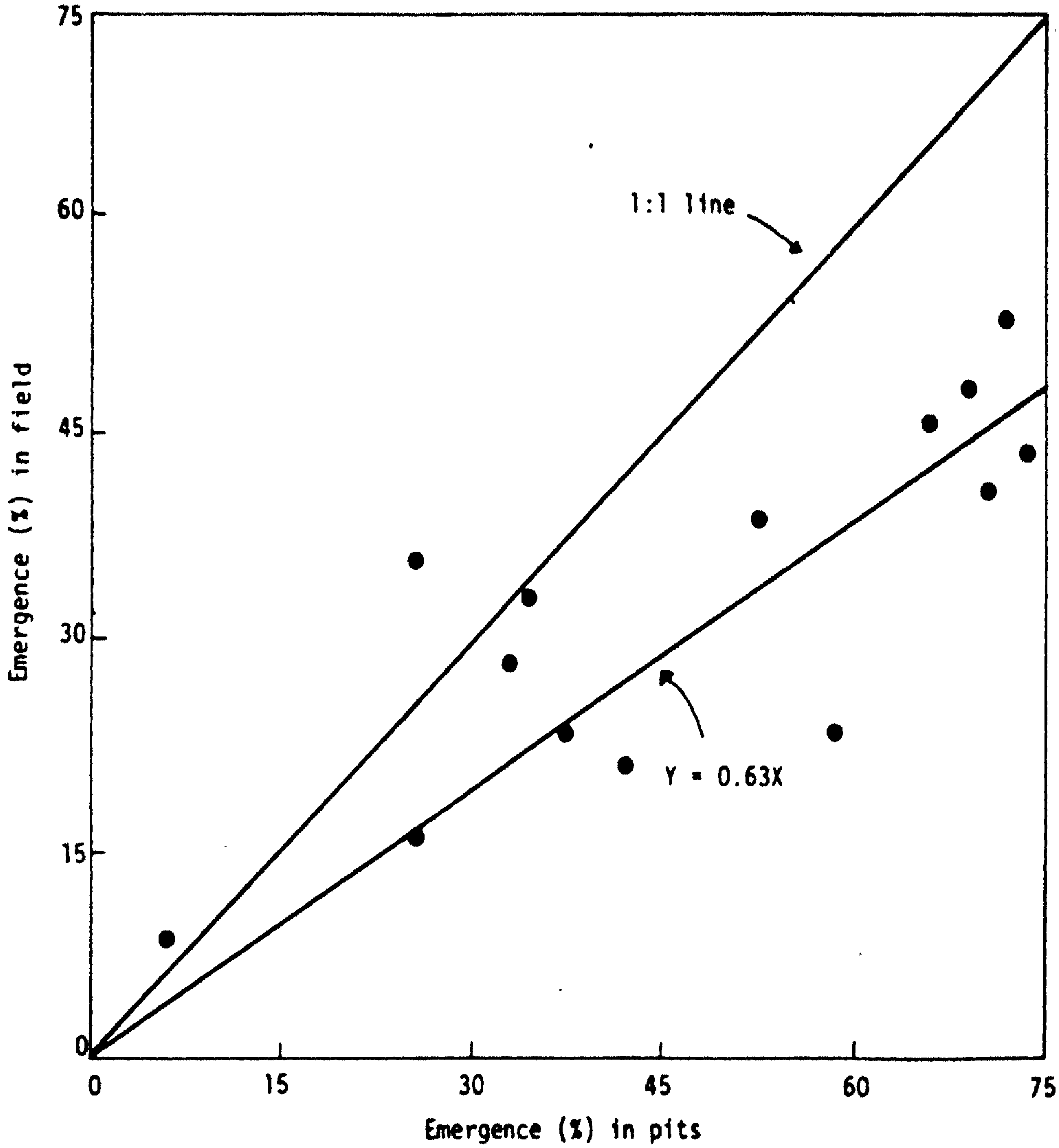


Figure 11. Mean % emergence of 16 sorghum varieties in charcoal pits vs % emergence in the low water application treatment of a field line source irrigation gradient.

