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9. ABSTRACT

In the development of improved high-yielding sorghum cultivars, cooperative research was conducted by teams from the University of Nebraska; North Central Region, ARS, USDA; the Rockefeller Foundation; and U.S.A.I.D.. Investigations carried out during this year were: Mead Experiment Station climatic data for 1975; dryland response of six grain sorghum hybrids grown at three plant populations; sorghum-soybean cropping systems; influence of seed size and density on germination, seedling emergence, and yield of grain sorghum; growth, yield, and nitrogen update in grain sorghum grown under varying rates of mulch; screening sorghum genotypes for differential uptake and utilization of phosphorus and iron; the effects of lodging on yield, protein, and test weight of grain sorghum; effect of high temperature on photosynthesis rate of sorghum and corn genotypes; stomatal and non-stomatal inhibition of photosynthesis at high temperatures in sorghum; studies of nitrate reductase activity in sorghum in relation to heat stress; caryopsis development in two sorghum hybrids and a line; the effect of induced high temperatures on sorghum grain development; relationship between laboratory and field observations of sorghum seedlings grown under cold temperatures; whole plant respiration in grain sorghum; energy quantities and time periods associated with sorghum stages; selection for protein in grain sorghum; and sorghum breeding and genetics. No general conclusions or recommendations are given.

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Annual Report No. 9

Research in

DEVELOPMENT OF IMPROVED HIGH-YIELDING SORGHUM CULTIVARS

February 12, 1975—February 11, 1976

Cooperative Research
by
The University of Nebraska
North Central Region, ARS, USDA
The Rockefeller Foundation
Agency for International Development
of the U.S. Department of State

TABLE OF CONTENTS

	Page
Acknowledgements	i
Contributing Personnel	iii
INVESTIGATIONS:	
Mead Experiment Station Climatic Data for 1975.	1
Dryland Response of Six Grain Sorghum Hybrids Grown at Three Plant Populations	16
Sorghum-Soybean Cropping Systems	20
Influence of Seed Size and Density on Germination, Seedling Emergence and Yield of Grain Sorghum	24
Growth, Yield and Nitrogen Uptake in Grain Sorghum Grown Under Varying Rates of Mulch.	29
Screening Sorghum Genotypes for Differential Uptake and Utilization of Phosphorus and Iron.	39
The Effects of Lodging on Yield, Protein, and Test Weight of Grain Sorghum	55
Effect of High Temperature on Photosynthesis Rate of Sorghum and Corn Genotypes.	61
Stomatal and Non-Stomatal Inhibition of Photosynthesis at High Temperatures in Sorghum	69
Studies of Nitrate Reductase Activity in Sorghum in Relation to Heat Stress	87

Page

Caryopsis Development in Two Sorghum Hybrids and a Line . 96

The Effect of Induced High Temperatures on Sorghum Grain Development 115

Relationship Between Laboratory and Field Observations of Sorghum Seedlings Grown Under Cold Temperatures 137

Whole Plant Respiration in Grain Sorghum 146

Energy Quantities and Time Periods Associated with Sorghum Stages 150

Selection for Protein in Grain Sorghum 158

Sorghum Breeding and Genetics 166

Publications 189

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A later in-house review was also very productive. Outside reviewers contributing were Dr. S. A. Eberhart (Funks International), Dr. A. B. Maunder (DeKalb AgResearch Inc.), Dr. G. Simpson (University of Saskatchewan), Mr. Richard Lewis (Nebraska State Senator, Mr. Clare Porter (representing Governor J. J. Exon), Mr. Danny Smith (graduate student representative) and University of Nebraska Regent Robert Raun. Their efforts are much appreciated.

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Thanks is due to many individuals in federal, state, and private agencies for consultation and suggestions in our research program. Finally, the research accomplishments would not have been possible without the dedicated, hard work of the technicians and hourly help who conscientiously helped perform the experiments, and to our secretary, Mrs. Betty Plamondon, for typing and other assistance in preparing the Report.

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MEAD EXPERIMENT STATION CLIMATIC DATA FOR 1975

M. D. Clegg

Variations in climate influences many physiological processes in plants. It is necessary then to have records of various climatic data to aid in interpretations of experimental results. Weather data from the Mead Experiment Station has been summarized using the Statistical Analysis System (SAS) developed at North Carolina State University (1). This system has the capabilities of many statistical analyses and data plotting. A minimum knowledge in computer programing is all that is necessary for one to be able to use it.

PROGRAM DICTIONARY AND METHODS

Because the system can only take names up to eight characters various abreviated names are used. The data collected was also converted to metric system units. The following names and units have been used for the various variables.

Air temperature (C).

Maximum - A MAX

Minimum - A MIN

Average Maximum-Minimum - - - - - - - - - - - AVE TEMP

Soil temperature (C) at a depth of 5 cm

Grass Covered soil.

Maximum - G MAX

Minimum - G MIN

Average Maximum-Minimum - - - - - - - - - - - AVE GRT

Bare soil.

Maximum - B MAX

Minimum - B MIN

Average Maximum-Minimum - - - - - - - - - - - - - - - - - - AVE BRT

Rainfall (cm/week) - RAIN

Accumulated Rainfall (cm)- - - - - - - - - - - - - - - - - - ARAIN

Evaporation, Class A pan (cm/week) - - - - - - - - - - EVAP

Accumulated Evaporation (cm) - - - - - - - - - - - - - - - AEVAP

Wind (km/week) - WIND

Accumulated Wind (km)- AWIND

Growing degree units (GDU's/week)- - - - - - - - - - GDU

Accumulated growing degree units (GDU's) - - - - AGDU

Growing degree units (GDU'S) were calculated using a base temperature of 15.5 C by the equation:

$$GDU = [(A\ MAX + A\ MIN)/2] - 15.5$$

The season described started March 1 and ended October 31. Evaporation data started March 15 and ended October 15. Weeks describe a seven day interval. The month and days for each week are as follows:

Week 1	March 1-7	Week 8	April 19-25
" 2	" 8-14	" 9	" May 2
" 3	" 15-21	" 10	May 3-9
" 4	" 22-28	" 11	" 10-16
" 5	" 29- April 4	" 12	" 17-23
" 6	April 5-11	" 13	" 24-30
" 7	" 12-18	" 14	" 31-June 6

Week 15	June 7-13	Week 26	Aug 23-29
" 16	" 14-20	" 27	" 30-Sept. 5
" 17	" 21-27	" 28	Sept 6-12
" 18	" 28-July 4	" 29	" 13-19
" 19	July 5-11	" 30	" 20-26
" 20	" 12-18	" 31	" 27-Oct. 3
" 21	" 19-25	" 32	Oct 4-10
" 22	" 26-Aug 1	" 33	" 11-17
" 23	Aug 2-8	" 34	" 18-24
" 24	9-15	" 35	" 25-31
" 25	16-22		

DISPLAY OF DATA

Figures 1-9 are average maximum-minimum temperature, growing degree units (15.5 C base temperature), accumulative growing degree units, precipitation, accumulative precipitation, pan evaporation, accumulative pan evaporation, wind and accumulative wind respectively. Superimposed upon each figure is the approximate planting period, the period when the crop is blooming and the harvest period.

Note that planting begins approximately when the average maximum-minimum temperature is 15.5° C, Figure 1. Growing degree units per week using 15.5 C as a base temperature also define the growing season, Figure 2.

Rainfall shows good distribution, but the amount per week after planting never exceeded 2.5 cm until mid August, Figure 4. The fall was exceptionally dry.

Evaporation exceeded 5 cm per week and at times evaporation exceeded 6 cm, figure 6. Note also evaporation was very high during the fall. This resulted in grain being harvested with low moisture and minimized drying. The total amount of rainfall for the season beginning March 1 and ending October 31 was 36 cm. Over this same period the evaporation

of water from a free surface was 123 cm. If a crop loses water by a factor of 0.8 x 123 cm through transpiration, then this would be approximately 3 times the amount of rainfall received during the season. Thus, good soil moisture storage must occur for adequate moisture to be available for a crop. The efficiency of water used can be increased by planting the proper maturity hybrids at a proper plant population and row spacing.

Table 1 contains the actual printout of the data. It also contains grass covered and bare soil temperature data.

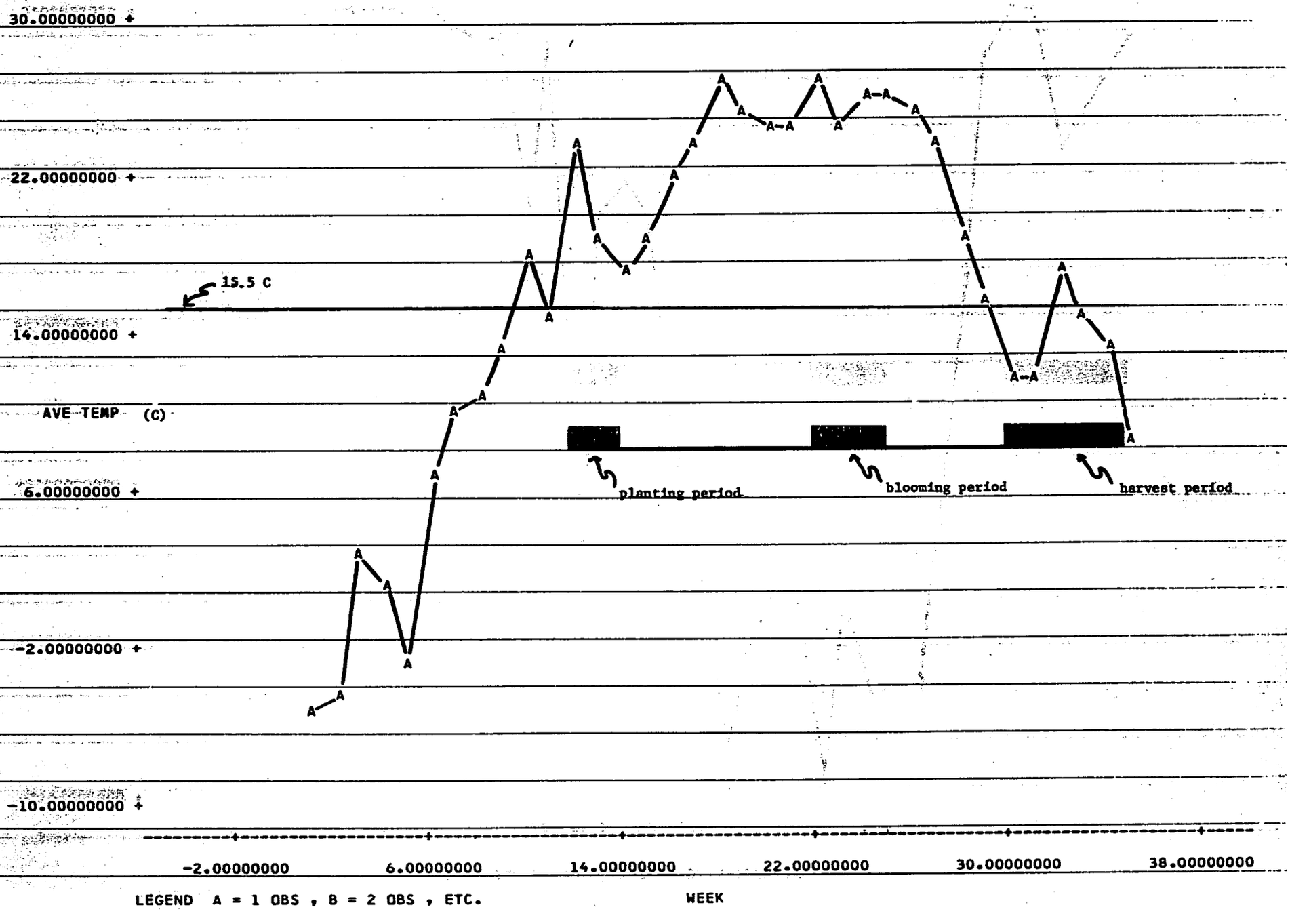
LITERATURE CITED

1. Barr, James and J. H. Goodnight. 1972. A user's guide to the statistical analysis system. Dept. of Statistics, North Carolina State University.

1975 MEAD WEATHER STATION DATA SUMMARY

Figure 1

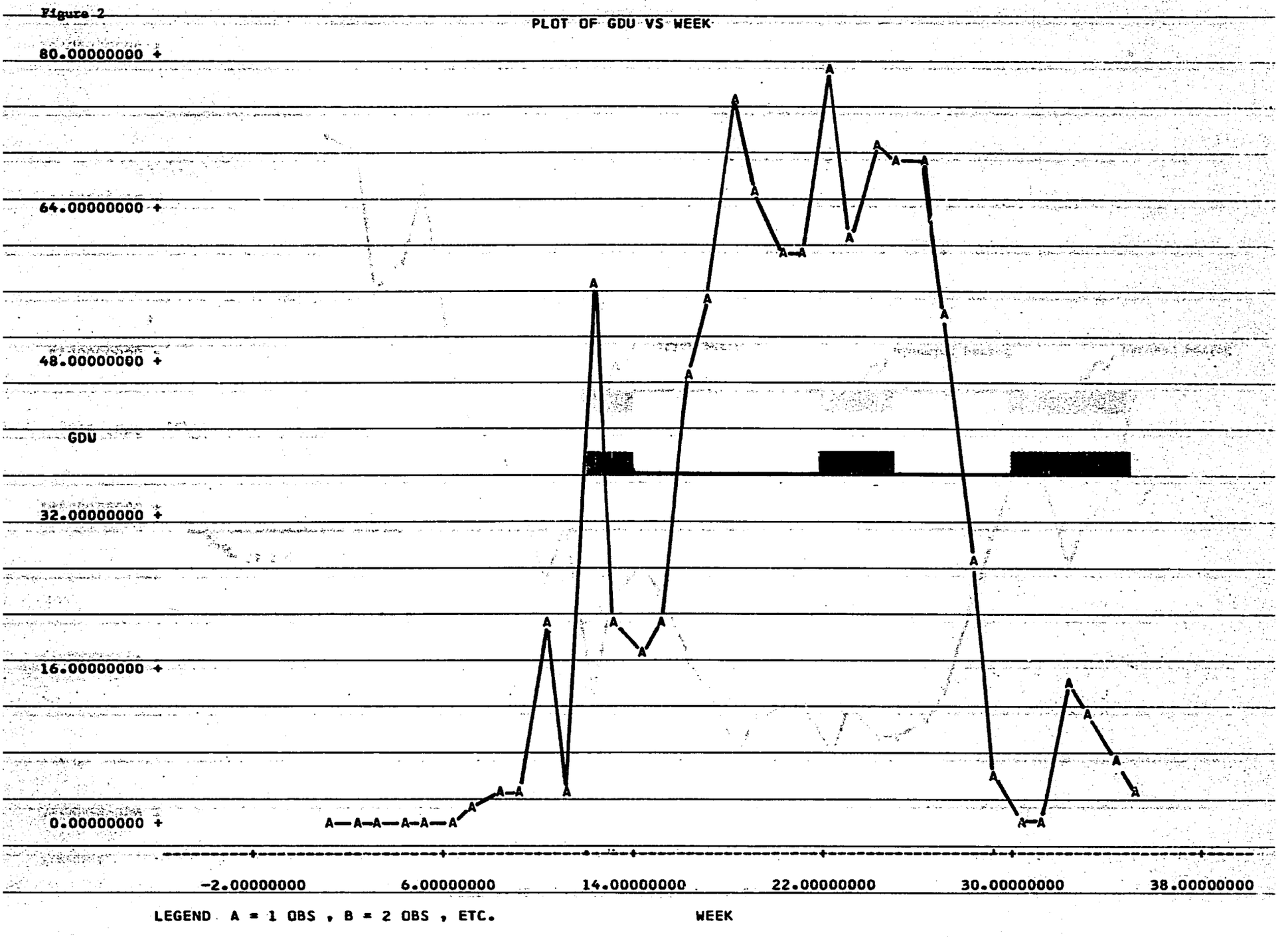
PLOT OF AVE TEMP VS WEEK



LEGEND A = 1 OBS , B = 2 OBS , ETC.

1975 MEAD WEATHER STATION DATA SUMMARY

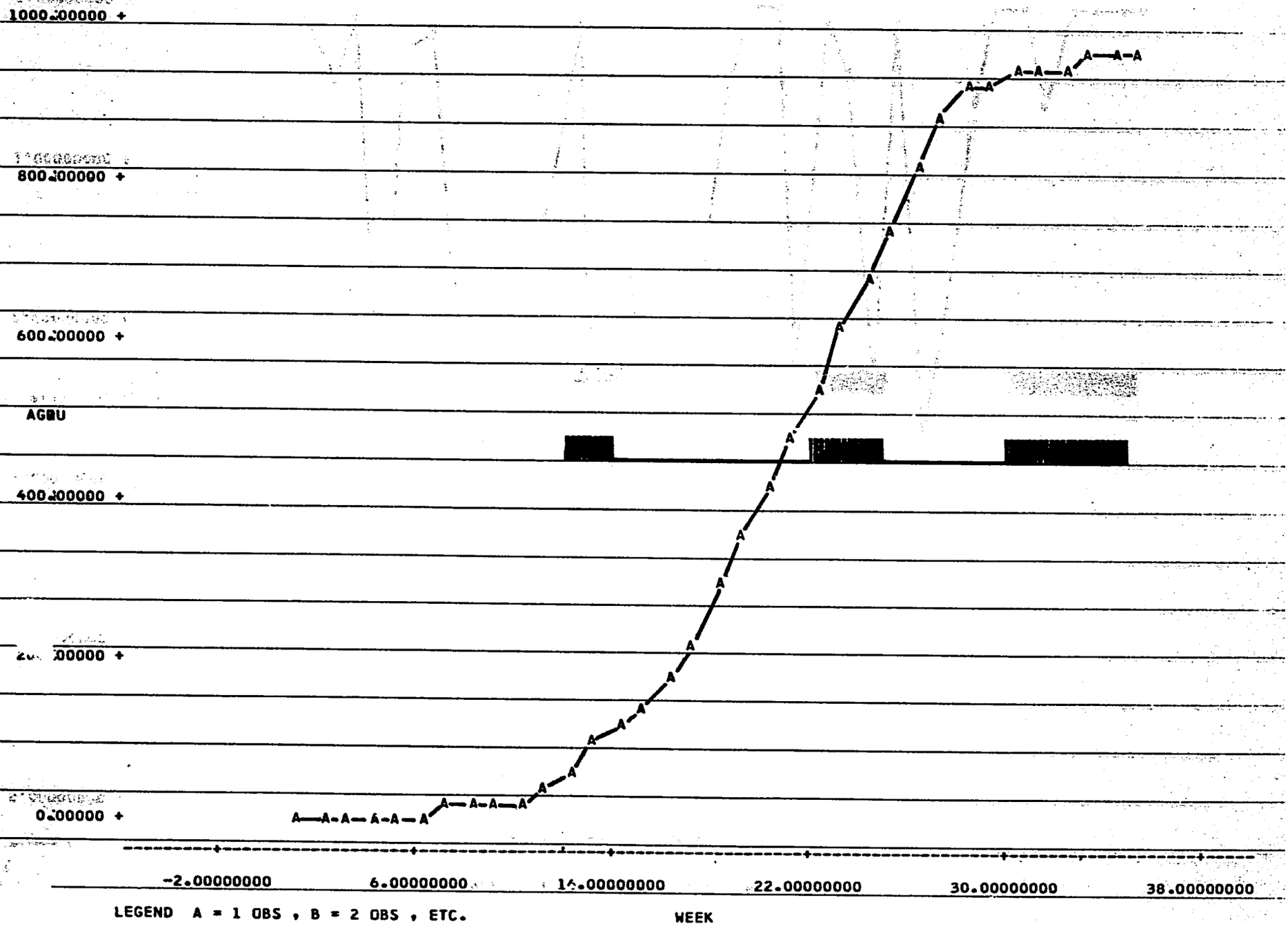
Figure 2



1975 MEAD WEATHER STATION DATA SUMMARY

Figure 3

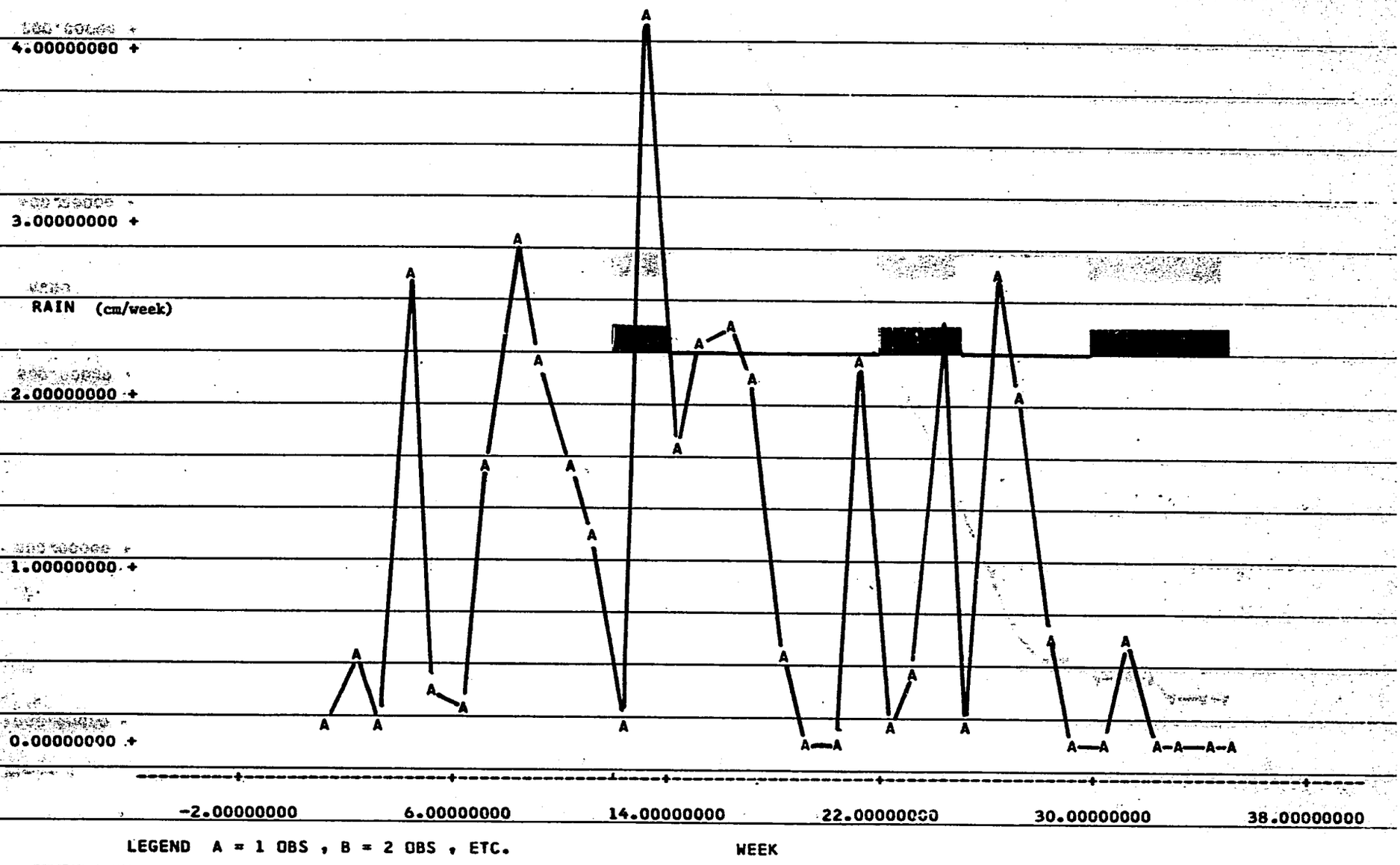
PLOT OF AGDU VS WEEK



1975 MEAD WEATHER STATION DATA SUMMARY

Figure 4

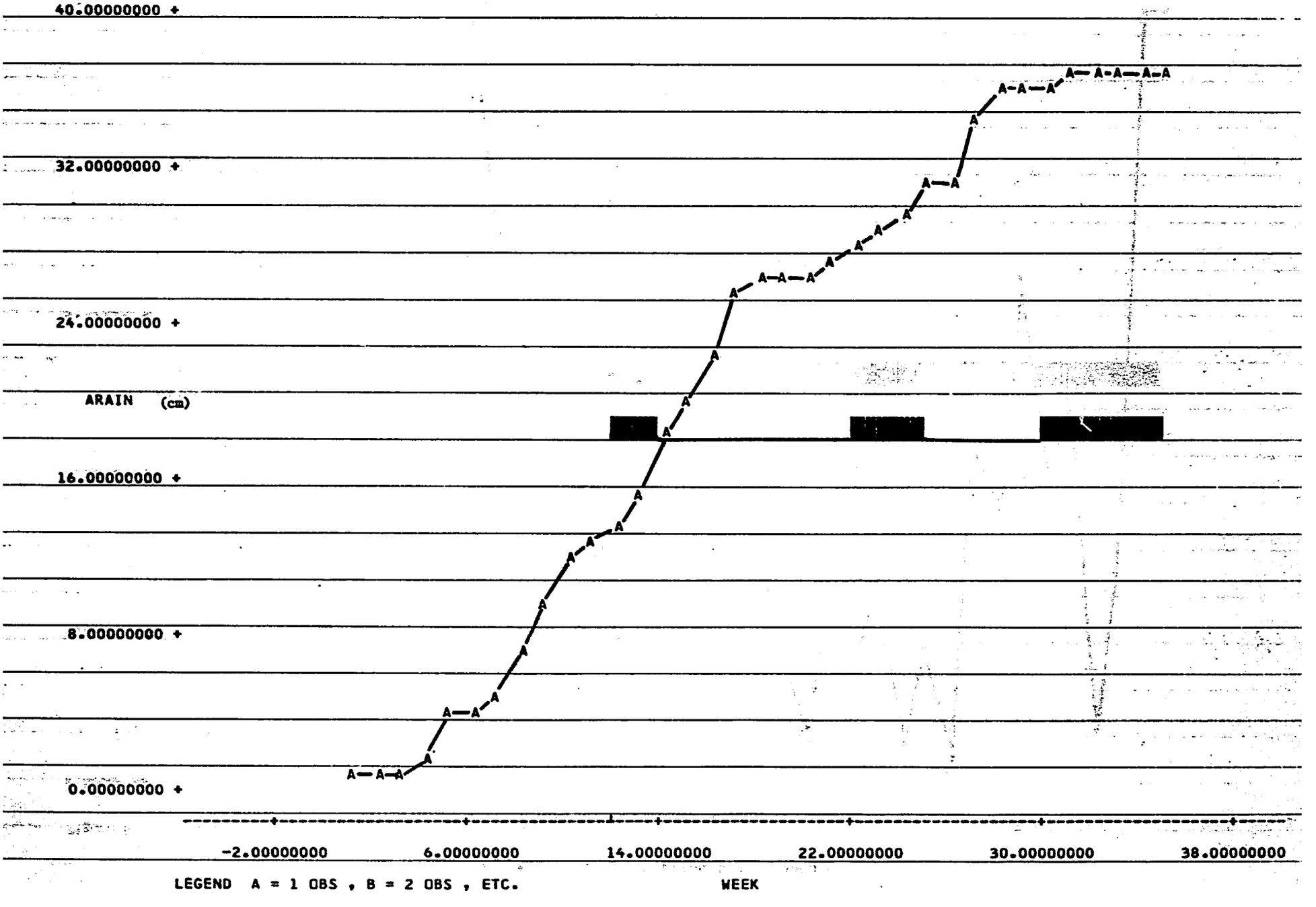
PLOT OF RAIN VS WEEK



1975 MEAD WEATHER STATION DATA SUMMARY

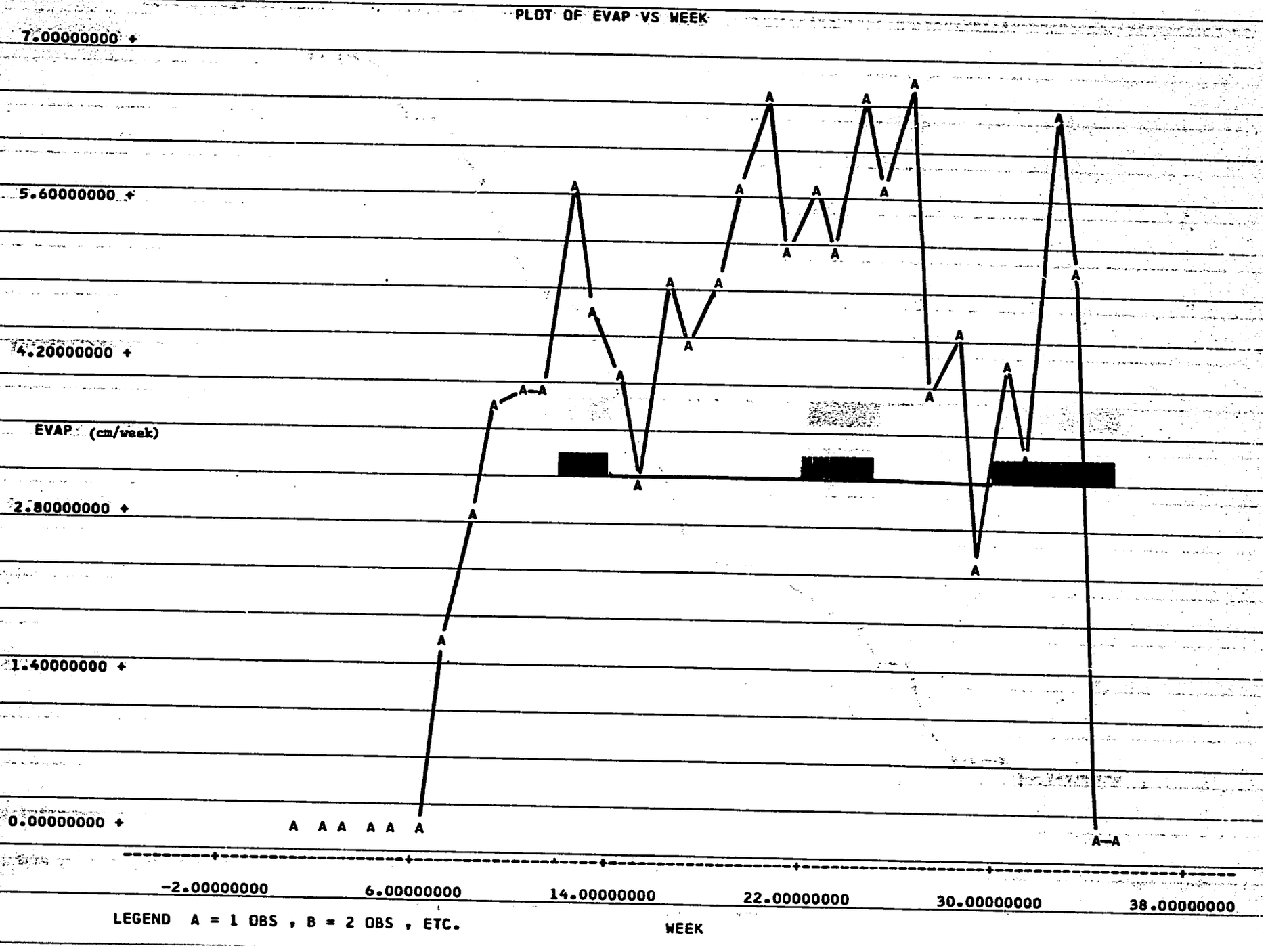
Figure 5

PLOT OF ARAIN VS WEEK



1975 MEAD WEATHER STATION DATA SUMMARY

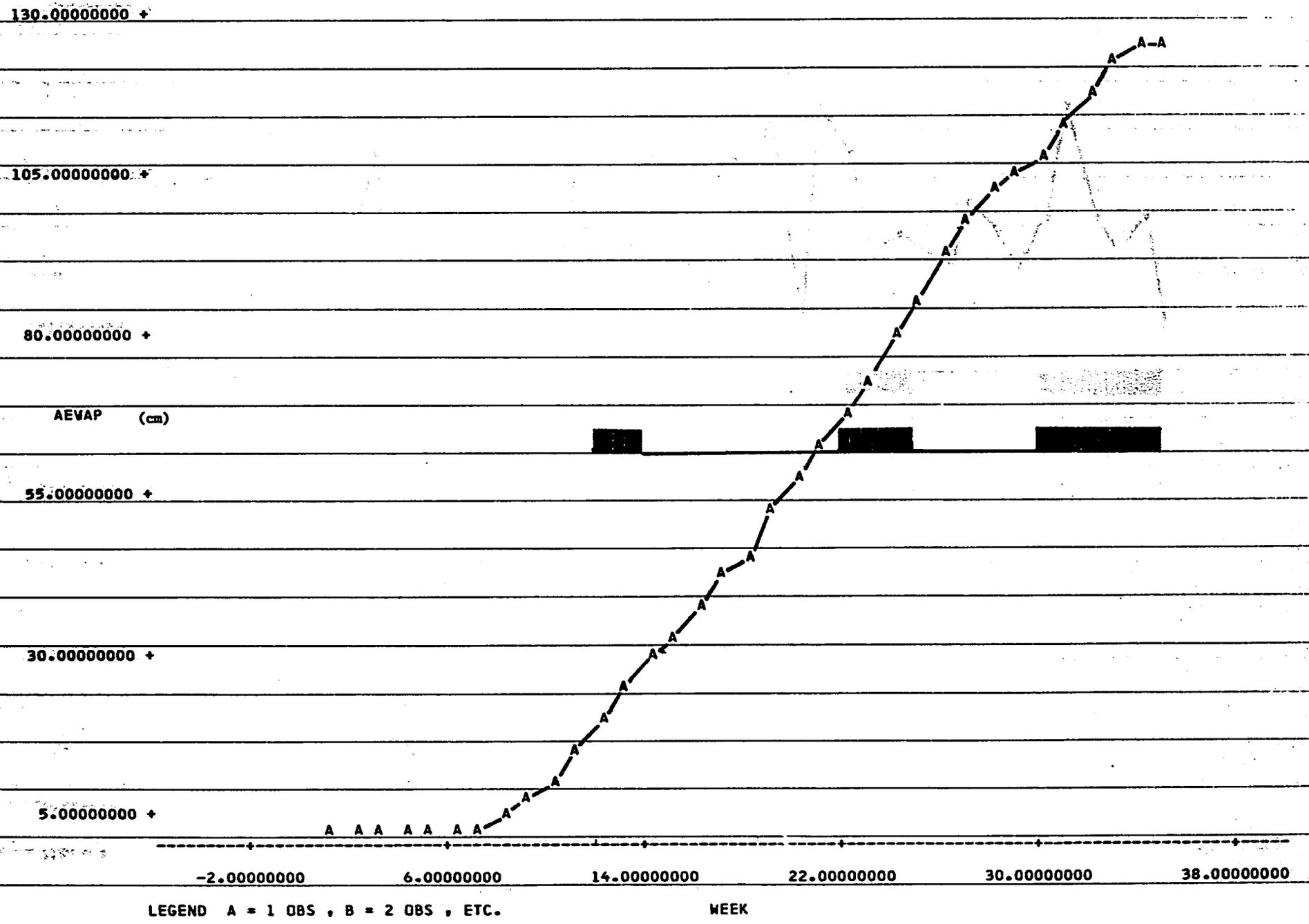
Figure 6



1975 MEAD WEATHER STATION DATA SUMMARY

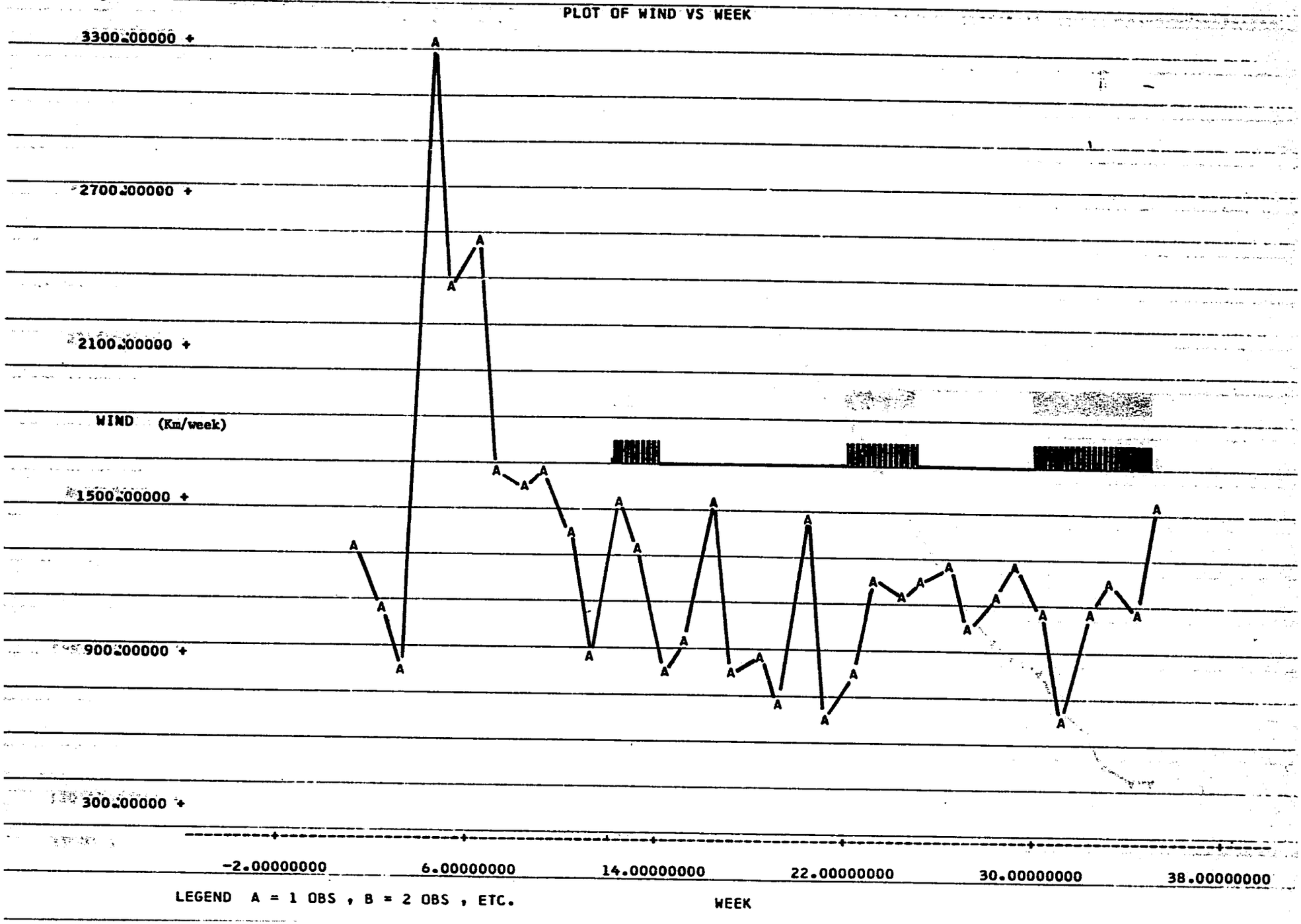
Figure 7

PLOT OF AEVAP VS WEEK



1975 MEAD WEATHER STATION DATA SUMMARY

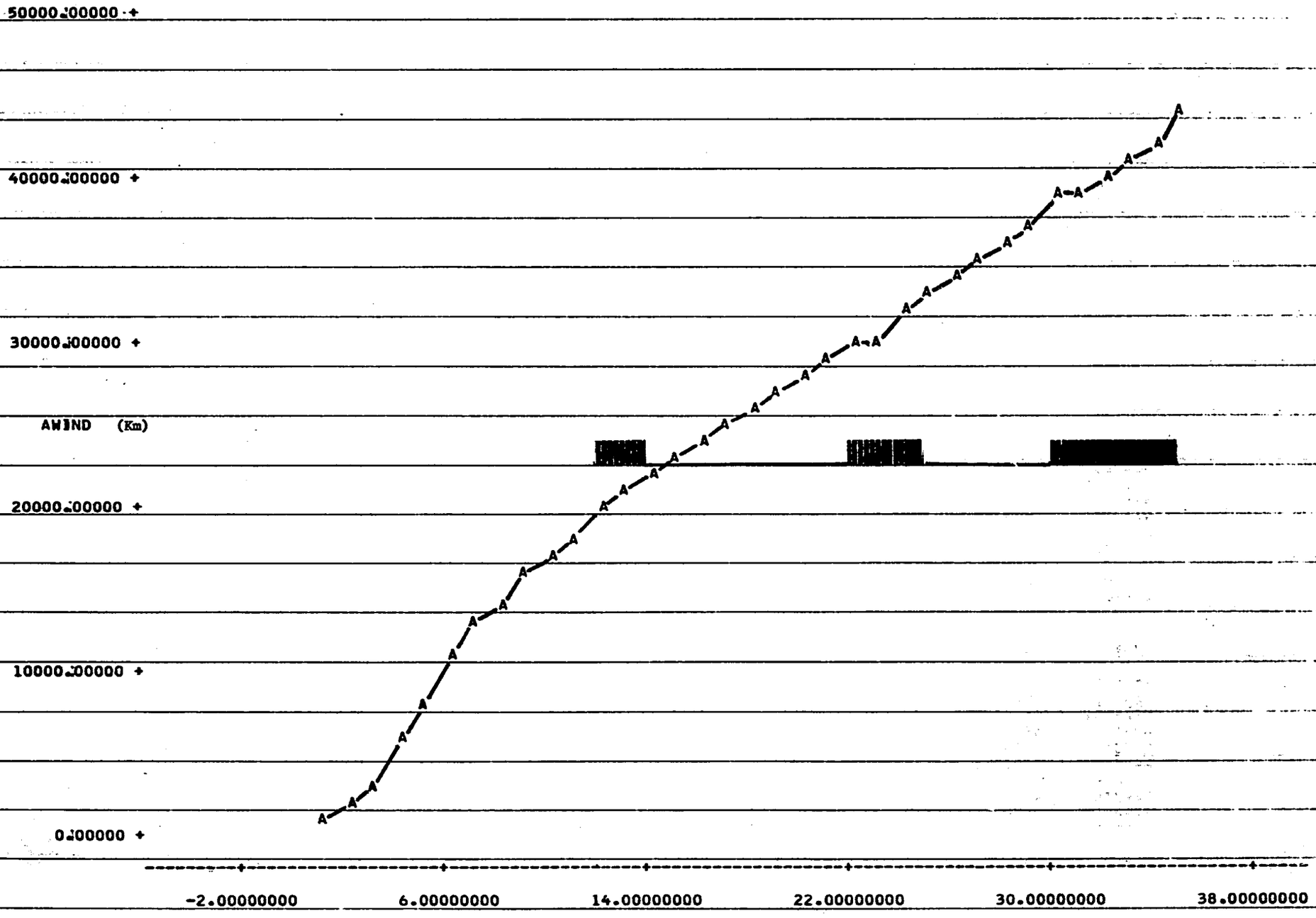
Figure 8



1975 MEAD WEATHER STATION DATA SUMMARY

Figure 9

PLOT OF AWIND VS WEEK



1975 MEAD WEATHER STATION DATA SUMMARY

Table 1 Cont.

OBS	WEEK	A MAX	A MIN	AVE TEMP	G MAX	G MIN	AVE GRT	B MAX	B MIN
26	26	32.5399	17.8573	25.1986	32.1431	23.4129	27.7780	38.5717	23.3335
27	27	28.6510	17.3017	22.9764	27.3018	21.5875	24.4446	31.9050	19.8414
28	28	25.2383	11.3493	18.2938	24.6827	17.3017	20.9922	30.0796	15.2382
29	29	20.8732	9.6033	15.2382	19.9208	14.5239	17.2224	25.5558	13.0160
30	30	19.5240	3.0953	11.3096	19.5240	11.1906	15.3573	24.7621	9.2858
31	31	20.0795	2.5397	11.3096	17.9367	9.2064	13.5715	23.6510	7.2223
32	32	26.7462	6.8255	16.7858	20.7938	11.2699	16.0319	26.6669	10.1588
33	33	25.5558	3.9683	14.7620	21.1906	11.9842	16.5874	26.5875	10.4763
34	34	22.6192	2.8572	12.7382	18.7303	9.2858	14.0080	24.2859	7.8572
35	35	15.6350	0.8730	8.2540	13.4128	6.7461	10.0794	17.0636	4.4445

OBS	AVE BRT	RAIN	ARAIN	EVAP	AEVAP	WIND	AWIND	GDU	AGDU
26	30.9526	2.6162	31.1114	6.6548	91.095	1252.07	33664.9	67.8903	816.163
27	25.8732	1.9812	33.7639	3.8608	95.979	964.00	34700.0	52.3346	873.418
28	22.6589	0.5842	35.4983	4.3942	100.014	1089.53	35755.0	25.8898	905.030
29	19.2859	0.0000	35.9156	2.2606	103.128	1226.32	36745.7	4.5558	918.800
30	17.0239	0.0000	35.9156	4.1656	106.553	1028.37	38082.6	0.0000	921.967
31	15.4366	0.5080	36.2059	3.2258	110.087	640.52	38745.2	0.0000	921.967
32	18.4128	0.0000	36.4236	6.3754	115.149	1067.00	39756.1	14.1117	930.976
33	18.5319	0.0000	36.4236	4.9784	121.064	1195.74	40924.5	9.6116	942.944
34	16.0716	0.0000	36.4236	0.0000	122.834	1071.82	41816.3	5.9447	947.564
35	10.7541	0.0000	36.4236	0.0000	122.834	1472.55	43294.8	2.5557	952.000

1975 MEAD WEATHER STATION DATA SUMMARY

Table 1

OBS	WEEK	A MAX	A MIN	AVE TEMP	G MAX	G MIN	AVE GRT	B MAX	B MIN
1	1	0.9524	-11.8255	-5.4356	0.0000	-0.1587	-0.0794	-0.5556	-0.7937
2	2	0.0000	-10.1588	-5.0794	0.0000	0.0000	0.0000	-0.2381	-0.5556
3	3	9.2064	-4.2064	2.5000	0.5556	0.0000	0.2778	4.2857	-0.5556
4	4	7.3016	-5.5556	0.8730	3.7302	1.2699	2.5000	7.6191	-1.9841
5	5	2.3016	-9.1271	-3.4127	1.1111	0.3968	0.7540	5.0794	-4.3651
6	6	11.0318	2.3016	6.6667	6.6667	3.4127	5.0397	12.8572	2.6984
7	7	15.2382	3.4921	9.3652	11.4287	5.7937	8.6112	19.5240	4.4445
8	8	16.4287	4.8413	10.6350	12.8572	7.3810	10.1191	19.1271	6.0318
9	9	20.0795	5.5556	12.8176	16.4287	10.3175	13.3731	22.6986	8.3334
10	10	24.2859	11.5874	17.9367	20.0002	13.0953	16.5478	28.4129	12.7779
11	11	22.3018	6.7461	14.5239	21.6668	14.0477	17.8573	29.1272	11.4287
12	12	30.3971	16.5874	23.4923	25.6351	17.5398	21.5875	35.1590	19.1271
13	13	24.3653	11.8255	18.0954	23.0161	16.7462	19.8811	28.7304	15.2382
14	14	24.2065	10.0001	17.1033	22.9367	15.7144	19.3256	28.0161	13.0160
15	15	23.5716	12.7779	18.1747	23.3335	16.8255	20.0795	27.8574	15.0001
16	16	27.6986	16.1112	21.9049	24.7621	18.8097	21.7859	28.9685	17.8573
17	17	29.7621	16.7462	23.2542	26.3494	21.5875	23.9684	29.6034	20.3176
18	18	33.0955	19.2859	26.1907	28.6510	22.4605	25.5558	33.8892	22.3811
19	19	32.7780	16.8255	24.8018	30.1590	22.3811	26.2701	43.6511	22.3018
20	20	30.8733	16.5874	23.7303	29.2066	20.5557	24.8812	42.3813	20.6351
21	21	31.1114	16.6668	23.8891	29.7621	22.2224	25.9923	40.2384	20.6351
22	22	33.8098	19.3652	26.5875	31.1114	22.8573	26.9843	41.3495	23.0954
23	23	31.8257	16.2700	24.0478	31.4288	21.9843	26.7066	39.6829	21.1113
24	24	32.4606	18.2541	25.3573	31.9844	23.6510	27.8177	37.8574	22.1430
25	25	32.4606	18.1747	25.3177	31.8257	23.0161	27.4209	37.4606	22.3811

OBS	AVE BRT	RAIN	ARAIN	EVAP	AEVAP	WIND	AWIND	GDU	AGDU
1	-0.6746	0.0762	0.0109	0.0000	0.000	1308.40	644.7	0.0000	0.000
2	-0.3968	0.4318	0.3846	0.0000	0.000	1046.07	1958.6	0.0000	0.000
3	1.8651	0.0762	0.5515	0.0000	0.000	825.59	2762.1	0.0000	0.000
4	2.8175	2.6162	1.3426	0.0000	0.000	3286.28	5034.9	0.0000	0.000
5	0.3571	0.2032	3.2875	0.0000	0.000	2338.38	7772.9	0.0000	0.000
6	7.7778	0.1524	3.4798	0.0000	0.000	2497.70	10485.1	0.0000	0.000
7	11.9842	1.5240	4.5647	1.6002	0.421	1580.38	12054.7	0.3335	0.095
8	12.5795	2.8448	6.7274	2.6924	3.063	1543.36	13771.4	2.8892	1.365
9	15.5160	2.1590	9.4669	3.6830	6.397	1602.91	15531.8	2.6114	5.747
10	20.5954	1.5240	11.2740	3.8100	9.939	1374.38	16855.3	19.7230	15.914
11	20.2779	1.1938	12.6202	3.8608	13.955	894.80	17917.7	2.3336	27.383
12	27.1431	0.0508	12.8089	5.7150	18.905	1495.08	19159.2	55.9458	55.256
13	21.9843	4.1656	14.9715	4.5466	24.373	1318.05	20572.5	20.0008	98.504
14	20.5160	1.6002	18.1537	3.9878	27.958	783.75	21529.1	16.3340	108.798
15	21.4287	2.2860	19.9281	2.9718	31.460	910.89	22447.4	20.5563	133.005
16	23.4129	2.3876	22.1597	4.8006	35.676	1488.64	23642.9	44.8346	164.760
17	24.9605	2.0828	25.0988	4.2164	40.183	838.47	24787.6	54.2791	216.221
18	28.1351	0.4064	25.6649	4.8768	44.646	857.78	25679.8	74.8348	283.397
19	32.9765	0.0000	25.7810	5.6388	50.223	671.10	26369.8	65.1125	357.756
20	31.5082	0.0000	25.7810	6.5278	55.601	1384.04	27306.7	57.6124	403.305
21	30.4368	2.1336	26.9458	5.0800	61.954	601.89	28387.7	58.7236	474.965
22	32.2225	0.0254	27.9327	5.7150	67.223	811.11	29079.5	77.6126	537.220
23	30.3971	0.3556	28.2956	5.1054	72.274	1145.85	29986.7	59.8347	608.285
24	30.0002	2.3876	29.2935	6.4516	78.852	1115.28	31359.0	69.0014	677.446
25	29.9209	0.0508	30.7340	5.6388	83.998	1153.90	32249.9	68.7236	738.629

DRYLAND RESPONSE OF SIX GRAIN SORGHUM HYBRIDS GROWN AT THREE PLANT POPULATIONS

Max D. Clegg, J. W. Maranville, J. D. Eastin and C. Y. Sullivan

Grain sorghum produces a relatively good grain crop when grown under dryland conditions. The 1974 summer was exceptionally dry through most of the sorghum growing season. Yields were reduced by lack of moisture combined with a cooler than normal late August and September. The plant population of a crop determines to a great extent the yield of grain sorghum especially if environmental conditions are marginal. The objective of this experiment was to: 1. evaluate sorghum grain yields when sorghum is planted at extremely low plant populations, at a fairly normal plant population and at a high plant population, and 2, to determine if erect hybrids perform more efficiently than the normal types.