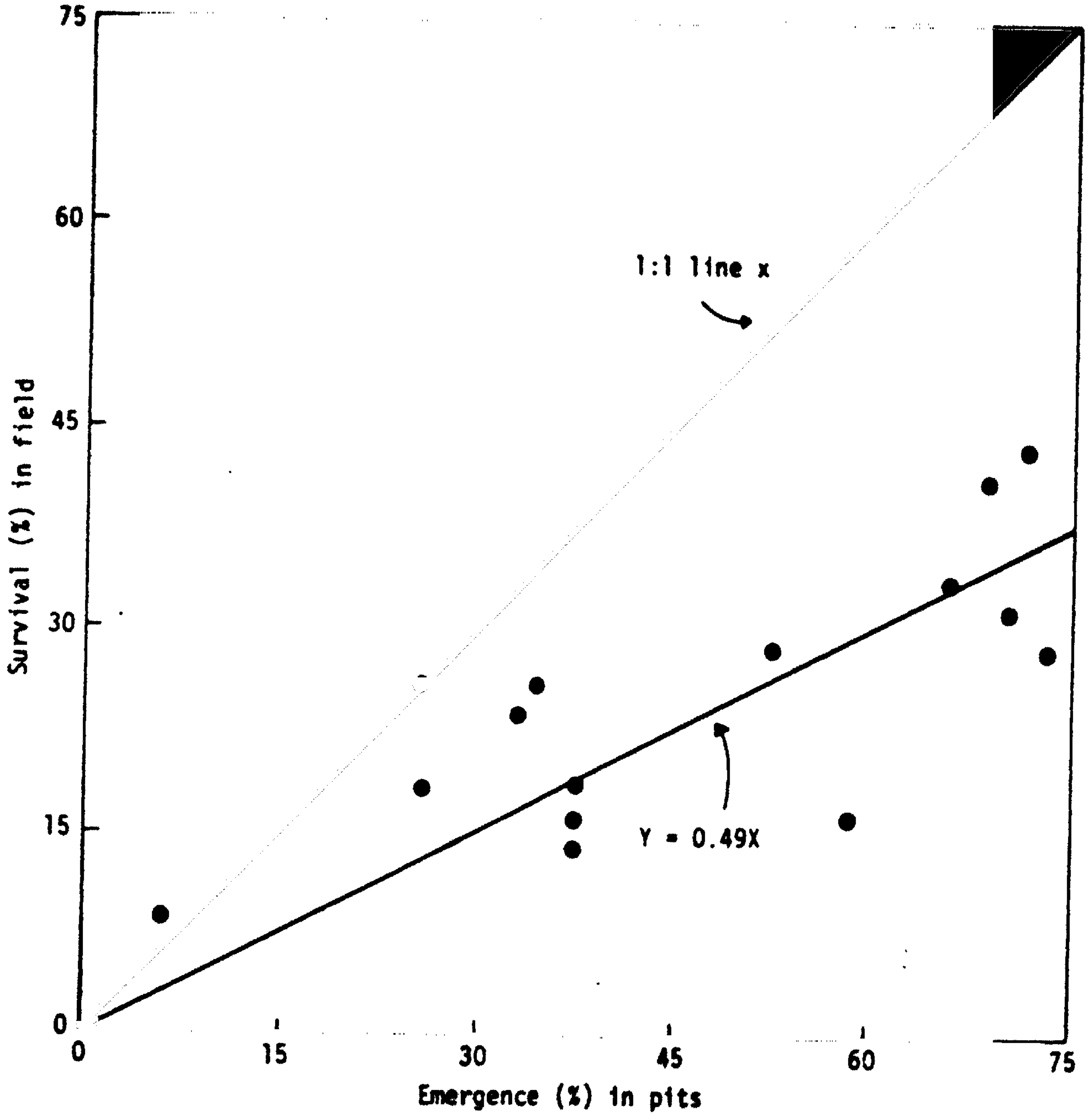


Figure 12. Mean % emergence of 16 sorghum varieties in charcoal pits vs % survival in the low water application treatment of a field line source irrigation gradient.