The rational for the last objective is based on the cosine response of leaves to light absorption. (1) Erect leaves should be less efficient in light absorption during the period of day when maximum light is received because the angle of incident radiation to a line perpendicular to the leaf would be large. For this reason they should have a lighter heat load and a smaller heat load would require less transpiration for cooling thus possibly more efficient in water utilization.

MATERIALS AND METHODS

Six sorghum hybrids (RS 626, DeKalb E-57, RS 671, Martin x SC33, CK-60 x SC33 and Redlan x SC33) were planted two times the desired plant population with a surface planter equipped with belt feeder attachments. The row spacing was 0.76 meters. After emergence the plots were thinned to

75,000, 225,000 and 375,000 plants per hectare. Routine weed control practices were performed throughout the growing season. The experiment was a factorial in a randomized complete block design with four replications. Plots were four rows 6 meters long. An analysis of variance was computed on the results and significant differences among means were tested with Duncan's Multiple Range Test at the 0.5 level of significance.

At maturity the heads from measured row lengths were harvested and threshed. Sorghum grain yield was expressed as kg/ha at 14% moisture. Plant height at maturity was measured in centimeters from the ground to an average head height. Days to 50% bloom are the number of days to when 50% of the plants were shedding pollen.

RESULTS AND DISCUSSION

Results of yield, height and days to 50% bloom for the six hybrids are shown in Table 1. The highest yielding hybrid was the erect hybrid CK-60 x SC33. It also yielded well at the higher populations. Differences in yield height and bloom were significally different. There was no real yield advantage by using erect hybrids over non-erect hybrids.

The influence of plant population on these same variable are shown in Table 2. Highest yields were obtained when the hybrids were planted at the lowest plant population. Yield continued to decrease as plant population increased. Thus with the less than desirable moisture conditions during the growing season, high plant populations resulted in more plant stress. Other than yield, this was also reflected by a decrease in sorghum plant height and an increase in the number of days to 50% bloom.

The results agree with the general recommendation that dryland sorghums should be planted at a low plant population. The amount of seed

Table 1. Yield, height and days to 50% bloom of six hybrids. Data are means of three plant populations and four replications. 1975.

Hybrids	Yield (kg/ha)	Height (cm)	Days to 50% bloom
1. RS 626	5748 a*	92.5 b	64.6 d
2. Dekalb E-57	5702 ab	99.6 a	67.2 c
3. RS 671	5802 a	89.2 c	68.9 a
4. Martin x XC33	5462 b	91.6 bc	68.0 b
5. CK-60 x SC33	6080 a	99.3 a	67.8 bc
6. Redlan x SC33	5314 b	99.6 a	74.2 a

* Numbers within a column followed by the same letter do not differ significantly using Duncan's Multiple Range Test.

Table 2. Yield of grain sorghum planted at three different plant populations. Data are means of six hybrids and four replications. 1975.

Plant populations**	Yield (kg/ha)	Height (cm)	Days to 50% bloom
1. 75,000 plants/ha	5997 a*	100.6 a	67.8 b
2. 225,000 plants/ha	5698 b	94.8 b	68.6 a
3. 375,000 plants/ha	5360 c	90.5 c	69.2 a

* Numbers within a column followed by the same letter do not differ significantly using Duncan's Multiple Range Test.

** Plant populations indicated were the plant population to which they were initially thinned after overplanting. The 75,000 plant population increased by 9%, the 225,000 and 375,000 plant population decreased 8% and 16% respectively.

needed to plant each rate was approximately 2.34 kg/ha (2.06 lbs/A), 7.03 kg/ha (6.19 lbs/A) and 11.72 kg/ha (10.32 lbs/A). This is assuming an emergence rate of 80%. The greatest advantage of planting at low plant populations is that if moisture is good the crop will tiller and thus compensate for the initial low plant population and maintain a good yield.

However, at high plant populations you do gain some yield advantage if moisture is good, but if moisture is lacking, vegetative growth occurs using moisture at the expense of a moisture reserve needed for grain production.

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SORGHUM-SOYBEAN CROPPING SYSTEMS

Max D. Clegg

Many factors influence the adaptability of a crop to a crop producing area. Climatically temperature and rainfall or water availability are probably the most important factors dictating establishment of crops. Among these factors are fuel and fertilizer costs. Various cropping systems can be established which can minimize the use of water, fertilizer (especially nitrogen) and tillage operations which reduce fuel consumption.

The sorghum-soybean combinations used in rotation were designed to possibly conserve water, nitrogen and fuel. Each tillage operation exposes moist soil which in turns dries resulting in soil moisture loss. Also greatest fuel consumption occurs during heavy tillage. By minimizing the number of tillage operations, both moisture and fuel can be conserved. Nitrogen can be fixed by legumes, so less chemical nitrogen would be needed following a legume such as soybeans.

The experiment was designed to reduce tillage by using no-till systems. Weeds were controlled using herbicides. Reduced tillage was implemented after soybeans because crop residue is a minimal problem. Tillage only followed sorghum, thus, in a rotation with the alternating of sorghum and soybeans heavy tillage was reduced by one-half. With a rotation of sorghum followed by two years of continuous soybeans, heavy tillage was reduced by one-third. A farmer by dividing his farm fields into one-half sorghum and one-half soybeans or one third sorghum and two-thirds soybeans immediately reduces his fuel expense. The affect on water and nitrogen conservation has yet to be evaluated.

MATERIALS AND METHODS

Permanent plots were established for rotating grain sorghum (RS 626) and soybeans (Amsoy) through a two year cycle in which sorghum and soybeans were alternated each year or a three year cycle in which sorghum was planted following two years of soybeans. The plots were six rows spaced .76 meters apart and six meters long. The sorghum was overplanted and thinned to a final population of approximately 125,000 plants per hectare. The soybeans were seeded 31 to 39 seeds per meter resulting in a plant population of 408,000 - 513,000 plants per acre if all survived. The treatments were randomized and replicated four times. The treatments consisted of:

1.	Continuous sorghum,		kg/ha N,	conventional tillage.			
2.	"	"	, 57	"	"	"	.
3.	"	"	, 114	"	"	"	.
4.	"	"	, 170	"	"	"	.
5.	"	"	,	no N	conventional tillage.		
6.	SB -SB - Sorg		,	kg/ha N,	conventional tillage following sorghum.		
7.	"		, 57	"	"	"	" .
8.	"		, 114	"	"	"	" .
9.	"		, 170	"	"	"	" .
10.	SB - Sorg		,	kg/ha N,	conventional tillage following sorghum.		
11.	"		, 57	"	"	"	" .
12.	"		, 114	"	"	"	" .
13.	"		, 170	"	"	"	" .

With exception of treatment five, the crops were planted with a no-till planter following soybeans.

In sorghum, weeds were controlled in the tilled plots in the conventional manner. Prior to planting the plots were disked and harrowed and after planting sprayed with a mixture of propachlor (2.7 kg/ha) and atrazine (1.1 kg/ha). Weeds were controlled in the no-till plots by initially

killing the spring germinated weeds with paraquot (4.5 l/ha) before they reached a height of ten centimeters. After planting the plots were sprayed the same as the conventional tilled plots or if some large weeds persisted the preemergence mixture plus paraquot was used. Weed control in soybeans was the same except the preemergence herbicide used was chloramben (6.7 l/ha). If necessary, further weed control was by cultivation.

Water available for the crop was from the natural sources prior to and during growth.

An analysis of variance was applied to the data and, if significances occurred, differences were determined using the Duncan's multiple range test.

RESULTS AND DISCUSSION

The first year drought and cool late summer temperatures coupled with high plant populations resulted in yields ranging from 878 to 1506 kg/ha for grain sorghum (Table 1). The yields were generally inverse with nitrogen levels.

Table 2 shows the results of grain sorghum yields in 1975. Yields generally increased with increased nitrogen. Also there is a suggestion of about 50 kg/ha nitrogen being contributed from two years sorghum. Statistically, yields were increased by nitrogen application. Bloom was shortened by nitrogen.

Soybean yields averaged 2681 and 1980 for 1974 and 1975 respectively. No significant differences occurred between treatments.

Initial results are encouraging. In 1976, soil tests are going to be made of each plot so nitrogen rates will not exceed the designated rates. Also, moisture will be monitored.

Table 1. Yield of grain sorghum planted in conventional and soybean-sorghum rotation systems. 1974.

Treatments		Yield (kg/ha)
Crop sequence	Nitrogen (kg/ha)	
1. Continuous sorghum	0	1234
2. " "	57	1195
3. " "	114	1075
4 " "	170	1027
6. Soybean-sorghum*	0	1238
7. " "	57	1506
8. " "	114	994
9. " "	170	878

* Sorghum was planted no-till.

Table 2. Yield and days to 50% bloom of grain sorghum planted in conventional and soybean-sorghum rotation systems. 1975.

Treatments		Yield (kg/ha)	50% bloom (days)
Crop sequence	nitrogen (kg/ha)		
1. Continuous sorghum	0	4511 c**	74 a
2. " "	57	5623 ab	70 b
3. " "	114	6050 ab	70 b
4. " "	170	6174 ab	70 b
10. Soybean-soybean-sorghum*	0	5079 bc	70 b
11. " " "	57	6074 ab	70 b
12. " " "	114	5346 abc	70 b
13. " " "	170	6328 a	69 b

* Sorghum was planted no-till
** Numbers within a column followed by the same letter do not differ significantly using Duncan's multiple range test.

INFLUENCE OF SEED SIZE AND DENSITY ON GERMINATION SEEDLING EMERGENCE AND YIELD OF GRAIN SORGHUM

Jerry W. Maranville and Max D. Clegg

A recent report (4) indicated that a higher percent germinating seed lot which was obtained by separating and retaining denser kernels, may produce a better stand in the field. Selecting larger kernels also improved germination and seedling stand. Final grain yield, however, was not improved significantly in the better germinating seed lots. Work with other plant types such as cotton still enforce the observation that fullness (density) is a better criteria than size in determining seed quality (2,3). Abdullahi and Vanderlip (1) also found in sorghum that there was no consistent improvement of establishment with larger size kernels although here was a trend for this to happen. In contrast to our findings in sorghum (1), Smith and Camper (5) showed that larger soybean kernels produced larger plants which yielded more although initial establishment from these kernels was not different from that of small kernels.

The following experiment reports on a continuation of the original study designed to evaluate primarily size and density of seed lots with regard to field performance.

MATERIALS AND METHODS

The experiment was conducted in a manner similar to that previously described (1) with some modification. Three hybrids were used, two of which are common to the area, and one experimental. RS 671 and

NC+ 70X were obtained from commercial sources as unprocessed seed and SC33 X Martin experimental was increased in Puerto Rico. The latter was included so as to have a seed lot with poor germination. Density separations were made on a sucrose solution of 1.237 density. Size separations were made using a sieve with 10/64 hole size. Field experimentation was the same as previous (1).

RESULTS AND DISCUSSION

Percent germination was significantly different among hybrids (Table 1) as well as kernel weight and kernel size (seeds/volume). RS 671 had the highest germinating seed lot but fell in between the other two hybrids for seed weight and size. The experimental hybrid had the poorest germinating lot, but was the heaviest as well as the largest.

Similar to a previous experiment (1), the denser seed (heavy) produced significantly better germination percentage (Table 1). In contrast, however, the large seed did not perform as well. The light seed was the poorest germinator, which again was similar to that observed previously. Significant differences were found among all treatments for seed weight with the large being the heaviest per seed and the small the lightest. There was no difference in seed size among the two density fractions indicating that seed size was not influential in altering the germination response observed for these two fractions.

Table 2 shows the actual field performance of the various hybrid seed lots subjected to the different treatments. RS 671 had a faster

early rate of emergence, but the experimental had more total seedlings emerge. Final stands appeared to be reduced below that of the final seedling emergence with 70X being significantly lower in final stand than the other two hybrids. This reduction did not reflect, however, in the final grain yield. The highest yield was from 70X followed by RS 671 and the experimental, respectively.

As expected, there was a significant difference between populations for all parameters measured (Table 2). The most obvious point here was that the difference in yield, although significantly higher for the greater population, was only 10% higher. The higher population produced 47% more total seedlings and 34% more plants at final harvest. This shows the ability of sorghum to compensate markedly to differences in population.

Table 1. Means of hybrids and treatments for percent germination, 1000 kernel weight and kernels per volume.

Hybrid	% Germination	wt. per 1000 kernels	kernels per 15 cc volume
RS 671	95.4 a	34.5 b	454 b
70X	90.6 b	32.0 c	520 a
Exp.	66.1 c	38.3 a	446 c
Treatment			
control	83.0 b	35.0 c	
large	82.8 b	38.9 a	
small	81.4 bc	30.3 e	
heavy	93.0 a	36.6 b	472 a
light	79.8 c	33.9 d	475 a

Values followed by the same letter are not significantly different at the 5% level of probability using Duncan's multiple range test.

Table 2. Means of hybrids, populations and treatments for emergence, final stand and grain yield.

Hybrid	Emergence 1 (plants/ha x 10^3)	Emergence 2 (plants/ha x 10^3)	Emergence 3 (plants/ha x 10^3)	Final Stand (plants/ha x 10^3)	Grain Yield (kg/ha)
RS 671	60.6 a	66.5 a	71.0 b	65.8 a	3901 b
70X	42.9 c	58.6 b	64.8 c	59.4 b	4338 a
Exp.	53.7 b	69.1 a	78.4 a	63.5 a	2677 c
Population					
125,000	35.8 b	43.8 b	49.2 b	50.1 b	3446 b
250,000	69.0 a	85.7 a	93.6 a	75.9 a	3831 a
Treatment					
control	56.5 a	69.3 a	76.3 a	64.3 a	3830 a
large	46.3 b	63.1 a	70.3 a	62.4 a	3608 a
small	50.3 ab	61.0 a	71.6 a	60.5 a	3388 a
heavy	56.0 a	67.5 a	71.1 a	64.2 a	3563 a
light	53.0 ab	62.9 a	67.6 a	63.7 a	3804 a

Values followed by the same letter are not significantly different at the 5% level of probability using Duncan's multiple range test.

Similar to the previous experiment (1), very little difference was noted among the treatments when averaged over populations and hybrids. (Table 2). The only significant difference was that the large seed treatment emerged slower than the control or heavy treatments. No differences, however, were detected in final seedling number, final stand or grain yield.

From the results of the two experiments, it is concluded that a more dense or large seed lot may have higher germination, but this does not mean that there will be an increase in number of seedlings emerging or final grain yield if the desired number of viable seeds are planted. It was observed, however, that the denser or larger seeds appeared to produce a more vigorous seedling. When conditions of stress are imposed such as soil crusting or low moisture, perhaps the benefit of a more vigorous seedling would be evident in final grain yield.

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GROWTH, YIELD AND NITROGEN UPTAKE IN GRAIN SORGHUM GROWN UNDER VARYING RATES OF MULCH

Jerry W. Maranville

A limited number of studies have determined, to some extent, patterns of nutrient uptake in grain sorghum in relation to growth. Vanderlip (7) reported that potassium is taken up most rapidly followed by nitrogen and phosphorus, respectively. A crop producing 9000 kg/ha of grain removes somewhere around 300 kg/ha of nitrogen under current production practices using current hybrids. This type of information seves as a guide to fertilization practices when combined with soil data. Little information is available, however, on whether this pattern is altered under different cultural conditions such as minimum or reduced tillage. Mulches remaining on the soil surface with such practices are known to reduce soil temperatures considerably (1, 3, 4), which influences the lateral spread and depth of penetration of the root system (3). A greater lateral spread in the shallower soil zone has been postulated to be associated with a more efficient utilization of nutrients early in the development of corn (2). A shallow root system is also more susceptible to leaching losses than deeper root systems (3). Increased water intake, however, and decreased evaporation often result in more available moisture under mulches than bare soil (1, 5, 6).

The alteration in soil temperature and moisture regimes may alter plant growth which in turn may alter nutrient uptake patterns. Soil nitrogen may also be less available to plants grown under mulches than with conventional means (6). Plants grown under mulches could require

different management practices particularly with respect to fertility. The following experiment was designed to determine some plant growth responses in sorghum grown under different mulching rates and the pattern of nitrogen uptake and accumulation in the tissues.

MATERIALS AND METHODS

Sorghum hybrids RS 626 and RS 671 were planted in 4 row plots on June 5, 1975, at Mead, Nebraska. The experimental site was uniformly fertilized with 112 kg/ha of N as ammonium nitrate and 45 kg/ha of actual P. Weeds were controlled with the application of 0.9 kg/ha atrazine plus 2.6 kg/ha propachlor applied preemergent. One week after seeding and just as plants were emerging, chopped dry sorghum residue was placed over designated plots at rates of 2200, 4400, and 8800 kg/ha with bare soil serving as a control. The experiment contained four replications in a split block design. Soil temeratures were monitored through the season at a depth of 7.5 cm by using bulb-type recording thermometers (tempscribes) in one replication of each treatment. Soil moisture was determined 30 days after seeding to a depth of 90 cm in 30 cm increments by manually coring and drying in an oven at 110 C for 48 hr. Three plants selected at random were removed from each plot 30 days after seeding for measurements of DM production and N uptake. Subsequent samplings were made in a similar manner at late boot and when seeds were in the milk stage of maturity. For the latter two samplings, plants were divided into various parts as 1. bottom one-half leaves; 2. top one-half leaves; 3. stem plus sheath; and 4. inflorescence (last sampling). Plants or parts were combined and dried at 80 C for 72 hr, weighed and ground

to pass a 40 mesh screen on a Wiley mill. Percent total N was determined by Kjeldahl. Percent protein in grain was determined at maturity by the Orange G dye binding method. Grain yields were determined by harvesting 3 m of the two center rows and converted to 14% moisture basis. Moisture at harvest was determined on 3 heads from each plot after drying at 80 C for 72 hr. Days to 50% bloom was determined as that time when 50% of the plants per plot were flowering.

RESULTS AND DISCUSSION

Table 1 shows the soil temperature alterations one may expect throughout the growing season when varying amounts of mulches cover the soil surface under the conditions of this experiment. Early in the season before the crop canopy fills in, the temperatures are considerably cooler than on bare soil. This may be as much as 10 C if the mulch is heavy. Later in the season after the canopy is filled in (8/1 to 8/5), there is little difference in maximum or minimum temperatures between any treatment. Late season temperatures seem to indicate that there may be some insulating effect from mulches as ambient air temperatures start cooling. The heavy mulch appeared to be warmer than the lighter mulch treatment. However, the control bare soil was still staying quite warm indicating that energy was apparently penetrating the canopy enough to directly warm the soil.

Soil moisture was higher at all soil depths measured if mulch was present versus the bare soil (Table 2). The differences were greatest at the one foot level and were similar among the mulching treatments at 60 or 90 cm depths. This most likely was due primarily to a savings from retardation of evaporative loss.

Table 1. Soil temperature in degrees C as an average of 4 day intervals recorded early, mid-, and late in the growing season.

Mulching Rate	Date					
	7/3 to 7/7		8/1 to 8/5		9/2 to 9/6	
	Max	Min	Max	Min	Max	Min
Control	40.2	26.7	30.7	23.1	24.8	20.1
2200 kg/ha	37.2	23.8	28.2	20.3	19.2	15.4
4400 kg/ha	37.0	25.1	29.0	21.2	21.5	16.4
8800 kg/ha	30.6	23.5	29.8	21.9	23.2	19.2

Table 2. Percent soil water in a 90 cm profile when determined 30 days after seeding.

Mulching Rate	Depth (cm)		
	30	60	90
Control	18.4	22.7	22.4
2200 kg/ha	18.9	23.4	23.8
4400 kg/ha	20.9	24.4	23.1
8800 kg/ha	21.2	24.2	23.6

The patterns of growth shown in Table 3 indicate that in this instance, soil temperature probably had a greater influence than the moisture difference. This is not particularly true when soil moisture is more limiting than in this experiment (5). The plants grown under heavy mulch were generally reduced by 45% in size (DM produced) and considerably delayed in maturity (7 leaf stage vs 9 leaf stage for control). Increased mulching rates progressively reduced growth and also stands

Table 3. Dry matter (DM) production in gm/plant taken at three stages of growth under varying mulching rates.

Growth Stage	Hybrid	Mulch Treatment kg/ha control	2200	4400	8800	Ave.
		gm DM/plant				
7 to 9 Leaf	626	3.49	2.60	2.05	2.16	2.58
	671	3.75	2.39	2.12	1.71	2.49
	Ave	3.62	2.50	2.09	1.94	
Late Boot	626	47.32	39.04	47.72	46.27	45.09
	671	69.13	67.26	66.62	68.51	67.88
	Ave	58.23	53.15	57.17	57.39	
Milk	626	87.11	100.99	103.31	107.04	99.61
	671	116.13	129.31	131.77	133.96	127.80
	Ave	101.62	115.15	117.54	120.50	

DM produced at the late boot growth stage was not different for any treatment although the later maturing RS 671 produced the largest amount. However at milk stage, there was a noticeable increase in DM per plant as mulches were progressively heavier. This was due to the fact that there was initial stand reduction and less competition between plants resulting in larger plants for the mulched treatments than control. This also apparently was reflected in the total yield of both grain and grain protein (Table 4). The advantage gained by moisture conservation (5, 6) were not evident in this experiment since little stress occurred during the season on these plots due to timely precipitation. Rather, the stand reductions due to cold soil temperatures reduced yield under mulch.

Table 4 also shows that the early delay in maturity of seedlings was carried through the season and resulted in as much as a 6 day difference in bloom date for the heavy mulch versus bare soil treatments. Any mulching treatment, however, delayed bloom date. This is also reflected in the moisture of the grain at harvest which increased progressively with increasing mulching rates. Undoubtedly, this could pose management problems if one must wait until low enough moisture levels are reached before harvesting. Delayed harvests normally result in reduced yields.

Total nitrogen uptake by various plant parts and whole plants are shown in Table 5. There was generally no difference in N uptake early in the season for any treatment although there was a reduction in RS 671 under the heaviest mulching rate due to reduced plant size primarily. Similarly, no apparent differences existed at late dough stage among treatments, but there was noticeably more taken up by RS 671 than RS 626,

Table 4. Effects of different mulching rates to certain parameters important in economic considerations.

Mulch Treatment	Hybrid	Days to 50% bloom	Final Stand plants/ha x 1000	Harvest Moisture %	Yield kg/ha	Protein g/ha
control	626	63	115.4	21.0	6170	652.5
	671	68	108.9	25.5	6440	677.8
	Ave	66	112.2	23.3	6305	665.2
2200 kg/ha	626	65	113.3	21.7	6255	658.1
	671	70	104.5	26.5	6340	665.4
	Ave	68	108.9	24.1	6300	661.8
4400 kg/ha	626	66	108.9	22.5	6355	670.8
	671	71	104.5	28.9	5450	571.4
	Ave	69	106.7	25.7	5900	621.1
8800 kg/ha	626	68	102.4	25.5	5300	643.9
	671	76	91.5	32.6	5100	546.1
	Ave	72	97.0	29.1	5200	545.0

Table 5. Uptake of nitrogen by two sorghum hybrids grown under different mulching rates.

Treatment	Hybrid	Plant Part	7 to 9 Leaf Stage	Late Boot Stage	Milk Stage
			mg N/plant		
control	626	top		351	287
		bottom		222	226
		stem		511	366
		head			605
		total	88.9	1084	1484
		top		335	443
		bottom		223	233
		stem		687	328
		head			790
		total	110.2	1245	1819
	Ave.	total	99.6	1165	1662
2200 kg/ha	626	top		248	357
		bottom		201	186
		stem		401	248
		head			794
		total	108.3	850	1584
	671	top		344	514
		bottom		233	240
		stem		625	316
		head			1001
		total	91.8	1202	2071
	Ave.	total	100.1	1026	1828
4400 kg/ha	626	top		351	382
		bottom		259	231
		stem		518	285
		head			766
		total	95.9	1128	1663
	671	top		350	507
		bottom		236	267
		stem		615	336
		head			951
		total	98.7	1201	2061
	Ave.	total	97.3	1165	1862
8800 kg/ha	626	top		316	377
		bottom		241	215
		stem		489	251
		head			838
		total	111.3	1046	1683

Table 5 (continued)

Treatment	Hybrid	Plant Part	7 to 9 Leaf Stage	Late Boot Stage	Milk Stage
			mg N/plant		
	671	top		423	523
		bottom		237	236
		stem		660	322
		head			1050
		total	81.8	1320	2132
	Ave.	total	102.2	1183	1908

the latter being the more short statured earlier maturing type. Stems plus sheaths contained nearly one half of the total plant N at this stage, followed by the top leaves and then the bottom leaves which had the least.

There was a trend for more nitrogen to be accumulated per plant at the milk stage as mulching rates were progressively heavier. However, concentrations were similar indicating that these higher N values again were the result of larger plants derived from poorer stands. The total amount of N removed per hectare of land was similar for all treatments. Similar to the boot stage of growth, RS 671 took up considerably more N per plant than RS 626. The most noticeable shift in N accumulation in the plant parts was from the stem to the grain (inflorescence). There was no gain in amount of N in the bottom leaves even though they gained slightly in weight. This was due to concentration reduction. Top leaves, however, did increase in total uptake due primarily to gain in weight rather than concentration.

The early indications from one years data on the alterations one may expect when growing sorghum under mulching systems indicate that growth patterns

can be changed. When moisture is not limiting, the reduced soil temperature early in the season is the predominant effect. A reduction in stand may result as well as a delay in maturity. Mulches do, however, conserve moisture which in certain seasons is critical.

Uptake of nitrogen does not appear to be altered in sorghum under mulch. Mulches affect plant growth directly which in turn affects N concentrations in plant material.

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SCREENING SORGHUM GENOTYPES FOR DIFFERENTIAL UPTAKE AND UTILIZATION OF PHOSPHORUS AND IRON

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Improved and expanded crop production will be required to meet future food demands. This will necessitate the continued use of fertilizer nutrients and possibly expansion of crop production to more environmentally stressed lands. Limited and more careful use of fertilizers will be desired and required because of their high cost, possibility for scarcity, and potential for pollution. Plants adapted to more environmentally stressed lands are also desired to help overcome some of the adverse conditions found on these lands.

One method for helping reduce fertilizer needs, or for getting greater production from fertilizer added, is to develop crop varieties or hybrids that are more efficient for the uptake and utilization of mineral elements. Studies have shown that marked diversity for mineral uptake and utilization exist in many plant genotypes (1,2,3,5,6,9,11,12,14,18,19,20,22,25,26,27). Large differences in tolerance to toxic elements have also been shown (7,13,15,16,17). Taking advantage of these differences and using them in plant breeding programs has great potential.

Only about 10% of the P added to soils is utilized by plants (4). This is a relatively low level of P efficiency and improvements in P uptake and utilization appear feasible. Differential P efficiencies have been noted for corn inbreds (13), soybeans (10), sorghum (8) and P concentrations in corn leaves appear to be genetically controlled (2,3,19,20). The identification and isolation of genotypes showing differential P efficiency

have not been done for sorghum.

Iron deficiency in sorghum of the Great Plains states has been, is, and will continue to be an important problem until corrective measures can be incorporated. This problem is most paramount on alkaline and calcareous soils. Correction of Fe deficiencies in plants does not appear feasible by Fe additions to the soil. This practice is prohibitive economically except for ornamentals and some very high price cash crops. Iron additions must be on a continual basis and with some crops more than one application per crop is required. Many of these soils have high Fe, but Fe is not available for plant use. The most feasible and long term solution for overcoming Fe deficiencies is to breed plants with greater efficiency for use of Fe. Wide differences in plant genotypes for Fe uptake and utilization are known (5,6,9,11,14,24,26) and are genetically controlled (10,26).

The objective of this study was to set up procedures and screen sorghum lines for their differential responses to P and Fe in soils. These results are preliminary, and additional experiments are being conducted to refine methodology and to screen more sorghum lines.

MATERIALS AND METHODS

Soils used in this study were reported to induce P and Fe deficiencies. Descriptions and properties of these soils are given in Table 1. Soils (1.6 kg/pot) were placed in plastic pots and each fertilized with 110 N and 140 K (kg/ha) as NH_4NO_3 and KH_2PO_4 or K_2SO_4. In addition, the low Fe soil received 110 kg/ha P as KH_2PO_4 and the low P soil received 10 kg/ha Fe as FeEDDHA (Fe ethylenediamine di(o-hydroxyphenylacetate). Plastic

Table 1. Description and properties of soils used to screen sorghum lines for P and Fe.

Property	Soil		
	Valentine	Bridgett	Sharpsburg
Location	Central Nebraska Sandhills	North Platte, Neb.	Lincoln, Neb.
Nutrient problem	P - def.	Fe - def.	Nondef.
Texture	Fine Sand	Calcareous Fine Sandy Loam	Silty Clay Loam
Classification	Typic Ustipsamment	Torriorthentic Haplustoll	Typic Argiudoll
Cultural Practice	Virgin desert (near center pivot system)	Cultivated	Unknown
pH	6.5	8.2	5.5 a 6.5 b
CEC (meq/100g)	2.81	11.90	---
Conductivity (mmhos)	---	0.23	<0.2
Ex Na (%)	0	2.44	---
NO_3 (ppm)	3	8	0.6
P (ppm)	10	10	18
K (ppm)	0.26	363	302
OM (%)	0.51	1.11	3.24
Mn (ppm)	14.42	8.34	---
Fe (ppm)	3.17	2.45	---
Zn (ppm)	1.43	1.01	---
Cu (ppm)	0.62	0.33	---
Ca (meq/100g)	1.57	6.39	---
Mg (meq/100g)	0.26	5.96	---

a pH before liming.
b pH after liming with 8000 kg/ha $CaCO_3$.

bags were placed under each pot to keep excess water and leached nutrients from being lost to the soil. Seed was obtained from the Nebraska sorghum breeding program. Seeds were planted, and after 10 days, seedlings were thinned to 3 plants/pot with duplicate pots for each line. Pots were randomized throughout and grown in a greenhouse.

Severe mineral deficiency symptoms appeared in plants within 24 days after planting. At this time, visual nutrient deficiency symptom ratings were recorded for each line on each soil and the plants harvested. Plants were cut about 1 cm above the soil, the bottom leaf discarded and the other leaves (sheaths included) water rinsed at the base, blotted dry, and placed in paper bags for drying. Plants grown on the low Fe soil were separated into upper (top 2) and lower leaves. Plant materials were oven dried at 70 C, weighed, ground to pass a 20-mesh screen, and analyzed for P and Fe. Phosphorus was analyzed by the molybdovandate color method (21) and Fe by the o-phenanthroline color method (24) on samples digested with sulfuric acid-hydrogen peroxide (23).

RESULTS AND DISCUSSION

P efficiency of sorghum lines: Of the 23 sorghum lines grown in the experiment (Table 2), KS35, Martin, EH-KS19 and KS5 grew better and produced the most dry matter on the low P soil. In contrast, CK60-Korgi, SC177-15E, CK60-Shallu, North Platte, and SC119-9-2-2-2 grew poorly and produced the least dry matter. Plants producing the most dry matter generally had the lowest degree of P deficiency and plants producing the least dry matter had the highest degree of P deficiency (Table 2). Concentrations of P in the leaves varied extensively with an overall average of 0.158% P. Phosphorus contents decreased with increased

Table 2. Dry-matter yields, degree of P deficiency and P concentrations and contents of sorghum lines grown on a low P (Valentine) and a nondeficient (Sharpsburg) soil.[a]

Sorghum Line	Valentine				Sharpsburg			
	Dry wt.	Def. symp.[b]	P	P	Dry wt.	Def. symp.	P	P
	g/plant		%	mg/plant	g/plant		%	mg/plant
KS 35	.680	0	.217	1.487	1.291	0	.472	6.04
Martin	.528	0	.174	.922	1.200	0	.376	4.51
EH-KS19	.502	0	.150	.748	1.479	0	.408	6.01
KS 5	.446	0	.228	1.077	1.236	0	.390	4.82
SC33-9-8-E4	.307	1	.153	.482	1.192	0	.452	5.38
Redlan	.272	0	.150	.351	1.358	0	.434	6.48
Tx412-Tx414	.265	2	.196	.520	1.190	(1 Fe)[c]	.456	5.38
CK 60	.232	0	.183	.446	1.255	0	.486	6.10
Plainsman	.217	2	.101	.235	1.360	0	.443	5.98
Redbine 60	.212	2	.122	.256	1.638	0	.378	6.20
Wheatland	.200	1	.203	.468	1.559	0	.404	6.83
SC118	.194	2	.124	.202	1.528	0	.310	4.68
SC29-6-1	.189	2	.108	.205	1.341	0	.379	4.72
SC500-6-1	.187	3	.103	.156	1.192	0	.314	3.74
TAM 618	.148	1	.148	.224	1.161	0	.534	5.96
TAM B1K25	.148	2	.146	.221	1.301	(1 Fe)	.353	4.65
TAM 428	.140	2	.126	.175	1.332	0	.500	5.42
Tx2536	.139	2	.146	.194	1.329	0	.302	3.10
SC119-9-2-2-2	.108	3	.182	.205	1.738	0	.318	4.57
No. Platte	.108	3	.130	.140	1.526	0	.377	5.74
CK 60-Shallu	.101	3	.185	.185	.869	(1 Fe)	.667	5.80
SC177-155	.100	3	.178	.180	1.592	0	.362	5.04
CK60-Korgi	.067	3	.172	.115	1.312	0	.568	7.47

P deficiency symptoms. Two sorghum hybrids (RS 610 and RS 626) grown on the low P soil for comparative purposes grew poorly without added P (Table 2). With added P, RS 626 grew better than any of the sorghum lines. However, when the sorghum lines were grown on a nondeficient soil, the dry matter production of the hybrids (1.80 g/plant average) was not extensively higher than that of the sorghum lines (1.35 g/plant average) (Table 2). The corn inbreds Pa36 (P-efficient) and WH (P-inefficient) (13) were also grown on the low P soil for comparative purposes. Both corn lines had severe P deficiency with no added P and had moderately severe P deficiency with 110 kg/ha added P.

The sorghum plants grown on a nondeficient soil grew well and showed no P deficiency symptoms (Table 2). Dry matter yield, P concentration and content differences among plants were not particularly significant and were markedly higher than for plants grown on the low P soil. Sorghum grew as well and took up as much P as corn when grown on the nondeficient soil.

The correlations between dry matter produced and P concentrations of plants grown on both soils was not significant. Phosphorus contents of plants grown on the low P soil were more closely correlated with dry weights which would be expected since contents include dry weights in their calculations. Phosphorus concentrations in leaves alone appeared to be a poor parameter or criteria for evaluating P efficiency. Dry matter production and P contents seem to be more closely associated with severity of P deficiency than P concentrations. Corn did not appear to be as efficient for P as sorghum and showed more severe deficiency symptoms than sorghum when grown in soils with comparable amounts of P.

Table 2, cont.

Sorghum Line	Valentine				Sharpsburg			
	Dry wt.	Def. symp.[b]	P	P	Dry wt.	Def. symp.	P	P
	g/plant		%	mg/plant	g/plant		%	mg/plant
	Lines used for comparisons							
RS 626	.217	1	.116	.250	1.667	0	.346	5.74
RS 610	.198	2	.076	.151	1.925	0	.378	7.25
RS 626 (P added)	.966	0	.330	3.180	1.667	0	.346	5.74
RS 610 (P added)	(No Plants)		---	----	1.925	0	.378	7.25
	Corn lines used for comparisons							
Pa36	.315	3	.138	.458	1.332	2	.246	3.16
WH	.397	3	.102	.396	.654	3	.263	1.72
Pa36 (P added)	.802	2	.836	5.614	1.332	2	.246	3.16
WH (P added)[d]	.273	2	.738	2.004	.654	3	.263	1.72

[a] Average of 4 plants grown in 2 pots.
[b] Def. Symp. Scale 0 - No deficiency, 1 - slight deficiency, 2 - moderate deficiency, 3 - severe deficiency.
[c] No P deficiency, but Fe deficiency was present. Scale same as for P deficiency.
[d] Plants did not grow normally.

When dry matter yield, P concentration, and P content were compared to KS35, only 5 of the 23 sorghum lines produced at least 50% the dry matter as KS35. Those sorghum lines that had P deficiency ratings of 3 (the most severe P deficiency rating) yielded only 10 to 15% the dry matter as KS35. Sorghum lines used in this experiment generally grew poorly on the low P soil. Phosphorus concentrations varied from 46 to 105% (average of 71%) that of KS35 and P contents were as much as 13 times lower as KS35. Seventeen of the sorghum lines had less than one-third the P content of KS35. The sorghum hybrids grown without P yielded only about 30% that of KS35. Phosphorus contents of the hybrids were only about 14% that of KS35 and P concentrations were about half that of KS35. Only with added P did the hybrids out perform KS35. The corn lines had higher dry matter yields and P contents than sorghum hybrids with no added P. However, with added P, the sorghum hybrids had higher dry weight yields and P contents than the corn lines. This would suggest that the hybrids used here were not very efficient for P.

KS35 increased dry matter yields only 2-fold when grown on a non-deficient soil compared to the low P soil. On the other hand, CK60-Korgi showed a 20-fold increase in dry matter when grown on the nondeficient soil compared to the low P soil. All sorghum lines showed about 2- to 3-fold reductions in P concentrations when grown on the low P soil compared to the nondeficient soil. Phosphorus contents, however, were markedly lower in plants grown on the low P soil compared to the nondeficient soil; KS35 had a 4-fold reduction and CK60-Korgi had a 65-fold reduction

<u>Fe efficiency of sorghum lines:</u> Of the sorghum lines grown on the low Fe soil, most grew relatively well (Table 3). CK60 and Redbine-60 grew

Table 3. Dry-matter yields, degree of Fe deficiency, and Fe and P concentrations and contents of sorghum lines grown on a low Fe (Bridgett) and a nondeficient (Sharpsburg) soil.[a]

	Bridgett							Sharpsburg					
Sorghum Line	Dry Wt.	Def. symp.	Upper leaf Fe	Tops Fe	Tops Fe	Tops P	Tops P	Dry wt	Def. symp.	Tops Fe	Tops Fe	Tops P	Tops P
	g/plant		ppm	ppm	ug/plant	%	mg/plant	g/plant		ppm	ug/pl	%	mg/pl
CK 60	1.288	0	218	206	265	.250	3.22	1.255	0	358	462	.486	6.10
Redbine 60	1.256	0	142	166	208	.270	3.40	1.638	0	316	516	.378	6.20
SC29-6-1	1.147	0	200	248	248	.345	4.40	1.341	0	303	403	.379	4.72
SC118	1.076	0	196	243	290	.332	3.57	1.528	0	388	595	.310	4.68
SC500-6-1	0.952	0	236	270	254	.389	3.23	1.192	0	300	353	.314	3.74
Tx 2536	0.935	1	134	148	141	.398	3.28	1.329	0	345	458	.302	3.10
Tx412 - Tx414	0.897	0	193	214	192	.426	3.81	1.190	1	366	435	.456	5.38
SC119-9-2-2-2	0.893	0	175	220	195	.375	3.30	1.738	0	325	556	.318	4.57
Redlan	0.873	0	177	208	187	.338	3.04	1.358	0	392	532	.434	6.48
SC177-15E	0.870	0	172	234	204	.473	4.08	1.592	0	348	556	.362	5.04
CK 60 - Korgi	0.863	2	90	144	110	.424	2.68	1.312	0	221	290	.568	7.47
Martin	0.857	0	158	183	159	.282	2.40	1.200	0	254	306	.376	4.51
SC33-9-8-E4	0.818	0	234	236	206	.390	3.30	1.192	0	227	270	.452	5.38
Plainsman	0.812	0	134	160	147	.366	3.32	1.360	0	356	484	.443	5.98
TAM 428	0.752	0	173	221	167	.369	2.99	1.332	0	350	466	.500	5.42
EH-KS19	0.714	2	196	231	160	.588	3.73	1.479	0	331	490	.408	6.01
KS5	0.669	2	164	186	125	.303	2.03	1.236	0	314	387	.390	4.82
Wheatland	0.633	2	182	217	138	.378	2.41	1.559	0	326	506	.404	6.83
CK 60 - Shallu	0.617	2	172	239	143	.524	3.21	0.869	1	304	262	.667	5.80
No. Platte	0.595	2	114	232	139	.356	2.11	1.526	0	202	307	.377	5.74
TAM BLK 25	0.570	1	208	208	119	.442	2.46	1.301	1	270	352	.353	4.65
TAM 618	0.551	2	176	224	124	.476	2.58	1.161	0	384	445	.534	5.96
KS35	0.448	1	140	147	68	.354	1.54	1.291	0	252	324	.472	6.04

Table 3, cont.

Sorghum Line	Bridgett							Sharpsburg					
	Dry wt	Def Symp.	Upper leaf Fe	Tops Fe	Tops Fe	Tops P	Tops P	Dry wt	Def. Symp.	Tops Fe	Tops Fe	Tops P	Tops P
	g/plant		ppm	ppm	ug/plant	%	mg/plant	g/plant		ppm	ug/pl	%	mg/pl
	Lines used for comparison												
RS 626	1.201	0	138	164	197	.329	3.98	1.667	0	183	308	.346	5.74
RS 610	0.852	1	128	190	119	.370	2.50	1.925	0	240	454	.378	7.25
RS 626 (+Fe)	1.132	0	146	202	228	.304	3.95	1.667	0	183	308	.346	5.74
RS 610 (+Fe)	1.682	0	147	201	332	.352	5.92	1.925	0	240	454	.378	7.25
	Corn lines used for comparison												
WF9	1.029	0	152	170	174	.322	2.83	1.420	0	222	314	.251	3.59
Ys_1/ys_1	0.198	3	238	302	48	.386	0.63	0.307	3	185	59	.454	1.60
WF9 (+Fe)	0.985	0	186	231	228	.222	2.18	1.420	0	222	314	.251	3.59
ys_1/ys_1 (Fe)	0.834	1	211	301	251	.312	2.59	0.307	3	185	59	.454	1.60

Average of 4 plants grown in 2 pots.

the best and produced the most dry matter and KS35 (in contrast to producing the most dry matter when grown on the low P soil) grew the worst and produced the least dry matter. Only about 3-fold differences in dry matter yields were noted between KS35 and CK60. Iron deficiency symptoms on sorghum were not as severe as they were on ys_1/ys_1 corn, nor were dry matter yield reductions for sorghum as severe as ys_1/ys_1 corn. Although dry matter yields generally followed Fe deficiency severity, many lines with some Fe deficiency produced relatively high amounts of dry matter. Iron concentrations in the top leaves (173 ug/g) were not significantly different from Fe concentrations in all the leaves (208 ug/g). Although the P concentrations varied extensively in the sorghum lines, those producing the highest dry matter seemed to contain lower P concentrations, and those producing lower dry matter seemed to contain higher P concentrations (Table 3). Plants showing greater Fe efficiency usually contain lower P (8,9,10,14a), and plants with higher P efficiency have been associated with lower Fe efficiency (8). The position of KS35 in Table 2 (grown on the low P soil) compared to its position in Table 3 (grown on the low Fe soil) seem to confirm this idea. Additional experiments and more careful analysis of the data are needed, however, before confirmation of this relationship can be verified.

Iron and P concentrations were lower in the sorghum hybrids (grown for comparison) than the average for the sorghum lines. Upper leaves had lower Fe concentrations than tops when grown with or without Fe. The corn genotype ys_1/ys_1 was Fe deficient even when more than the usual amount of Fe was added (double). Dry matter yields increased 4-fold, however, with

this added Fe. Added Fe had no effect on WF9 yield but did increase Fe concentrations in the leaves from 152 to 182 ug/g in the upper two leaves and from 170 to 231 ug/g in all leaves. Iron concentrations in the plants grown on this low Fe soil were generally higher than those found in Fe deficient plants grown on other low Fe soils (8,14). As expected, Fe and P contents decreased as dry weights decreased.

Dry matter yields remained unchanged for CK60 when grown on the nondeficient soil compared to the low Fe soil. Both Fe and P concentrations and contents were about 2-fold higher in plants grown on the nondeficient soil, but more than adequate Fe was available for CK60 growth on the low Fe soil. On the other hand, KS35 dry matter yields increased about 3-fold when grown on nondeficient soil compared to the low Fe soil. Leaf concentrations of Fe and P were lower in KS35 plants grown on the low Fe soil than plants grown on the nondeficient soil, but not much different from the changes noted for CK60 grown on the same soils.

RS610 and RS626 grown on the low Fe soil with added Fe had higher Fe concentrations in their leaves than plants grown on the same soil without added Fe. Iron deficiency was overcome and dry matter yields increased 2-fold in RS610 from the added Fe, but added Fe had no effect on RS626. When grown on the nondeficient soil, these inbreds had higher Fe concentrations and contents and higher dry matter yields then when grown on the low Fe soil (with or without added Fe)

The corn genotype ys_1/ys_1 had higher Fe and P concentrations than WF9 when grown on the low Fe soil, but dry matter yields of ys_1/ys_1 were

5 times lower than those of WF9. Added Fe to the low Fe soil improved ys_1/ys_1 growth significantly but had no effect on WF9 growth. Moderately severe Fe deficiency was noted for ys_1/ys_1 grown on the supposedly non-deficient soil. The corn genotype ys_1/ys_1 utilizes Fe very poorly even in soils where many plants grow normally without Fe deficiency.

Conclusion: Large differences were noted for sorghum lines when grown on Valentine (low P) soil. When these lines were grown on a nondeficient soil, growth, P concentrations, and P contents were markedly higher. This indicated that most of the sorghum lines had the potential to grow well if nutritional conditions are proper. Phosphorus concentration alone was not a good criteria to screen sorghum plants for P efficiency. The identification of superior lines for P nutrition appears feasible using this soil. More recent experiments, however, indicate that this soil may not be desirable for P screening studies. Problems of water retention and movement and seed germination appear, and these are of major concern.

Differences among sorghum lines for Fe nutrition when plants are grown on the low Fe soil were not as great as those noted for other low Fe soils (8,14). Iron concentrations in upper or all leaves alone were not good parameters or criteria to differentiate plant responses for Fe. Phosphorus concentrations also appear to be important in the Fe status of plants. Other soils or induced Fe deficiency conditions deserve checking and evaluation.

Growth (dry matter yields) and mineral deficiency symptoms appear

to be among the better criteria for screening differences in plants for P and Fe nutrition in soils. More pronounced differences among lines would be desired. Other parameters and criteria to evaluate plants for Fe and P need investigation in order to obtain more accurate screening results.

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THE EFFECTS OF LODGING ON YIELD, PROTEIN, AND TEST WEIGHT OF GRAIN SORGHUM

Jeffrey C. Larson and Jerry W. Maranville

A previous experiment conducted in 1973 (2) indicated that lodging can markedly reduce yields and alter protein concentrations and test weights. The effect was also shown to be greater by stalk breakage in comparison to root lodging and was more severe the earlier the lodging occurred. It has been demonstrated that lodging decreases yields in many of the small grain crops (1, 3, 5, 6, 8), and in the case of winter wheat, the earlier lodging was most detrimental to yield (8). A reduction in total protein production for this crop was shown by Laude and Pauli (3). Pendleton (6) reported that the earlier and the more severe the lodging, the lower the yield and test weight for oats. Similar alterations were noted in barley (1). These alterations due to lodging are of economic importance. The following experiments conducted in 1974 and 1975 were to confirm the effects demonstrated earlier in grain sorghum.

MATERIALS AND METHODS

Field experiments were conducted in 1974 and 1975 at the State Experiment Station at Mead, Nebraska. Two grain sorghum hybrids were used. RS 626, a medium maturity, and RS 671, a medium late maturity hybrid were planted in a randomized split plot design with four replications. Each plot was of four rows, 4.5 m in length, at a population thinned to 250,000 plants per hectare. The experiment consisted of a check and 6 treatments which included: root lodging

45 degrees at heading, early dough, and hard dough, and stalk break of the peduncle at heading, early dough, and hard dough. Weeds were controlled with .9 kg atrazine and 2.7 kg ramrod per acre. One cultivation was necessary at the preboot stage to help control weeds. The experiments were sprinkler irrigated once at the preboot stage and later at heading. The root lodged plots were artificially lodged using an iron rod the length of the plot. Lodged plants were held in place with twine running between stakes placed at both ends and the middle of each row of treatment. Four rows were lodged in all treatments, and 3 m of the two center rows were harvested for yield.

Protein was determined by the method described by Udy (7) as modified by Maranville (4) for grain sorghum. Test weights were obtained by standard elevator procedure using a calibrated known volume container. Yields were adjusted to a 14% moisture basis.

RESULTS AND DISCUSSION

Data for combined lodging treatments for 1974 and 1975 generally showed a reduction in grain yield to occur and the reduction tended to be greatest for the earliest treatments. The lowest yield was observed for the stalk break at heading treatment which showed a yield reduction of 1952.4 kilograms per hectare from that of the control (Table 1).

There was a highly significant treatment x year interaction with respect to yield, which indicated that the treatments did not always produce the same effect each year. Varieties, however, reacted similarly to treatments each year. As shown in Table 1, the lodging type and the time at which it occurred were important. The trend was toward decreased yield for the earlier and more severe (stalk break) treatments, although

Table 1. Effect of various lodging treatments on two grain sorghum hybrids over two years to yield, test weight, percent protein and total protein.

Treatment	kg/ha Yield	kg/hl Test Weight	Percent Protein	kg/ha Total Protein
1. control	6233.7 a[1]	70.4 b	10.0 ab	625.0 b
2. 45° @ heading	5310.8 b	69.2 ab	10.1 ab	573.4 c
3. 45° @ soft dough	5423.8 b	68.8 a	10.3 b	551.9 c
4. 45° @ hard dough	6183.4 a	69.2 ab	10.2 b	633.5 b
5. S.B. @ heading	4281.3 c	68.5 a	10.2 b	436.3 d
6. S.B. @ soft dough	5474.1 b	69.0 ab	10.2 b	560.6 a c
7. S.B. @ hard dough	6164.6 a	70.6 b	9.8 a	603.7 ab

[1]Means followed by the same letter are not significantly different at the 5% level according to Duncan's Multiple Range Test.

this was not always the case. Results obtained in 1973 (2) indicated that the type of lodging was the predominate factor in yield reduction. The present experiments, however, would imply that the time of lodging was the most important factor although both were important in all cases. The hard dough treatments for the stalk break and root lodging showed no decrease in yield from the control. This indicated that if lodging occurred close to physiological maturity there would be little or no yield reduction occurring other than perhaps harvesting loss.

There was little difference noted in percent protein among treatments. The lowest was 9.8% for the stalk break at hard dough (Table 1). This was in contrast to 1973 where the percent protein tended to be significantly higher with lower yielding treatments. There was a trend for most lodging treatments in 1974 and 1975 to have a higher percent protein, but it wasn't significant. Perhaps climatic conditions affecting the plant after lodging caused the treatments to perform differently each year with respect to

protein concentration and the subsequent treatment x protein interaction.

Total protein reflects a combination of yield and percent protein. The yield affected the results more than the concentration of protein since the highest yielding plots also had the highest total protein (Table 1). The control, root lodging and stalk break at hard dough treatments had the highest values for total protein with 625.0, 633.5, and 603.7 kilograms per hectare, respectively. The lowest was obtained with the stalk break at heading which yielded 436.3 kilograms per hectare. These treatments were also the highest and lowest respectively for grain yield and agrees with results found in 1973 (2) where the total protein was chiefly a reflection of grain yield.

The test weight was reduced significantly in the lodging treatments from the control. The control and stalk break at hard dough had the highest test weights at 70.4 and 70.6 kilograms per hectoliter and shown in Table 1. These were significantly higher than the stalk break at heading and root lodging at soft dough. This again was similar to the results found in 1973 (2) where the lodging treatments caused significant test weight reductions.

The hybrids were significantly different with respect to test weight and protein concentration but not yield (Table 2). The difference in the protein concentration was reflected in the total protein which was higher for RS 671.

Table 2. Yield, test weight, percent protein and total protein of two grain sorghum hybrids over lodging treatments for two years.

Hybrid	kg/ha Yield	kg/hl Test wt.	Percent Protein	kg/ha Total protein
RS 626	5587.7 a[1]	71.5 a	9.6 b	541.7 b
RS 671	5573.9 a	67.3 b	10.6 a	586.4 a

[1]Means followed by the same letter are not significantly different at the 5% level according to Duncan's Multiple Range Test.

SUMMARY AND CONCLUSION

These experiments confirmed those of the 1973 experiment in that lodging decreased yield, test weight and total protein production in grain sorghum. Protein concentration generally tended to increase which was most likely due to the lower grain yield. Yields tended to be lower with earlier and increased severity of lodging. The lowest yield was found with the stalk break at heading treatment which had a 31.3% reduction from the control. The percent protein values for the low yielding treatments tended to be higher than the control, but the differences were not significant as they were in 1973. The test weights were reduced by lodging treatments and may be the primary reason for the grain yield reductions. Apparently, photosynthesis and/or translocation are severely impaired due to lodging. This has been suggested previously (3). Total protein production was generally a reflection of grain yield rather than protein concentration of the grain.

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EFFECT OF HIGH TEMPERATURE ON PHOTOSYNTHESIS RATE OF SORGHUM AND CORN GENOTYPES

Norma V. Norcio and C. Y. Sullivan

This report is a continuation of the study relating to temperature effects on photosynthesis in sorghum and corn genotypes (1). In this study four sorghum genotypes, RS 626, RS 691, 9040 and Redlan and two corn genotypes, N142 and N7A, were included. Photosynthesis and respiration rates were measured at panicle initiation and flowering stages and at two temperature levels, 40 and 43 C using the oxygen evolution technique.

Table 1 shows the ANOVA for the effect of temperature on the photosynthesis rate of the different entries at two temperature levels and at two stages of growth. Average values for photosynthesis rate at 40 C for all genotypes were 54.79 and 60.0 μmoles O_2 evolved/dm^2/hr, while at 43 C they were 54.72 and 17.08 μmoles O_2 evolved/dm^2/hr for panicle initiation and flowering stages, respectively. These values were all highly significant when compared to the L.S.D. (.01) temp x stage) of 3.35 μmoles O_2 evolved/dm^2/hr.

At 40 C small variations (insignificant) in photosynthesis rates were observed between the different entries at panicle initiation stage. The different entries nearly maintained their rates up to flowering except for RS 691. The value at 40 C reported for RS 691 (33.14 μmoles/dm^2/hr) was unreasonably low compared to the value at 43 C (49.81 μmoles/dm^2/hr) at the same stage so that some mechanical error may have affected its reading, although the oxygen electrode was checked and calibrated daily.

At 43 C there was an abrupt decline in the photosynthesis rate of RS 626 and Redlan at flowering stage, while 9040 and RS 691 maintained an appreciably higher rate compared to the corn lines. There was a higher photosynthesis rate at panicle initiation than at flowering stage both at 40 and 43 C. The sensitivity of the flowering stage to the higher temperature used (43 C) was shown clearly as it affected RS 626 and Redlan (Figures 1 and 2).

The ability to maintain a higher photosynthetic rate at these two growth stages when exposed to high temperature stress is important in the growth and development of the plant. Sorghum lines which are able to photosynthesize at an appreciable rate when subjected to this stress will be favorable in selecting for parent materials in a breeding program geared towards varietal improvement under environmental stress.

As reported previously, the respiration rate at 43 C was higher than that at 40 C. (Figure 3).

Figure 4 shows the relationship between photosynthesis rate and heat tolerance of one of the sorghum entries (hybrid) RS 691 and its parents, 9040 and Redlan. Although this was an average of a few observations, a positive trend in the relationship between these two parameters is noticeable. The same relationship exists both at 40 and 43 C. This in effect proves the effectiveness of the leaf conductivity test as a tool in selecting lines which are more heat tolerant from a large amount of breeding material. Specific photosynthetic measurements can then be made on the narrowed selections.

These results show some genotypic differences in photosynthesis rate as affected by stages of growth and temperature. Flowering stage exhibited a lower photosynthesis rate compared to panicle initiation. Some genotypes showed a highly sensitive response to elevated temperatures at the flowering stage as compared to that at the panicle initiation stage, while others were capable of maintaining their photosynthesis rate under periods of high temperature stress.

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Table 1. Analysis of Variance table for the effect of temperature on photosynthesis rate of sorghum and corn genotypes at two temperature levels and two stages of growth.

Source of Variance	DF	Mean Squares
Replication	3	211.93
Variety (Var)	5	998.21**
Temperature (Temp)	1	5578.30**
Var x Temp	5	2084.14**
Stage	1	12120.54**
Var x Stage	5	1211.83**
Temp x Stage	1	4994.94**
Var x Temp x Stage	5	1535.93**
Error	69	230.82

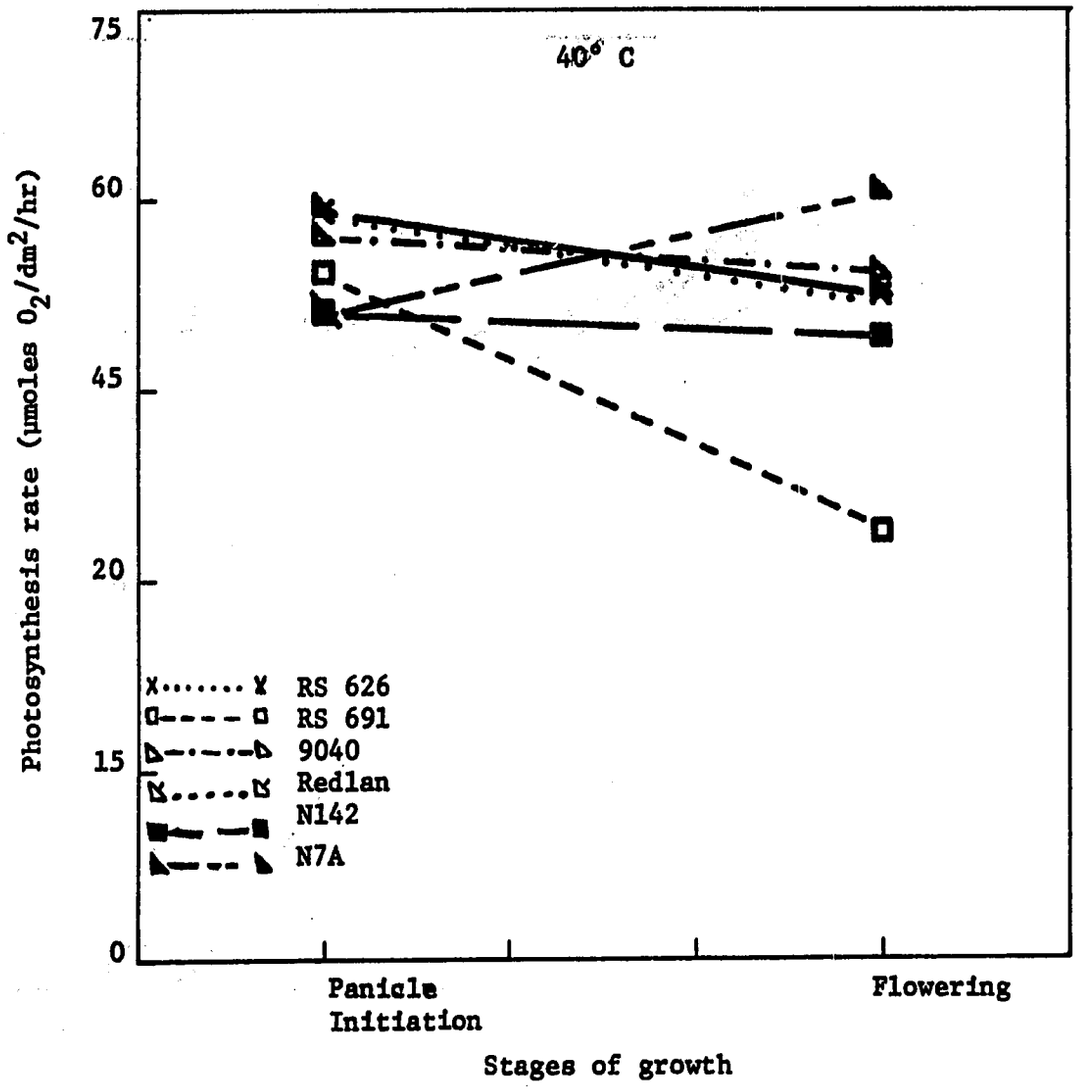

Figure 1. Photosynthesis rate of sorghum and corn genotypes at two stages of growth at 40°C.

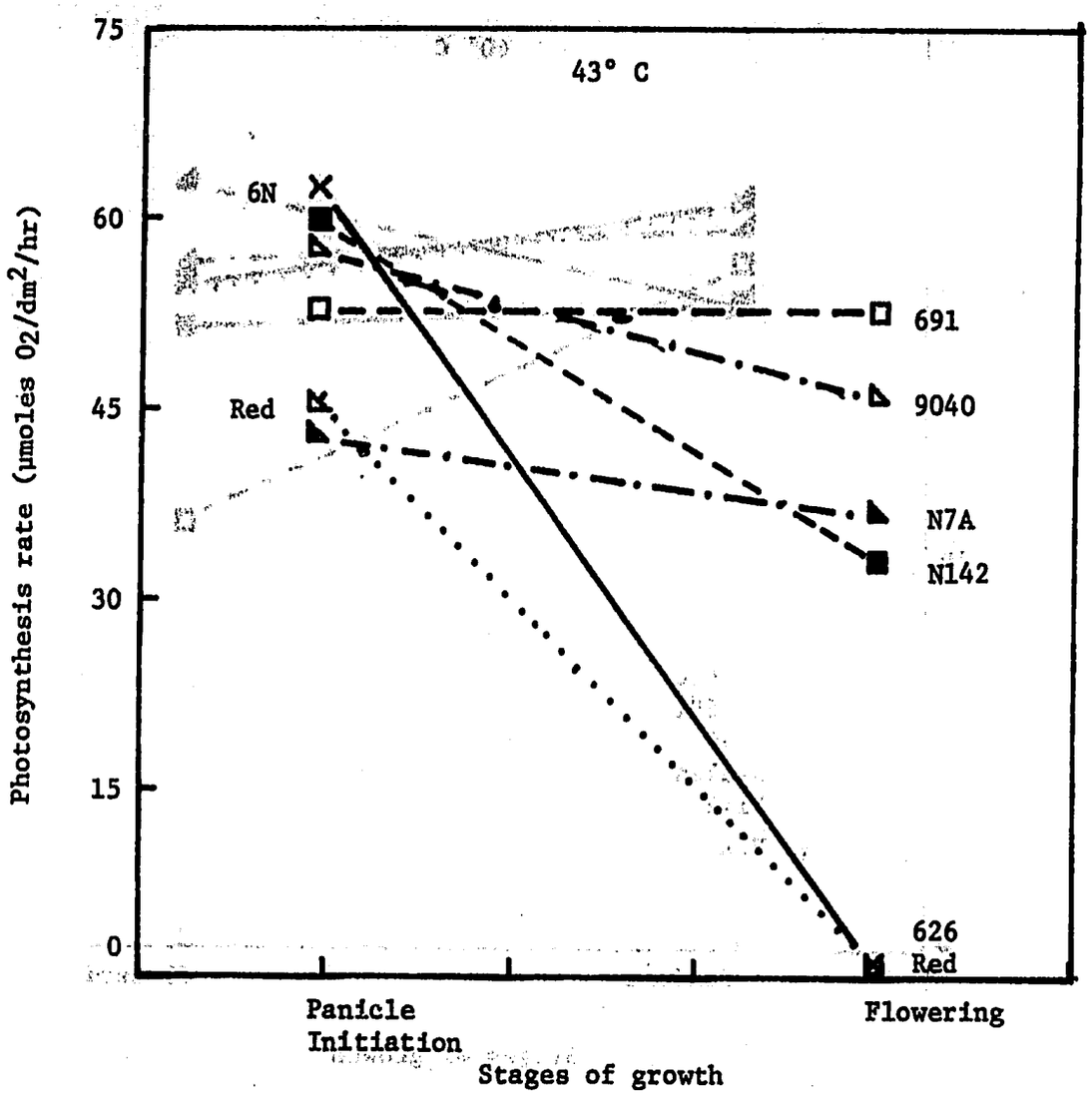

Figure 2. Photosynthesis rate of sorghum and corn genotypes at two stages of growth at 43° C.

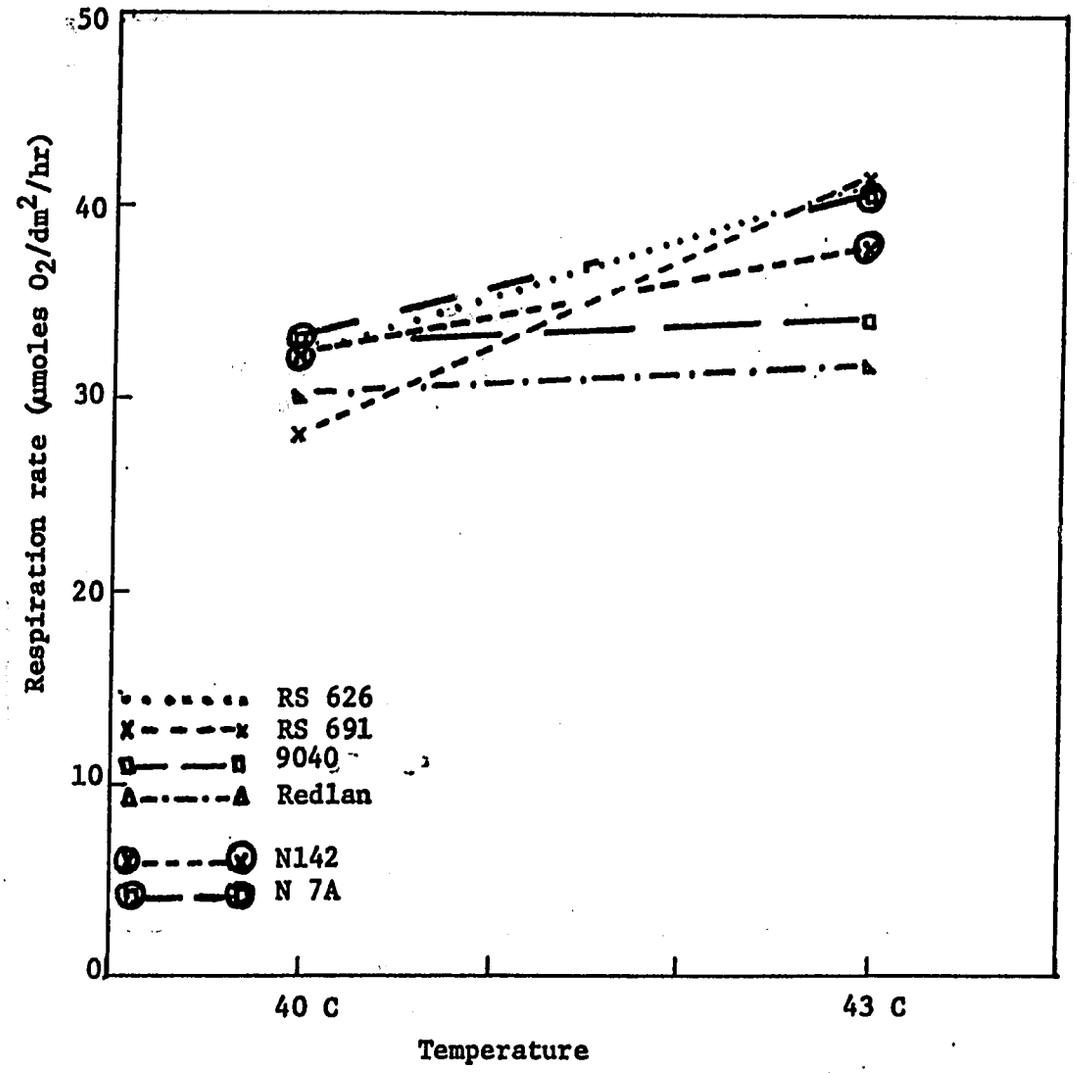

Figure 3. Temperature influence on the respiration rate of sorghum and corn genotypes. (Combined means of two growth stages)

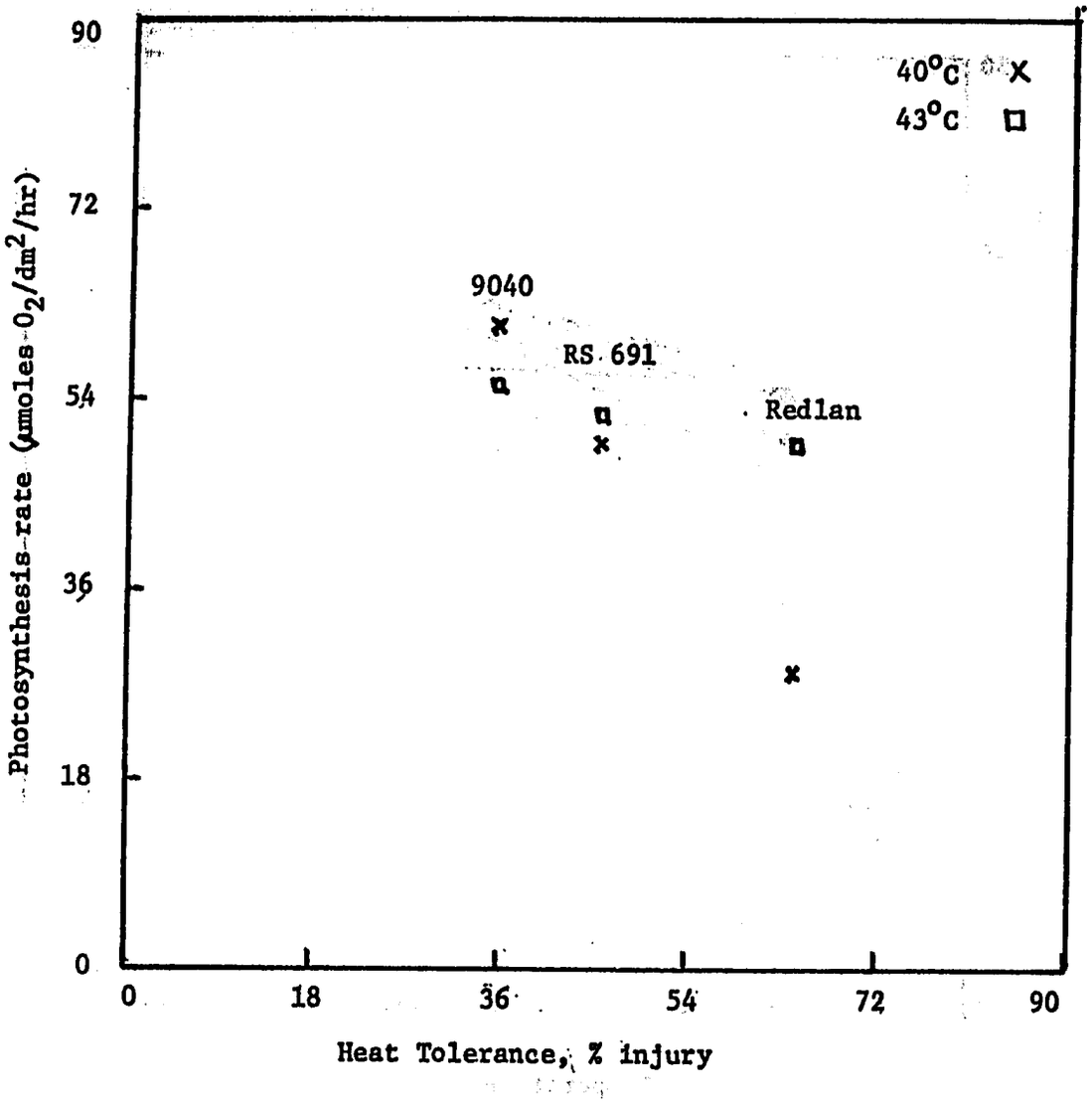

Figure 4. The relationship between photosynthesis and heat tolerance of a sorghum hybrid and its parental lines. (Photosynthesis readings were made one day after the heat tolerance test was done)

STOMATAL AND NON-STOMATAL INHIBITION OF PHOTOSYNTHESIS AT HIGH TEMPERATURES IN SORGHUM

N. V. Norcio and C. Y. Sullivan

The closure of stomates has been claimed to reduce photosynthesis by inhibiting the supply of CO_2. Mederski, et al. (1975) reported that stomatal regulation of CO_2 diffusion in the leaf decreased with increased leaf water deficits. However, when air was forced through the leaf, the rate of assimilation was not inhibited by an increasing leaf water deficit. They concluded that the inhibition of net carbon exchange with increasing leaf water deficit was due to an increase in diffusive resistance to gas exchange and not a change in mesophyll resistance.

Heichel and Musgrave (1970) studied the relationship between photosynthesis and moisture stress in corn under field conditions. They found a significant correlation between these two factors. Also, they found three different patterns in the photosynthesis rate of corn lines as affected by drought, namely; a) photosynthesis declined with leaf water potential but without apparent stomatal control, (b) photosynthesis declined with leaf water potential and stomatal conductivity, and (c) photosynthesis declined with stomatal conductivity but responded little to decreased leaf water potential.

Boyer and Bowen (1970) showed a parallel reduction in CO_2 between sunflower chloroplasts and intact plants having low leaf water potentials. They attributed this to a decrease in chloroplast activity as the photosynthetic electron transport system was affected.

El sharkawy, et al. (1964) reported that leaf net photosynthetic rates were depressed by high water deficits and high temperatures in some species. They also claimed that temperature optima for species with high photosynthesis rates, as in sorghum were higher than in species with lower photosynthetic rates, as in cotton. Maximum net photosynthesis was found in sorghum to occur at temperatures of 30-45 C. Downton and Slatyer (1972) found lower temperature regimes of 25/20 C day-night temperature to be maximum for cotton. Also ribulose di-P carboxylase activity was highest at this temperature combination.

Studies have shown that water deficits, as well as high temperature, affects net photosynthesis. This could be expressed through desiccation or high temperature effects at the photochemical level, or by decreased diffusivity from stomatal closure, or a combination of these effects. This study was conducted to determine the effect of high temperature only on the photosynthetic mechanism of sorghum.

MATERIALS AND METHODS

In order to study the biophysical and biochemical effects of high temperature on photosynthesis of sorghum plants, two systems were employed. The first system measured photosynthesis by oxygen evolution of chloroplasts in vivo thereby eliminating the physical resistance offered by the stomata and the boundary layer. Oxygen was measured polarographically by a Clark oxygen electrode and a Beckman Field Analyzer. The output was recorded on a Speedomax H. Recorder. A leaf section (4.0 x 8.0 cm) was immersed in a sodium carbonate and sodium bicarbonate buffer solution (Umbreit, et al. (1964). This source of

high CO_2 partial pressure which gave a CO_2 concentration of 5,000 ppm, promoted stomatal closure, and favored cuticular diffusion of CO_2 into the leaf.

The other system employed the use of an infra-red gas analyzer for measuring net CO_2 exchange of intact leaves. With this system, the air coming from the mixing tank was divided equally. One half was passed through a humidifier and a flow meter before it entered the leaf chamber. Then it passed into the reference cell of the analyzer. The other half of the air from the mixing tank was passed thru a flowmeter and a drier and into the sample cell of the analyzer. The differential in the CO_2 concentration between the leaf chamber air and the mixing tank was recorded by a Speedomax H recorder. Net photosynthesis was expressed in mg $CO_2/dm^2/hr$.

Temperature control in both systems was maintained by immersing the leaf chamber in a thermostated water bath. A thermocouple was placed on the abaxial surface of the leaf and read no more than one degree higher than the water bath. A conditioning period of 10 minutes was allowed for each leaf section to equilibrate to water bath temperature. Another 15 minutes was utilized for either photosynthesis or respiration measurement. On the average, it took from 30-45 minutes to finish one leaf section from the time it was cut and mounted in the leaf chamber until it was replaced by a fresh sample.

Light intensity was provided by two 300-watt Sylvania floodlights with a maximum intensity of 900 $\mu E/m^2/sec$. Half and quarter of this light intensity was imposed by using 3 and 5 layers, respectively, of cheesecloth between the leaf chamber and the light source.

Due to wettness of the leaf surface, the status of stomatal conductance was determined by an Alvim Porometer immediately upon removal of the leaf from the chamber. A diffusion porometer was unsuitable for this use. Briefly, the porosity of the leaf was determined by imposing 80 mm Hg pressure on the leaf and recording the reduction in pressure in 30 seconds. Leaf conductance was expressed in $cc/cm^2/sec$.

The genotypes used in this experiment included two sorghum hybrids and their parental lines namely:

Hybrid	Parents
RS 626	CK 60, TX 414
RS 691	Redlan, 9040

Seeds were planted in pots and were grown in the greenhouse at a temperature of 30/22 C day-night temperature up to flowering stage. They were transferred to growth chambers for conditioning at 27/22 C day-night temperature and then half were transferred to another chamber for heat treatment at 44/22 C for 24 hours. Photosynthesis measurements were done at three temperature levels and at three light levels after the preheat treatment.

RESULTS AND DISCUSSION

a) Non-stomatal inhibition (Oxygen evolution technique)

Table 1 shows the ANOVA for the effect of heat treatment on photosynthesis of six sorghum genotypes using the oxygen electrode. There were no significant differences between the heat treated and the control plants. On the average, photosynthesis rates of the control plants were higher at 40 and 43 C, however, at 46 C the average photosynthesis of

the treated plants maintained at a fairly constant rate, while the control plants declined abruptly (Figure 1). This indicates that the photochemical apparatus of the treated plants acquired some hardening or was more resistant to thermal inactivation than the controls.

The response of the different genotypes to high temperature can be gleaned from Figure 2. Among the hybrids used, RS 626 had a higher photosynthesis rate than RS 691 at the three temperatures used. The parent lines on the other hand, had lower rates except for 9040 which had an increased rate at 46 C. It should be noted that the photosynthesis rate of the hybrids followed the trend of one of the parent lines. Also that some hybrid vigor is expressed in the photosynthesis rates.

Genotype differences in photosynthesis rates, as light intensity was decreased, were highly significant. The decrease was more significant from full light to half light than from half light to 1/4 light (Figure 3). Except for Redlan, there was a parallel decrease in photosynthesis rate for all genotypes as light decreased.

b) Including Stomatal Inhibition (Gas exchange technique)

The ANOVA for the effect of heat treatment on photosynthesis rate of six sorghum genotypes using the infra-red gas analyzer is shown in Table 2. The control plants had a higher photosynthetic rate compared to the treated and this difference was highly significant at 40 and 43 C but not at 46 C. The CO_2 diffusion was inhibited in treated plants as shown by the lower rates. The stomates were apparently sensitive to the high temperature treatment. The highest temperature treatment (46 C) induced further stomatal closure in the treated plants and photosynthesis declined

abruptly, but there was a greater decline in the controls relative to the rate at 43 C (Figure 4).

Among the hybrids studied, RS 691 had a higher photosynthesis rate than RS 626 at the three temperatures studied. On the average, the hybrids had higher rates than the parental lines, except for 9040. Again the contribution of one of the parents to the hybrid is very eminent (Figure 5).

As in the oxygen evolution experiment, the response of the different genotypes to decreasing light intensity was observed (Figure 6).

c) Leaf Conductance

Table 3 shows the ANOVA for leaf conductance of six sorghum genotypes which were subjected to heat treatment. The preheat treatment affected the stomatal conductance of the plants particularly when subsequently exposed to 43 and 46 C (Figure 7) during the photosynthesis measurements.

Figure 8 compares the average leaf conductances of the preheat treated and control plants of the different genotypes after photosynthesis measurements at 40, 43 and 46 C. The stomates of 9040 were the most sensitive to the preheat treatment followed by RS 691, TX 414, RS 626, Redlan and the least affected was CK60. This decrease in stomatal conductance did not affect the photosynthesis rate of 9040 and RS 691.

In the hybrid RS 691, the decreased photosynthesis rate from 43 C to 46 C could be explained by decreased leaf conductance limiting CO_2 diffusion into the mesophyll. Redlan, however, did not increase at 46 C even though the stomates partially opened. Measurements of oxygen evolution did show an increased rate at 46 C over that at 43 C.

When comparing high temperature effects on the hybrids and their parents, with hybrid RS 626, it was only TX 414 whose photosynthesis rate was affected by the stomatal conductance. The other parent as well as the other hybrid were more affected at the chloroplast level.

SUMMARY

These results show that temperature affects both the stomatal and photochemical apparatus of sorghum leaves and that the two may interact. Plants that were preheat treated showed thermal stability at the chloroplast level in the high temperature range that was used in the measurements. Some of the entries, however, were affected by the heat treatment at the stomatal level as shown by the lower leaf conductance thus exhibiting lower photosynthesis rate as measured by the gas exchange technique.

Both hybrids exhibited hybrid vigor in photoshynthesis rate and followed the response of one of the parent lines.

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Table 1. Effect of heat treatment on photosynthesis rate of six sorghum genotypes using the oxygen electrode.

ANOVA

Source of Variance	DF	Mean Squares
Heat treatment (HT)	1	96.80^{ns}
Temperature (Temp)	2	9018.38**
HT x Temp	2	7636.60**
Variety (Var)	5	2988.92**
HT x Variety	5	624.39^{ns}
Temperature x Variety	10	89[illegible].75**
HT x Temp X Var	10	646.72^{ns}
Error a	72	358.05
Light	2	87773.41**
HT x Light	2	23.14^{ns}
Temp x Light	4	677.48**
HT x Temp x Light	4	1157.01**
Variety x Light	10	957.86**
HT x Var x Light	10	282.37**
Temp x Var x Light	20	248.69**
HT x Temp x Var x Light	20	245.83**
Error b	144	84.28

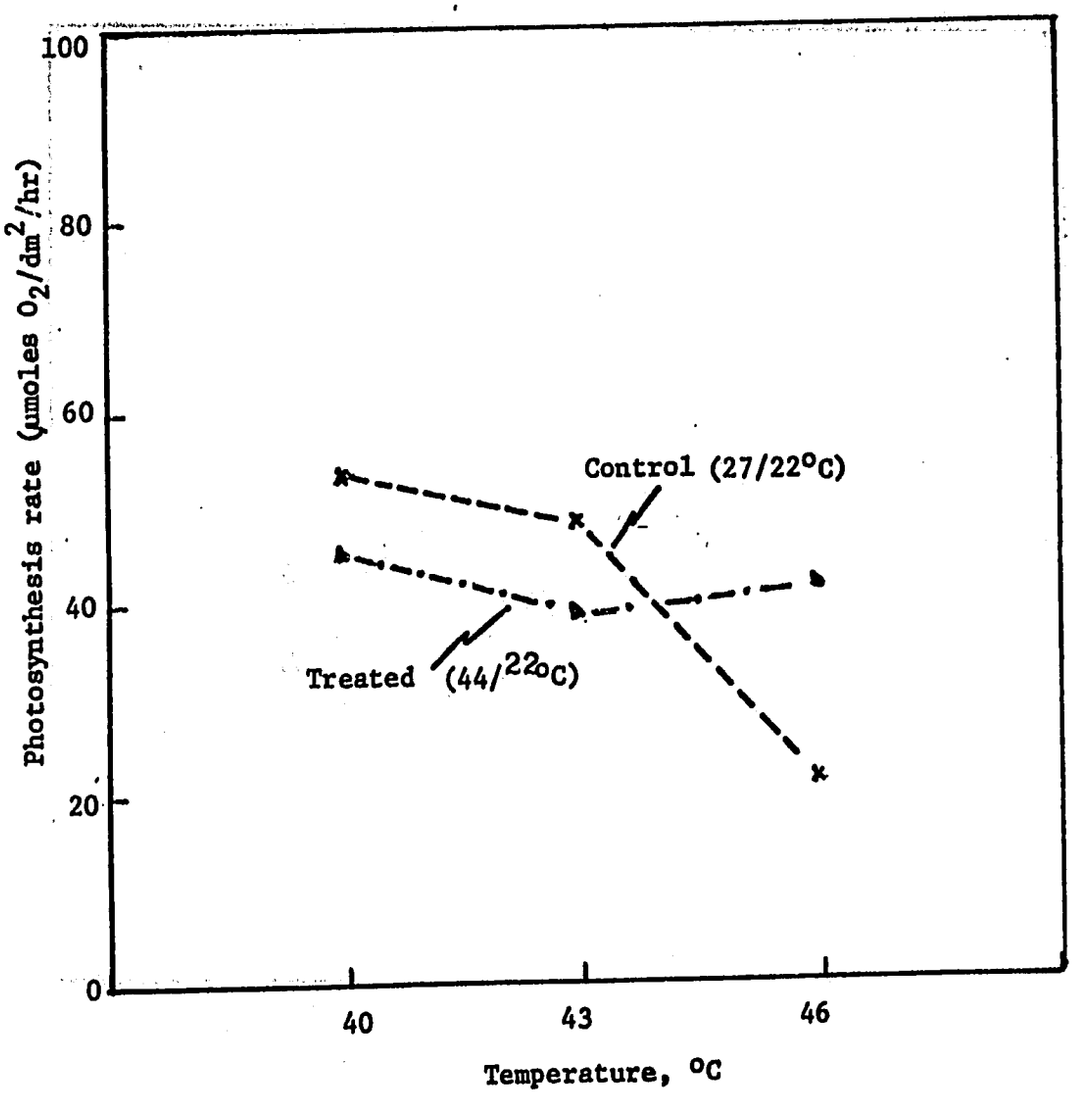

Figure 1. - Effect of temperature on photosynthesis rate of six sorghum genotypes as measured by the oxygen electrode

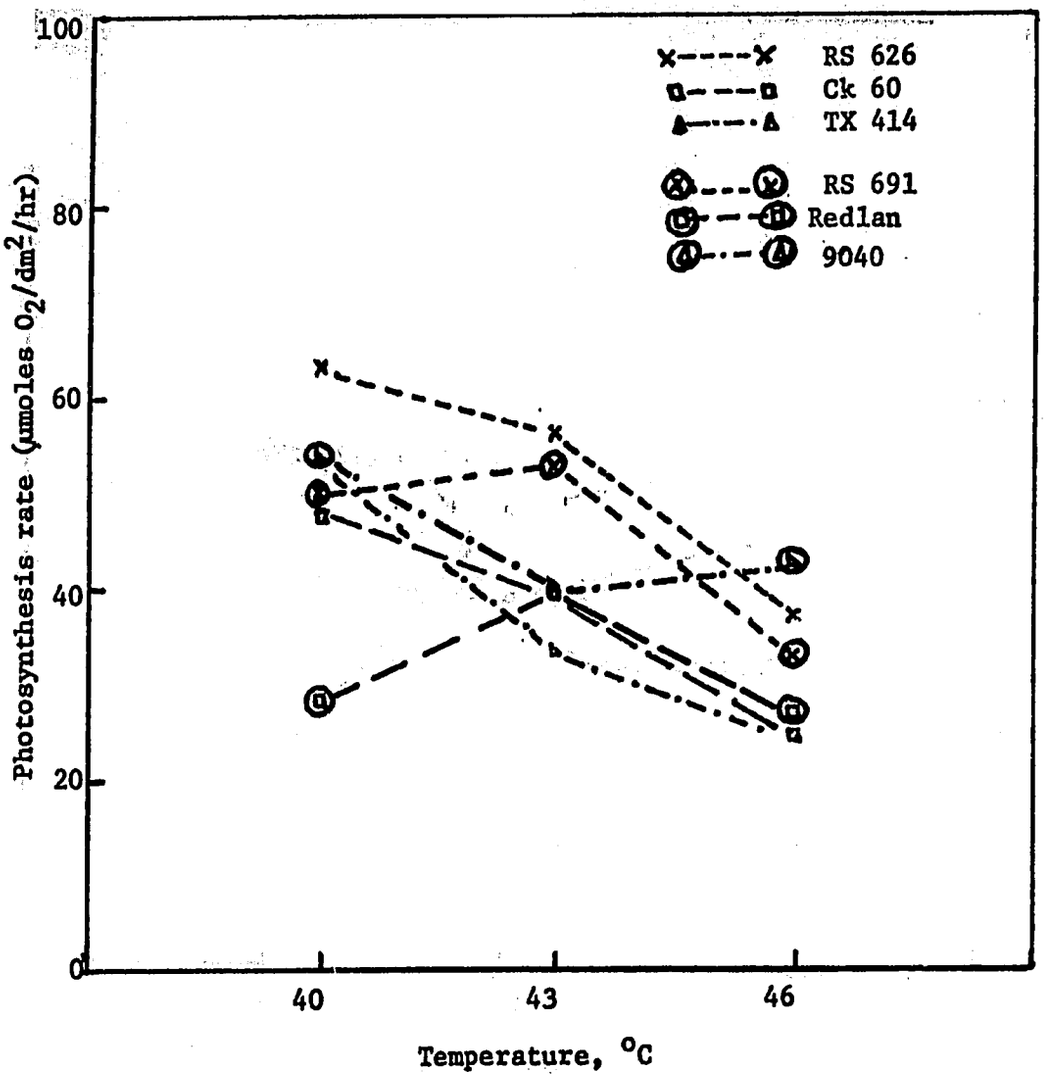

Figure 2. Effect of temperature on photosynthesis rate of sorghum hybrids and lines as measured by the oxygen electrode. (Combined means of heat treated and untreated plants)

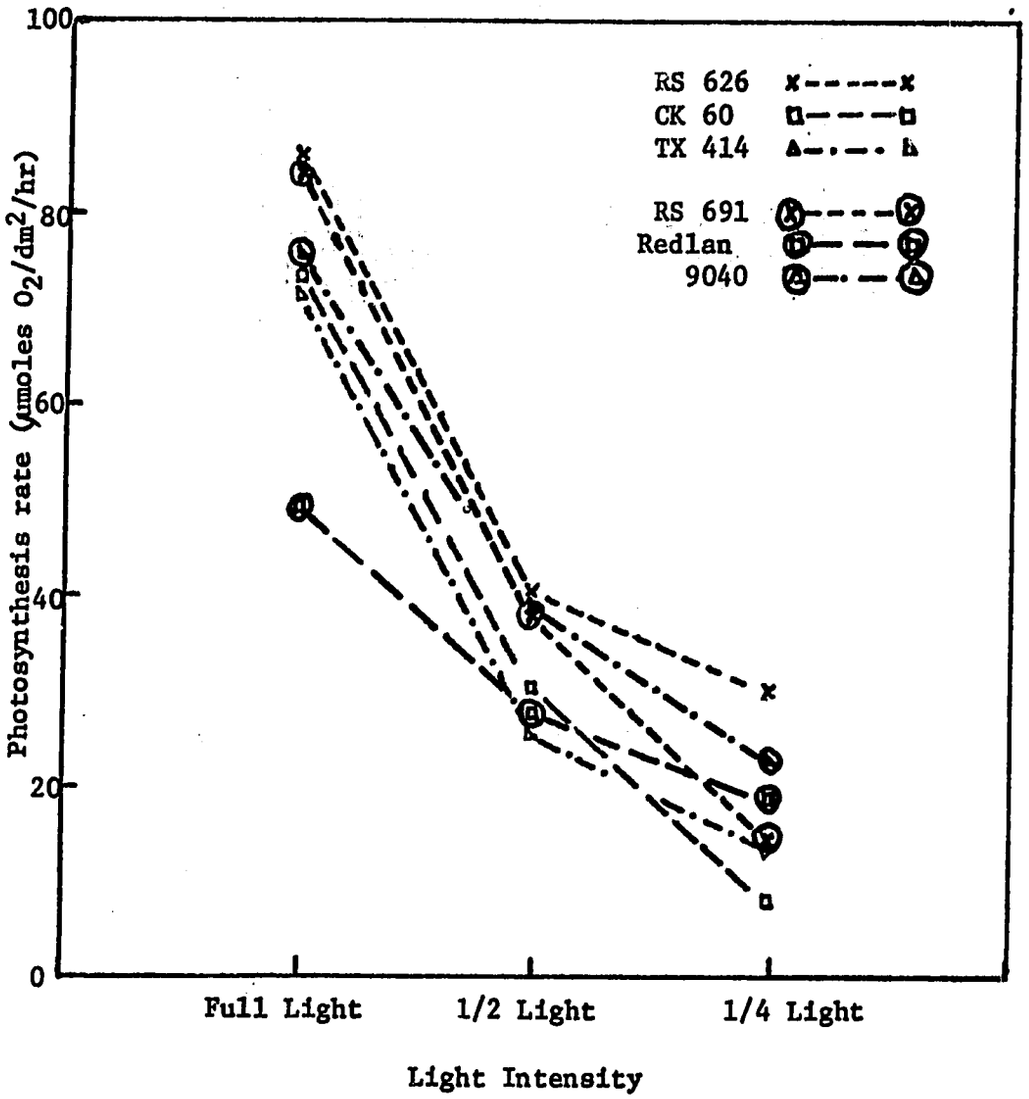

Figure 3. Effect of varying light intensity on photosynthesis rate of sorghum hybrids and parent lines as measured by the oxygen electrode. (Combined means of heat treated and untreated plants)

Table 2. Effect of heat treatment on photosynthesis rate of six sorghum genotypes using the IRGA.

ANOVA

Source of Variance	DF	Mean Squares
Heat Treatment (HT)	1	1134.42**
Temperature (Temp)	2	2517.09**
HT x Temp	2	171.47**
Variety (Var)	5	369.87**
HT x Var	5	32.45**
Temp x Var	10	71.00**
HT x Temp x Var	10	12.36**
Error a	72	2.92
Light	2	2226.11**
HT x Light	2	246.28**
Temp x Light	4	557.76**
HT x Temp X Light	4	60.74**
Var x Light	10	85.17**
HT x Var x Light	10	7.69**
Temp x Var x Light	20	20.45**
HT x Temp x Var x Light	20	4.77ns
Error b	144	2.79

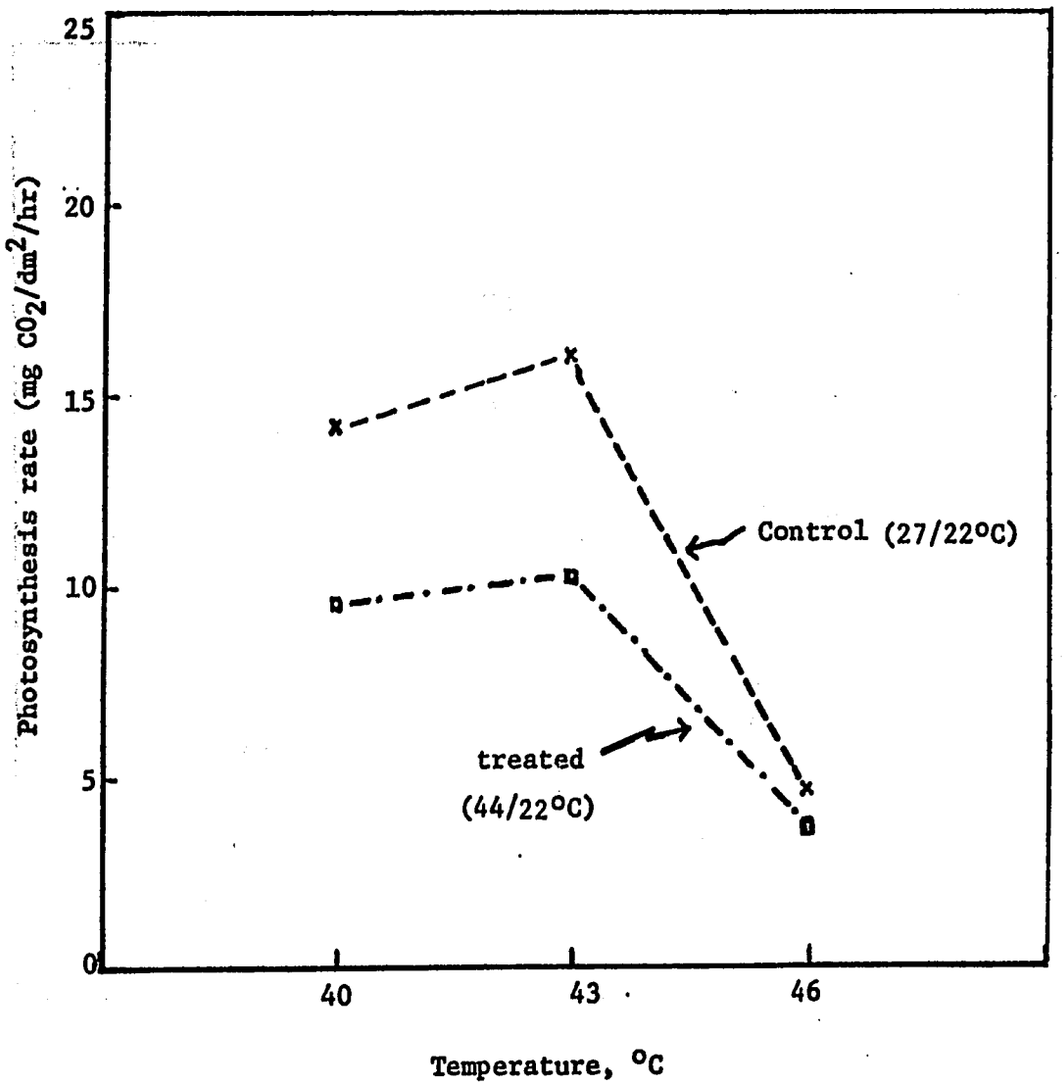

Figure 4. Effect of temperature on photosynthesis rate of six sorghum genotypes as measured by the IRGA.

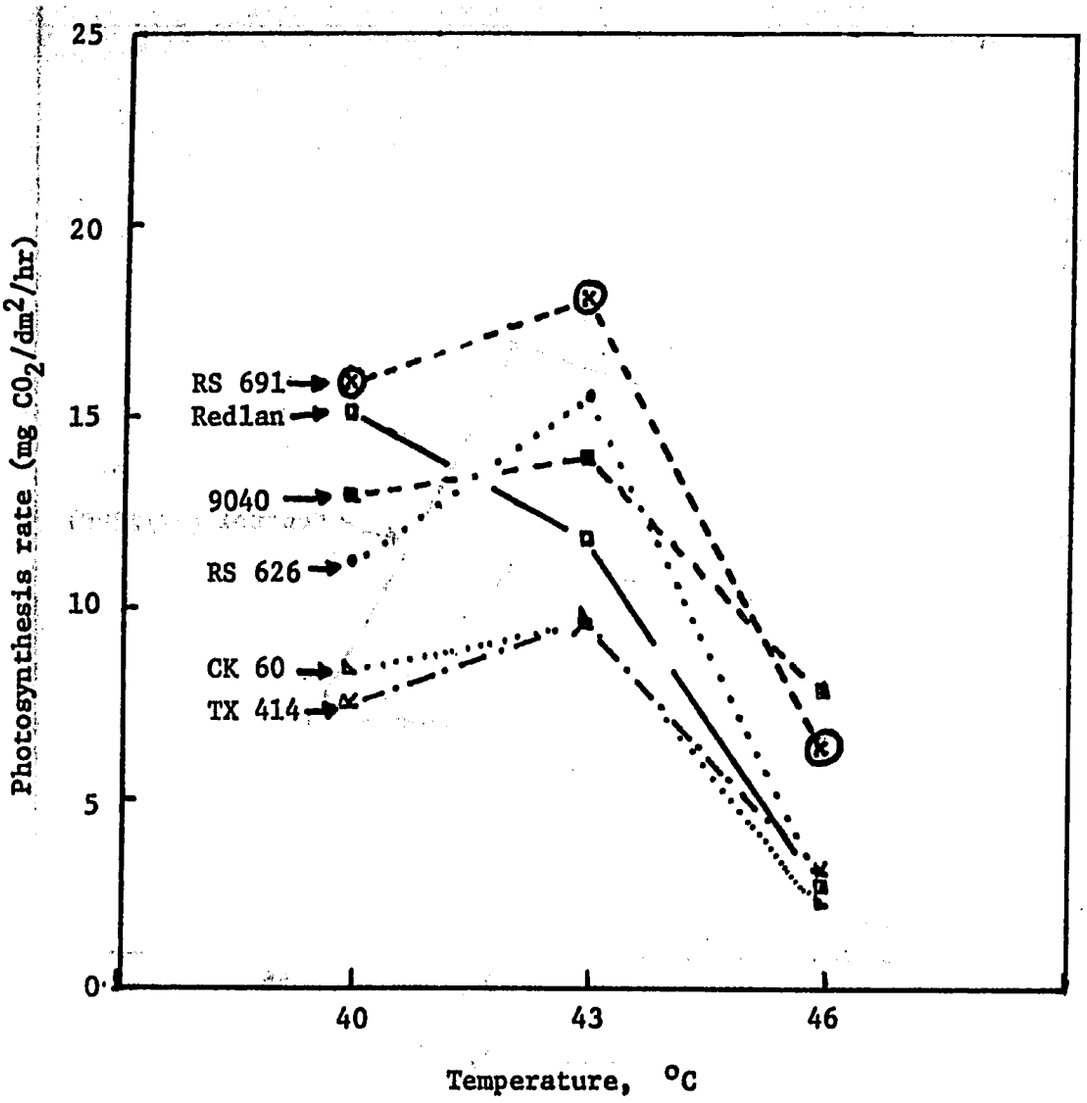

Figure 5. Effect of temperature on photosynthesis rate of sorghum hybrids and parent lines as measured by the IRGA. (Combined means of heat-treated and untreated plants)

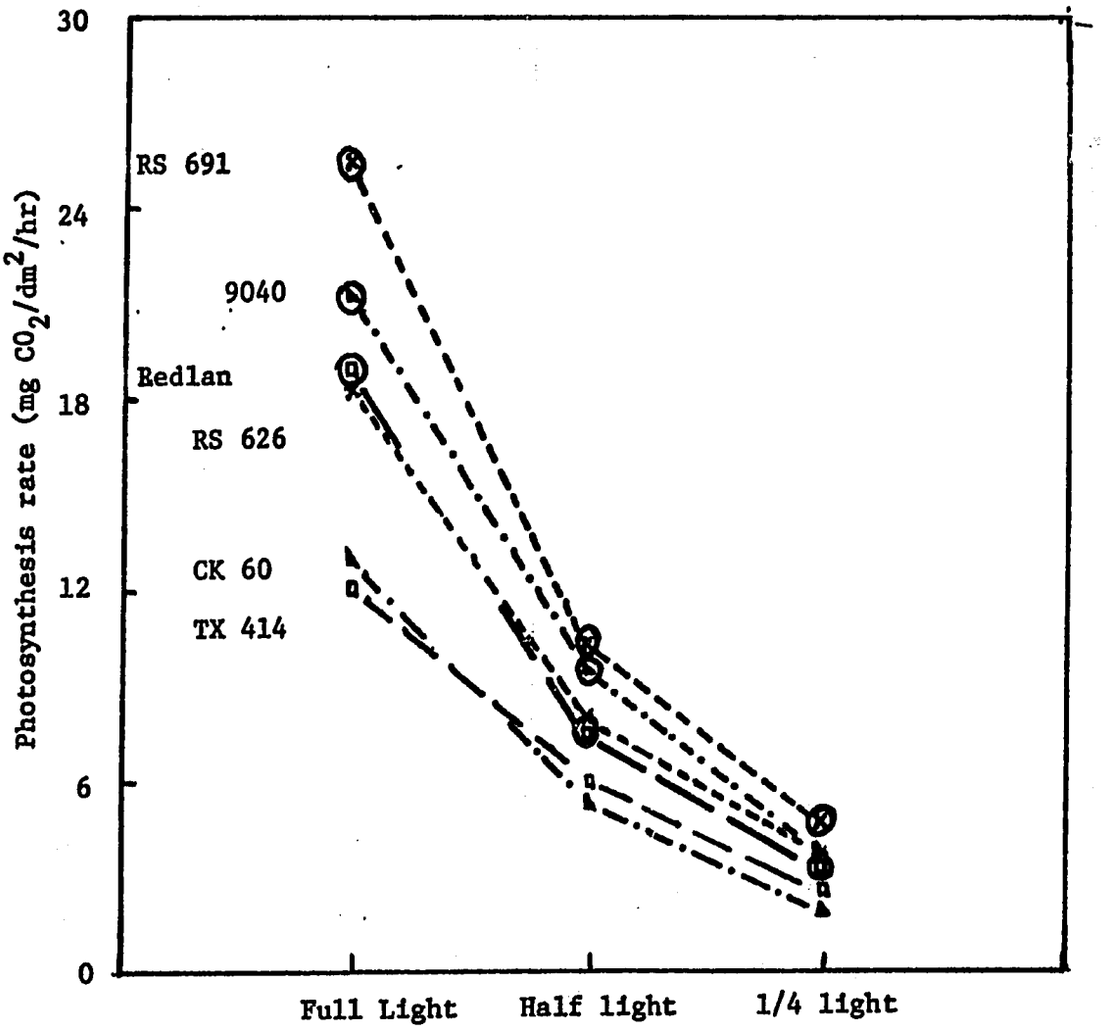

Figure 6. Effect of varying light intensities on photosynthesis rate of sorghum hybrids and parent lines as measured by the IRGA. (Combined means of heat treated and untreated plants)

Table 3. Effect of heat treatment on the leaf conductance of six sorghum genotypes using the Alvim Porometer.

ANOVA

Source of Variance	DF	Mean Squares
Heat Treatment (HT)	1	7.79**
Temperature (Temp)	2	2.34**
HT x Temp	2	7.82**
Variety (Var)	5	6.21**
HT x Var	5	0.66**
Temp x Var	10	0.57**
HT x Temp x Var	10	1.49**

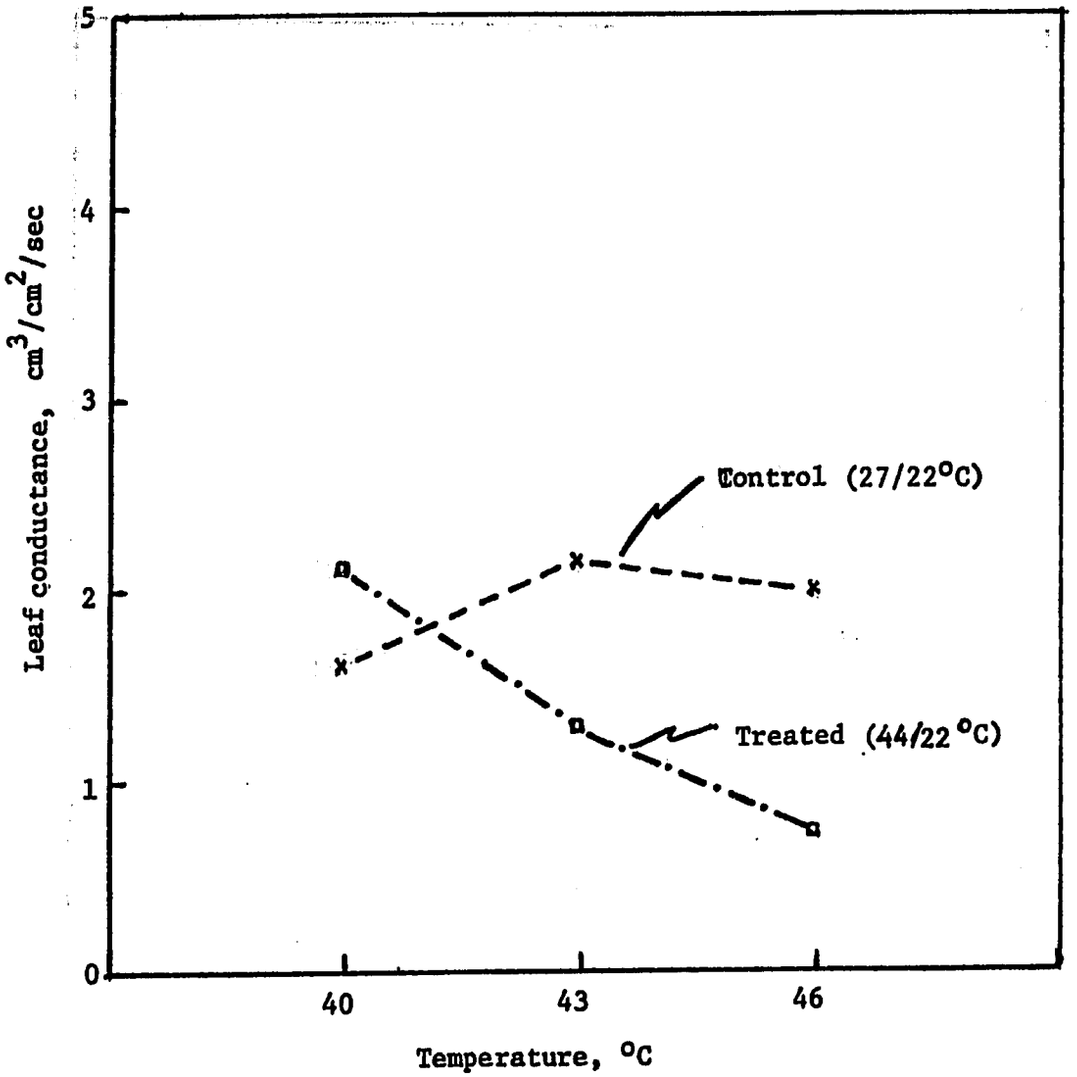

Figure 7. Values for conductance as measured with a pressure porometer at varying leaf temperatures.

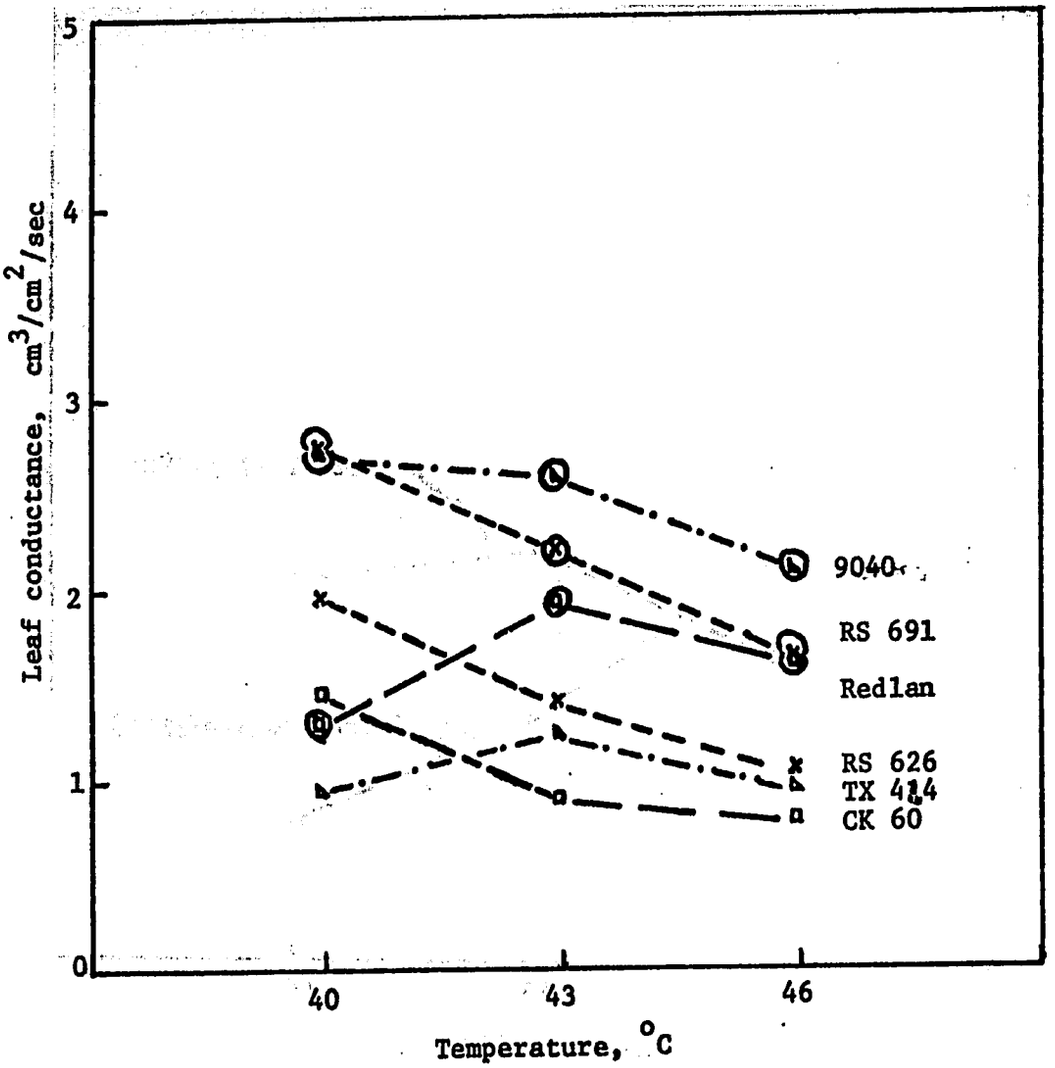

Figure 8. Values for leaf conductance of sorghum hybrids and parental lines at varying temperatures. (Combined means of heat-treated and untreated plants)

STUDIES OF NITRATE REDUCTASE ACTIVITY IN SORGHUM IN RELATION TO HEAT STRESS

Jerry W. Maranville and C. Y. Sullivan

Resistance of plants to irreversible injury from high temperature stress is often associated with stabilization of protoplasmic proteins (1, 2). Enzymes are known to "heat harden" i.e. activity not decreasing appreciably at high temperatures after whole plants are exposed to high but sub-lethal temperatures prior to the enzyme test. Several researchers studying a variety of enzymes such as urease (3), ATP-ase (4), phosphatase (5), malic dehydrogenase (6) and others have shown this effect. Much of the thinking generally centers around the ability of proteins to make the necessary adaptation of the level of their conformational flexibility of the macromolecule (2). The level of cell thermostability is characteristic of a given plant species which in turn is likely dependent on its origin. Plants evolved or growing in high temperature climates are most likely more thermophilic. Closely related species living under considerably different temperature conditions possess different cell thermostabilities (2). Differences in thermostability within the same species are also evident as well as the ability to heat harden (8). The exact magnitude that enzyme stability lends to overall heat resistance is not known, but most likely varies with genotype. Pal, et al. (9) have suggested that rate of loss of nitrate reductase activity may be a measurement useful in screening corn genotypes for heat tolerance.

The following experiment was designed to determine the relationship

of nitrate reductase activity to overall performance of grain sorghum subjected to high temperatures. One of the primary objectives was to evaluate this enzyme activity measurement for potential use in selecting sorghum genotypes which possess heat resistance.

MATERIALS AND METHODS

Initial experiments were conducted in order to determine at what temperature our tests of enzyme activity could be conducted for evaluating and determining genotypic differences with some certainty. Hybrid RS 671 was selected as the genotype to be used as a control since we have determined this hybrid to be moderately heat stress susceptible in our laboratory. Nitrate reductase activity was determined *in vitro* using the nickel chloride extraction and assay procedure (7). Seedlings were grown in vermiculite trays in a growth chamber set on 14 hr days and constant 24 C temperature to insure no or only slight heat hardening had occurred in the leaf material. Seedlings were harvested 10 days after planting and assays performed in water baths set at 25 C, 30 C, 35 C, 40 C, and 45 C on fresh leaf extracts. The results (Figure 1) showed 40 C to be the value where most, but not all, of the activity was lost and was thus selected as the temperature to perform the assays. All tests were compared to a 30 C control group and the results were reported as percentages of control.

Genotype comparisons were made on selected materials preliminarily screened for heat (drought) resistance and rated according to their performance.

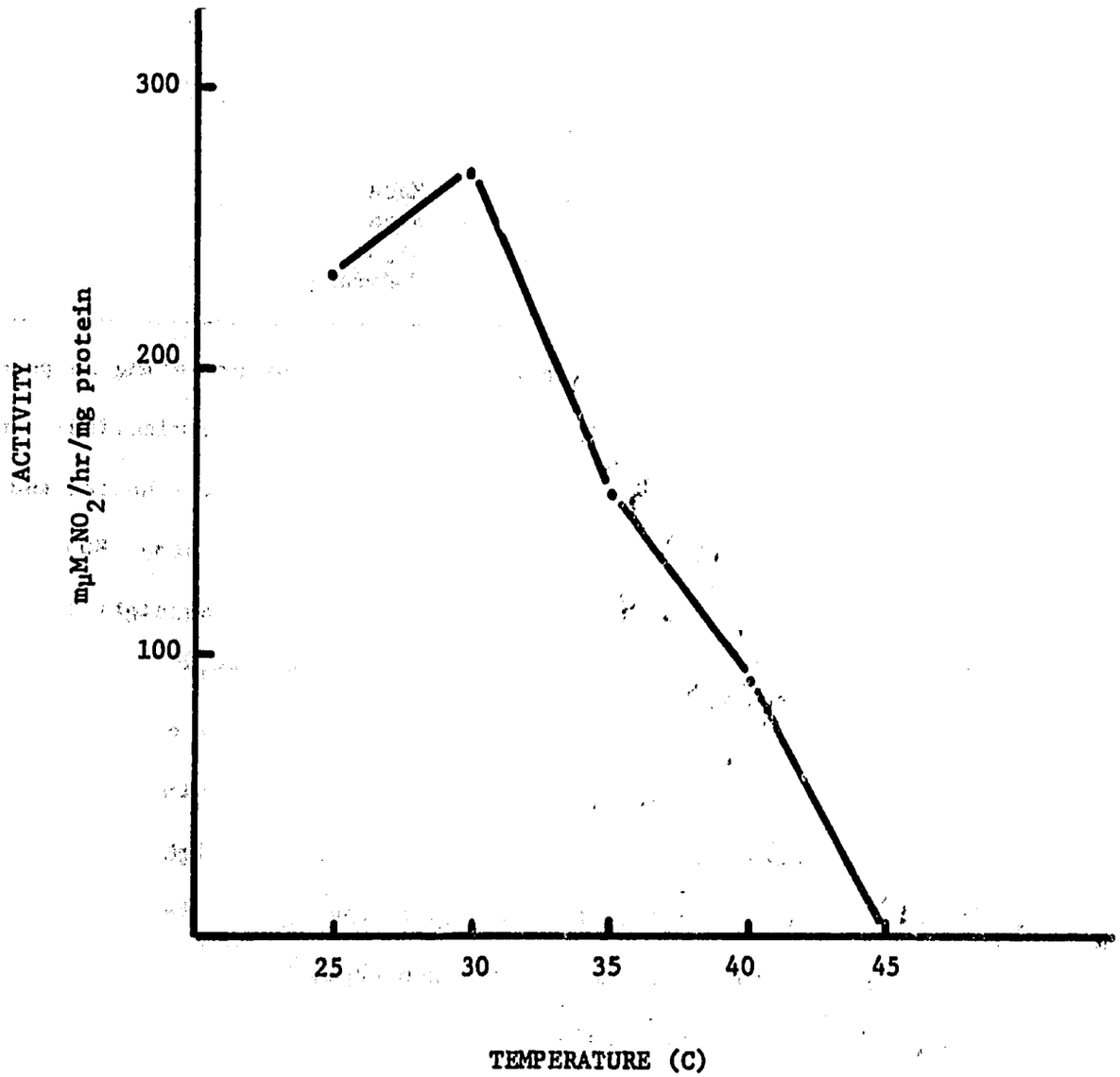

Figure 1. Nitrate reductase activity of RS 671 grain sorghum at different assay temperatures.

Table 1 shows the genotypes used and their ratings as to apparent resistant to heat stress.

Table 1.

Genotype	Drought Resistance Rating
RS 671	Moderate
M-35	High
Shallu	Low
Dwarf Milo	Moderate
Tx 414	Moderate
9040	High
Exp. 4104 (M-35 selection)	High
Exp. 4184 (M-35 selection)	Moderate

Three replications of each genotype were grown by preparing 24 pots for each of two growth chambers with a mixture of peat: vermiculite: sand (1:1:1). Light (heat) was supplied by 6 each 400 watt metal halide and 400 watt high pressure sodium bulbs per chamber producing about 800 $\mu EM^2 sec^{-1}$ intensity at the top of the pots (109 cm from source). Day/night temperatures were 30/25 C in one chamber and 40/25 C in the other at a relative humidity of about 65% day and 85% night. A similar number of pots were prepared and placed in a third chamber having conditions similar to the 30/25 C regime chamber previously described except that light was supplied by 12 metal halide lamps. Day length in all chambers was 14 hr. Excess seeds were planted in 3 pots each of the genotypes (Table 1) with each pot being considered a replication.

For the first experiment, the excess plants were harvested 18 days after planting for determination of nitrate reductase activity. Four

plants remaining per pot were used to determine plant height, number of leaves, and total dry matter accumulation at 21 and 40 days after seeding.

The second experiment consisted of measurements to distinguish heat hardening characters expressed by the genotypes. Heat tolerance was determined on two replications of plants grown 25 days in a 30/25 C day night chamber by the conductivity method (10). Simultaneous nitrate reductase assays were conducted on the same two replications. Plants were then hardened by elevating the chamber temperature to 40/25 C day/night for 6 days. At this time the cellular heat tolerance and nitrate reductase tests were repeated.

RESULTS AND DISCUSSION

Table 2 shows the results of the first experiment. In general the plants grown at 40 C did not appear to have as stable of nitrate reductase enzyme as those grown at 30 C. When the assay temperature was performed at 40 C, there was a 54.3% reduction in activity from the 30 C assay (control) for the plants grown at the higher temperature while only a 47.0% reduction for the lower temperature growth group. This comparison apparently reflects the growth differences observed. Average dry matter production for the 30 C group after 21 days from planting was 1.08 gm/plant while only 0.17 gm/plant was produced in the 40 C group. The entire plant growth system including enzymes was apparently hindered when the complete growing cycle from planting to the normal 8 or 9-leaf stage was subjected to high temperatures. Nitrate reductase activity did not appear to reflect the original ranking with regard to possible heat or drought

Table 2. Nitrate reductase activity as percent reduction at the elevated assay temperature for 8 sorghum genotypes grown at 30/25 C, 40/25 C day/night temperature regimes. Genotypes are ranked according to average performance.

Genotype	Rating	30 C Growth Temp.	40 C Growth Temp.	Ave.
		% Reduction		
Tx 414	Moderate	36.8	35.2	36.0
RS 671	Moderate	49.1	37.2	43.2
Dwarf Milo	Moderate	48.9	39.6	44.3
9040	High	36.2	61.2	48.7
Exp. 4184	Moderate	35.0	65.1	50.1
Shallu	Low	46.0	59.5	52.8
Exp. 4104	High	54.6	64.8	59.7
M 35	High	69.1	71.9	70.5
	Ave	47.0	54.3	

resistance. However, the growth observed (DM production) did not reflect the original ranking either. It is possible that in some cases, the seedling performance which was measured here, does not reflect the overall reaction of the genotype to heat or drought. Rather, it is more an indication of the seed vigor and seed performance of a given lot. Some seed lots produce good vigorous seedlings while others do not depending on the environment under which they were produced. RS 671 for example ranked high in both nitrate reductase activity stability as well as growth. Exp. 4104, on the other hand, ranked low in these measurements, but normally show good drought (heat) resistance during a dry season. Genotype M-35 is in a similar category, but again showed only moderate growth at 40 C and poorest enzyme stability. It was interesting to note that the

growth of the top three genotypes (most DM produced) after 40 days were also the top three genotypes with respect to enzyme stability to heat. The ones having the least growth at 40 C generally had the least enzyme stability although this relationship was not always exact.

The second experiment is summarized in Table 3. Both tests showed that hardening had occurred in plants exposed to 6 days of 40 C temperature. Nitrate reductase activity was reduced on the average by only 41.8 percent when the assay temperature was 40 C for the hardened group in comparison to 60.5 percent for the control group. Similarly, the percent injury for the hardened group by the conductivity test was only 6.0 percent in comparison to 25.8 percent for the controls. Enzyme activity according to original rank for heat resistance again did not particularly seem to show a strong relationship. However, the conductivity test seemed inconclusive with respect to this point also. The genotype M-35 did perform according to its observed high heat and drought resistance in our tests (Table 3), having the most stable nitrate reductase activity after hardening and the least injury with the conductivity test. Shallu appeared to be quite a hardy genotype according to the two laboratory tests, but actually has performed very poorly in other tests including the field. This points out that judgement of overall heat (drought) resistance usually can't be made from limited tests. Factors such as root systems, leaf resistance to water diffusion, ability to become dormant and others play important roles in the overall reaction to stress. Also, performance of young plants may be different from that of older field grown plants. More testing and refinement is apparently necessary before the nitrate reductase test could be used to substantially add to a selection program for heat and drought resistance of sorghum.

Table 3. Nitrate reductase activity as percent reduction at the elevated assay temperature and percent injury at 52 C for 15 min according to the conductivity test for 8 sorghum genotypes heat hardened for 6 days in comparison to a 30/25 day/night control group. Genotypes are ranked according to performance for average enzyme stability.

Genotype	Rating	Nitrate Reductase Control Group	Nitrate Reductase Hardened Group	Ave	Conductivity Test Control Group	Conductivity Test Hardened Group	Ave
		% Reduction			% Injury		
Exp. 4184	Moderate	49.1	36.9	43.0	22.0	4.5	13.3
Shallu	Low	52.5	40.5	46.5	38.7	3.5	21.1
9040	High	58.0	43.2	50.6	14.9	5.0	10.0
M 35	High	64.9	36.9	50.9	28.1	3.9	16.0
4104	High	63.3	43.2	53.3	26.3	8.3	17.3
Tx 414	Moderate	69.0	38.5	53.8	24.8	6.0	15.4
RS 671	Moderate	68.5	40.5	54.5	42.8	12.0	27.4
Dwarf Milo	Moderate	58.7	54.6	56.7	8.4	4.7	6.6
	Ave	60.5	41.8		25.8	6.0	

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CARYOPSIS DEVELOPMENT IN TWO SORGHUM HYBRIDS AND A LINE

Todd E. Dickinson and Jerry D. Eastin

INTRODUCTION

Grain sorghum caryopsis development has been investigated to a relatively limited degree. Most data have been gathered on a total panicle basis by periodically measuring total grain dry matter accumulation. However, blooming ordinarily proceeds in sorghum over a four to seven day period at Lincoln, Nebraska, giving rise to various maturity levels in the panicle at any one time. Little has been done on grain development in various parts of the panicle. Possibly, more detailed knowledge about the development of individual kernels or small panicle sections would define the kernel growth curve better and be useful to physiologists and plant breeders in crop improvement efforts. Further, comparisons between the development of hybrids and lines could be useful in explaining yield differences.

Research on caryopsis development, but on a full panicle basis has been done by Collier (2), Eastin (4), Gibson and Schertz (5) and Kersting *et al.* (7). Gibson and Schertz (5) worked with RS 610 and its parents. They found the hybrid to have more kernels than the female parent but not the male parent. Also RS 610 was found to outweigh the parents on a kernel weight basis. RS 610 had a two-day longer grain filling period and a faster rate of kernel growth. Collier's (2) data suggest greater

linearity in the growth curve and a longer period of linear growth in RS 610 over at least one parent. This may partially explain why hybrids generally outyields lines of the same general maturity.

MATERIALS AND METHODS

This experiment was conducted to follow caryopsis development of two grain sorghum hybrids and one grain sorghum line. The genotypes used were two open-pedigree hybrids: RS671 (Redlan x Tx415) and RS633 (Martin x NB6250). The line used was Martin B.

A split-plot design with randomized blocks was used with eight replications. Whole plots were a factorial combination of different panicle sections of the three genotypes. The split plots were 12 harvest dates randomly allocated within each whole plot. Individual panicles tagged on the same bloom date (within a genotype) were the experimental units.

Each panicle was measured for total length and a proportinate section was cut by length from the panicle. Section one was the top quarter of a panicle, section two the second quarter, section three the third quarter, and section four was the bottom quarter. Panicle sections were used to check for variation in grain fill characteristics rather than using a more tedious individual kernel approach. A whole panicle treatment was labeled section five and was divided by a factor of four when necessary to make it more or less comparable to the other sections. A different panicle was used for each section thereby permitting a good estimate of error.

The experiment was planted in 30 inch rows, fertilized with 100 lbs. of N and was furrow irrigated. For weed control atrazine and propachlor were used and greenbugs were controlled with Diazinon and Cygon. Stand counts at the end of the growing season showed RS671 to have a stand of about 147,500 plants/ha (59,000 plants/A) while RS633 and Martin B had around 137,500 plants/ha (55,000 plants /A).

All panicles in each genotype were tagged on one day, at tip bloom. Tip bloom for RS633 was August 1, and for RS671 and Martin was August 4. Five days after tip bloom the first harvest was taken and a subsequent harvest every five days thereafter until harvest date twelve. Harvests were therefore staggered with the equivalent harvests of RS671 and Martin being three days behind RS633.

Harvested panicles were sectioned and then oven dried to a constant weight at 100° C. Data collected were total dry weights of each section and grain weight per hundred seeds. All sections were hand threshed. Higher than normal temperatures shortened the filling period of genotypes from a normal of near forty days to about twenty-nine days. Fifty percent black layer at the tip for RS671 and RS633 was August 29 and was August 30 for Martin. Fifty percent black layer at the base, for all three genotypes, was September 6.

Harvest date one was dropped from the data because the immature state of the grain was giving inconsistent results with only the larger grains being threshed from the panicles. Harvest date eleven was not taken. This was due to the fact some panicles were lost near the end of the season because of stock rot in the peduncle and the remaining panicles were wanted for harvest date twelve.

RESULTS AND DISCUSSION

Table 1 contains the analysis of variance table for the total section dry weights of all three genotypes. In all three genotypes, dry weight of section five was not significantly different than dry weight of sections one to four averaged. This can be seen in the S5 vs S1 to S4 x D interaction. These results were expected because section five was defined as a whole panicle treatment divided by a factor of four to make it comparable to the other treatments. Confirmation of this point means a proper sampling and head dividing procedure was used. Also attainable from this table is the point that the first four sections act differently among themselves. This can be seen in the Among S1 to S4 x D interaction. Table 2 is a list of total dry weight means with significant differences shown with Duncan's Multiple Range Test.

As can be seen in Figure 1 through Figure 3, dry weights of sections two and three are fairly close and are generally larger than section five. Dry weights of sections one and four resemble one another staying mostly below section five. Linearity tests were run on dry weight of section five for the three genotypes to see if possibly the hybrids maintained linear dry matter production longer in the first harvest dates than the line. This may show why hybrids outyield lines. The results in Table 3 and 4 show that dry matter production of all genotypes was linear through date six but only dry matter production of RS633 was linear through date seven.

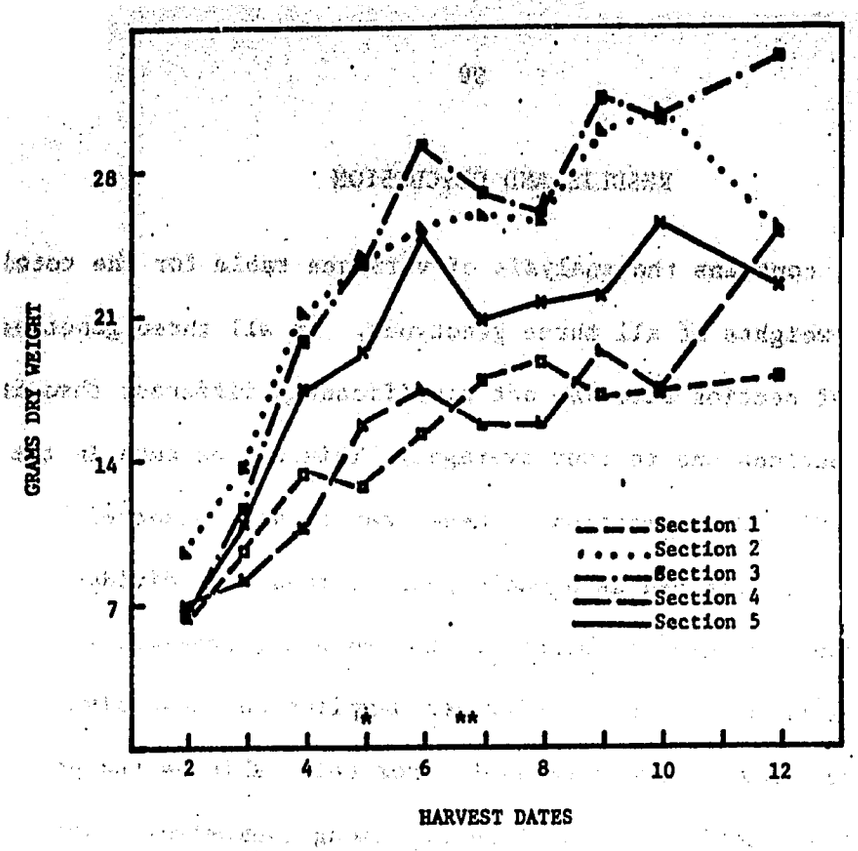

Figure 1. Mean total section dry weight of RS671 studied for panicle development at Mead, Nebraska, in 1975. Asterisks represent black layer dates at the tip (*) and the base (**). Experiment one.

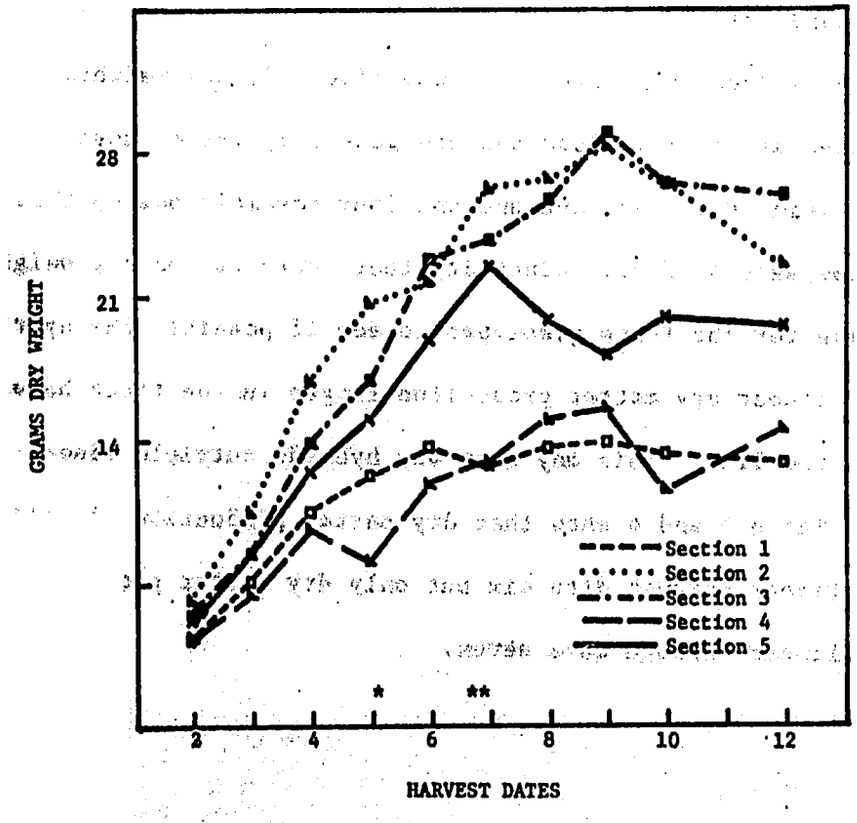

Figure 2. Mean total section dry weight of RS633 studied for panicle development at Mead, Nebraska, in 1975. Asterisks represent black layer dates at the tip (*) and the base (**). Experiment one.

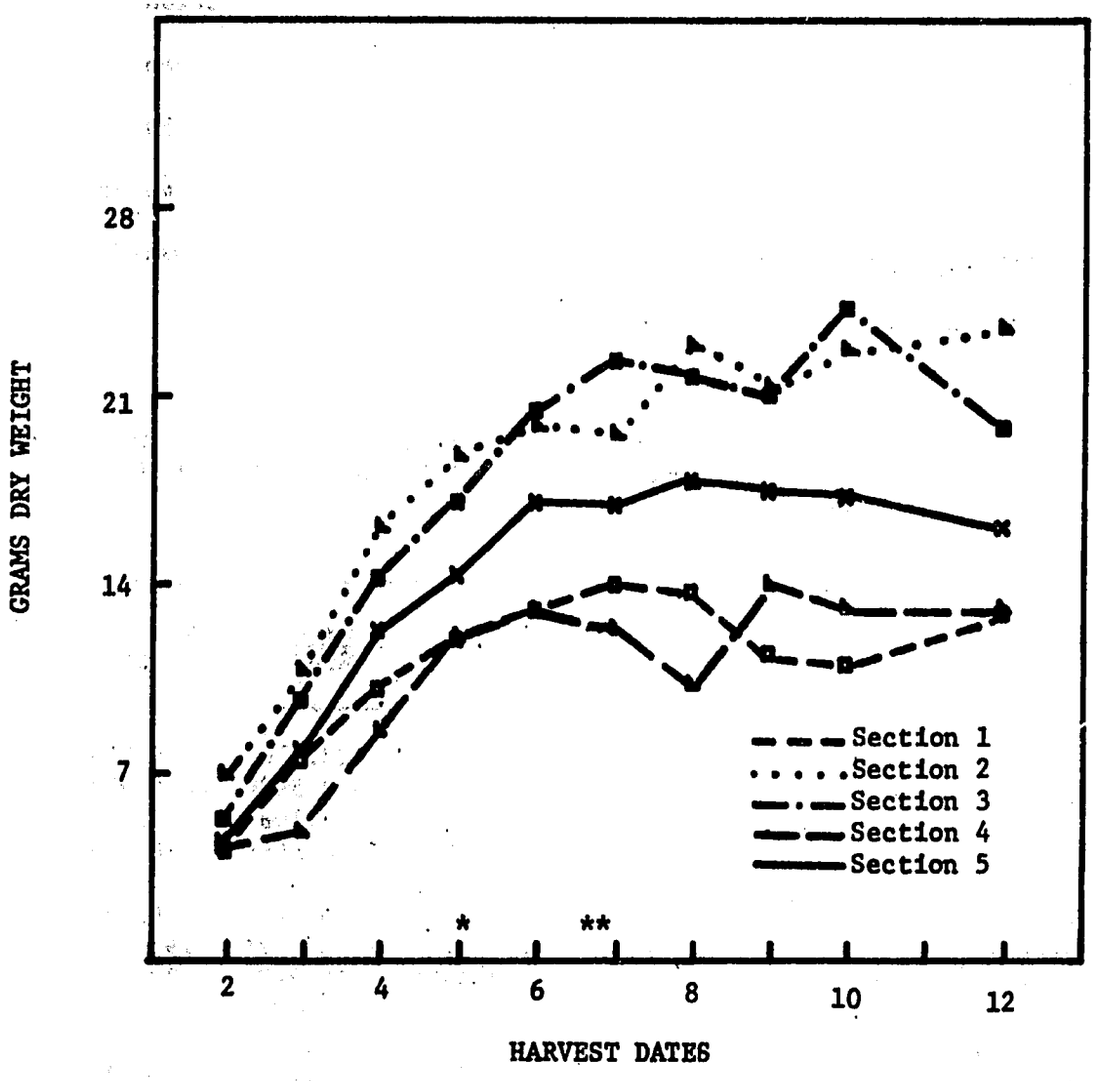

Figure 3. Mean total section dry weight of Martin B studied for panicle development at Mead, Nebraska, in 1975. Asterisks represent black layer dates at the tip (*) and the base (**).

Comparison of means in Table 2 show RS RS671 to be consistently heavier in total section dry weights than Martin and usually those of RS633. Sectional dry weights of RS633 were heavier than those of Martin in sections two, three and five and about equal in sections one and four.

Comparison of section five in the three genotypes shows sectional dry matter accumulation of RS671 to be much higher than Martin. Also dry matter accumulation occurs for a longer period of time in RS633 than Martin. Thus, these differences in rate or time can possibly account for the superior yield advantage hybrids have over lines.

Table 1. Analyses of variance of the total section dry weights in the three genotypes studied for panicle development at Mead, Nebraska, in 1975.

Source	d.f.	Mean Square		
		RS671	RS633	Martin B
Reps	7	54.625*	23.270	6.964
Sections (S)	4	1474.253*	1618.593*	1034.918*
S 5 vs S1 to S 4	1	0.403	3.798	3.229
Among S 1 to S 4	3	1161.195*	2156.858*	1378.815*
Error a	28	17.083	19.862	16.660
Dates (D)	9	1425.911*	1215.552*	791.566*
S x D	36	53.560*	52.367*	23.783*
S 5 vs S 1 to S 4 x D	9	20.736	19.308	2.412
Among S 1 to S 4 x D	27	64.501*	63.386*	30.906*
Error b	315	23.496	13.267	10.886

* Significant at the .05 level of probability.

Table 2. Means of the total section dry weight in three genotypes studied for panicle development at Mead, Nebraska, in 1975.[1]

Section[2]	Date[3]	Total Section Dry Weight		
		RS671	RS633	Martin B
1	2	6.20a	4.06a	4.06a
1	3	9.39b	6.91b	7.27b
1	4	13.11c	10.29c	9.91c
1	5	12.48c	12.07d	11.75de
1	6	15.03d	13.45de	12.84ef
1	7	17.60e	12.58de	13.79f
1	8	18.48e	13.44de	13.51f
1	9	16.87e	13.72e	11.21cd
1	10	17.19e	13.15de	10.82cd
1	12	17.77e	12.75de	12.73ef
2	2	9.33a	6.02a	6.82a
2	3	13.43b	10.32b	10.65b
2	4	20.93c	16.69c	16.01c
2	5	23.29d	20.50d	18.67d
2	6	25.01e	21.54de	19.77d
2	7	25.62e	26.04f	19.47d
2	8	25.38e	26.53f	22.77f
2	9	29.72f	28.12g	21.22c
2	10	30.70f	26.33f	22.60f
2	12	24.75de	22.42e	23.41f
3	2	6.36a	5.23a	5.09a
3	3	11.42b	8.26b	9.50b
3	4	19.54c	13.66c	14.03c
3	5	23.33d	16.70d	16.86d
3	6	29.02f	22.55e	20.26ef
3	7	26.68e	23.48e	22.11g
3	8	25.77e	25.47f	21.52fg
3	9	31.28g	28.70g	20.83efg
3	10	30.26fg	26.26f	24.05h
3	12	33.31h	25.71f	19.62e

Table 2. (Continued)

Section 2/	Date 3/	Total Section Dry Weight		
		RS671	RS633	Martin B
4	2	6.73a	4.20a	3.89a
4	3	8.01a	6.32b	4.70a
4	4	10.51b	9.51d	8.41b
4	5	15.46c	7.97c	11.93d
4	6	17.23d	11.69e	12.92de
4	7	15.46c	12.82e	12.21d
4	8	15.52e	14.83f	10.13c
4	9	19.01e	15.43f	13.88e
4	10	16.98cd	11.50e	13.00de
4	12	25.06f	14.43f	12.96de
5	2	6.57a	4.97a	4.25a
5	3	10.70b	8.26b	7.66b
5	4	17.19c	12.23c	12.07c
5	5	19.01d	14.78d	14.33d
5	6	24.58f	18.66ef	16.83ef
5	7	20.54de	22.23g	16.74ef
5	8	21.37e	19.63f	17.66f
5	9	21.69e	17.95e	17.26ef
5	10	25.17f	19.77f	17.05ef
5	12	22.17e	19.38f	15.91e

1/ Means followed by the same letter are not significantly different at the .05 probability level, using Duncan's Multiple Range Test. Comparisons are made only within each subdivision of the table. Subdivision is defined as one section in one genotype.

2/ Sections represent various portions of a panicle. Section one is the top quarter of a panicle followed by sections two and three until section four which is the bottom quarter of the panicle. Section five is a whole panicle divided by a factor of four to make it comparable to the first four sections.

3/ Dates represent harvest dates in five day intervals from tip bloom of the panicle (e.g. Date 3 is fifteen days after tip bloom).

Table 3. Test of linearity of the total section dry weights of the three genotypes for section five from harvest dates two to six.

Source	d.f.	Mean Square		
		RS671	RS633	Martin B
Reps	7	21.295*	18.204*	8.105*
Dates (D)	4	400.856*	230.574*	203.362*
D linear	1	1572.629*	919.232*	800.713*
D quadratic	1	1.815	0.030	8.002
D cubic	1	1.541	0.348	0.104
D deviate	1	27.437	2.684	4.611
Error	28	7.243	6.075	2.775

* Significant at the .05 level of probability.

Table 4. Test of linearity of the total section dry weights of the three genotypes for section five from harvest dates two to seven.

Source	d.f	Mean Square		
		RS671	RS633	Martin B
Reps	7	18.588	15.532	4.061
Dates (D)	5	353.122*	329.916*	206.740*
D linear	1	1468.012*	1646.229*	967.584*
D deviate	4	74.400*	0.838	16.529*
Error	35	9.619	8.881	4.775

* Significant at the .05 level of probability

Generally the significant differences which occur between section dry weights after black layer are unexplainable in this experiment, but could be due to error in sectioning of the panicles. Data from a seed weight study support this explanation.

Table 5 shows the analyses of variance for seed weight (weight/100 seed) in the three genotypes. RS671 and RS633 respond very similarly in terms of the treatment by date interactions. Treatments one to four act differently among themselves over time, but when averaged, they respond the same as the panicle (treatment five) throughout the grain filling period. There was no treatment by date interaction with Martin and likewise the breakdown of the treatments appear not to differ among themselves over time.

Table 5. Analyses of variance of the dry seed weight per hundred seeds in three genotypes studied for panicle development at Mead, Nebraska, in 1975

Source	d.f.	Mean Square		
		RS671	RS633	Martin B
Reps	7	0.198*	0.114	0.075
Sections (S)	4	1.790*	0.564*	1.179*
S 5 vs S 1 to S 4	1	0.025	0.134	0.003
Among S 1 to S 4	3	2.379*	0.708*	1.751*
Error a	28	0.043	0.060	0.040
Dates (D)	9	14.818*	18.085*	19.373*
S x D	36	0.193*	0.185*	0.078
S 5 vs S 1 to S 4	9	0.053	0.026	0.076
Among S 1 to S 4	27	0.240*	0.238	0.079
Error b	315	0.054	0.052	0.060

* Significant at the .05 probability level.

Table 6 shows the means of the dry seed weight per hundred seeds of the three genotypes. Figures 4, 5 and 6 illustrate changes in seed weight per 100 with time. Tests of linearity were run on data presented in all three graphs from harvest date two to five and two to six. Harvest date five was about the time of black layer at the tip of the panicles and between dates six and seven was the time of black layer at the base. The tests of linearity are found in Tables 7 and 8.

RS633 seed weight increases were not linear when tested from dates two through five or two through six. However, seed weight increases for RS671 and Martin were linear through date five but not through date six. The significant Date linear x Section interaction of RS671 means that when analyzed together, the sections act linear. But when analyzed alone there appears to be deviations from the average curve of linearity. As in Figure 4, this appears to be the case as section four development as measured by changing seed weight was increased at a rate slower than section one.

Generally, except for seeds in section four in RS671 and RS633, once the panicle was at the black layer stage, peak yield was obtained. This conforms to the finding of Eastin (3) with respect to assimilate accumulation around the black layer period. A possible reason for the continued increase in seed weight of RS633 and RS671 in section four could be that the seed at the base of the head was more variable in maturity and an error in deciding black layer in this section was made.

Comparisons of means in Table 6 for harvest dates five to seven for all sections show Martin to be heavier than the two hybrids for weight per hundred seeds. Even though Martin seed was heavier seed, numbers were higher in the RS671 and RS633 enabling them to yield more

than Martin. This suggests that seed number is a more influential factor in yield than seed weight as discussed by Kambal and Webster (6), Malm (8), Niehaus and Pickett (9), and Blum (1).

The variation after date seven, or about the time of black layer at the base, are not significantly different from one another except for seed weights of section four of RS671 which increased through the last harvest date. Since there is less variation in seed weight than in total section dry weights, this would support the reasoning that there was some error in the sampling of the sections and resulting in the significant differences in total section weights after black layer.

SUMMARY

Two hybrids and one line were used to follow the development of the grain sorghum caryopsis. Sectioning the panicles into fourths and averaging the four sectional weights gave the same weight as one-fourth of the total panicle weight. However, the upper and lower quarters did develop slower than the whole panicle while the two middle quarters were shown to develop faster than the whole panicle. In total section dry weights the hybrids developed faster and did yield more than the line.

However, comparisons made on the seed weight per hundred seeds showed the line to develop as fast as the two hybrids but generally the line reached higher seed weights than either hybrid. It is believed that these data support the theory that seed number plays a more significant role in the development of the sorghum panicle than does seed size since it is known that the two hybrids generally have more seed per panicle than the line. Also, grain weight in all five of the sections appear to reach equivalent levels in the order of section one, two, five, three, and four as was expected. Section five represents the seed weight from a full panicle.

Table 6. Means of the dry seed weight per hundred seeds in three genotypes studied for panicle development at Mead, Nebraska, in 1975[1]

Section[2]	Date[3]	Dry Seed Weight per 100 Seeds		
		RS671	RS633	Martin B
1	2	0.48a	0.41a	0.51a
1	3	1.22b	1.03b	1.18b
1	4	1.68c	1.55c	1.72c
1	5	2.07c	1.66cd	2.11d
1	6	2.03c	2.00de	2.38d
1	7	2.02c	2.19e	2.36d
1	8	2.04c	2.03de	2.35de
1	9	2.05c	1.86cde	2.29d
1	10	1.97c	2.00de	2.34d
1	12	2.01c	1.78cd	2.29d
2	2	0.32a	0.27a	0.35a
2	3	0.89b	0.78b	0.89b
2	4	1.37c	1.34c	1.58c
2	5	1.81d	1.72d	2.00d
2	6	1.95d	1.85de	2.29d
2	7	2.00d	2.29f	2.25d
2	8	1.89d	2.15ef	2.31d
2	9	2.12d	2.20ef	2.13d
2	10	2.12d	2.23f	2.31d
2	12	1.88d	2.03def	2.32d
3	2	0.23a	0.23a	0.27a
3	3	0.69b	0.61b	0.77b
3	4	1.18c	1.10c	1.31c
3	5	1.68d	1.47d	1.87d
3	6	1.99de	1.86e	2.20d
3	7	1.98de	2.01ef	2.24d
3	8	2.09e	2.24f	2.12d
3	9	2.19e	2.32f	2.23d
3	10	2.24e	2.21ef	2.25d
3	12	2.13e	2.15ef	2.18d

Table 6. (Continued)

Section[2/]	Date[3/]	Dry Seed Weight per 100 Seeds		
		RS671	RS633	Martin B
4	2	0.15a	0.16a	0.17a
4	3	0.52b	0.42a	0.56b
4	4	0.87c	0.91b	1.12c
4	5	1.24d	1.18b	1.53d
4	6	1.41de	1.68c	2.12e
4	7	1.58def	1.87de	2.06e
4	8	1.73efg	2.05de	2.14e
4	9	1.82fg	2.25e	2.09e
4	10	2.02gh	2.10de	2.18e
4	12	2.20h	2.10de	2.29e
5	2	0.31a	0.34a	0.35a
5	3	0.78b	0.67a	0.81b
5	4	1.37c	1.25b	1.53c
5	5	1.60cd	1.63c	1.86cd
5	6	1.91de	1.93cd	2.25e
5	7	2.01e	2.14d	2.34e
5	8	2.09e	2.13d	2.39e
5	9	1.92de	2.10d	2.24e
5	10	2.12e	2.20d	2.14de
5	12	2.05e	2.15d	2.07de

1/ Means followed by the same letter are not significantly different at the .05 probability level, using Duncan's Multiple Range Test. Comparisons are made only within each subdivision of the table. Subdivision is defined as one section in one genotype.

2/ Sections represent various portions of a panicle. Section one is the top quarter of a panicle followed by sections two and three until section four which is the bottom quarter of a panicle. section five is a whole panicle.

3/ Dates represent harvest dates in five day intervals from tip bloom of the panicle (e.g. Date 3 is fifteen days after tip bloom).

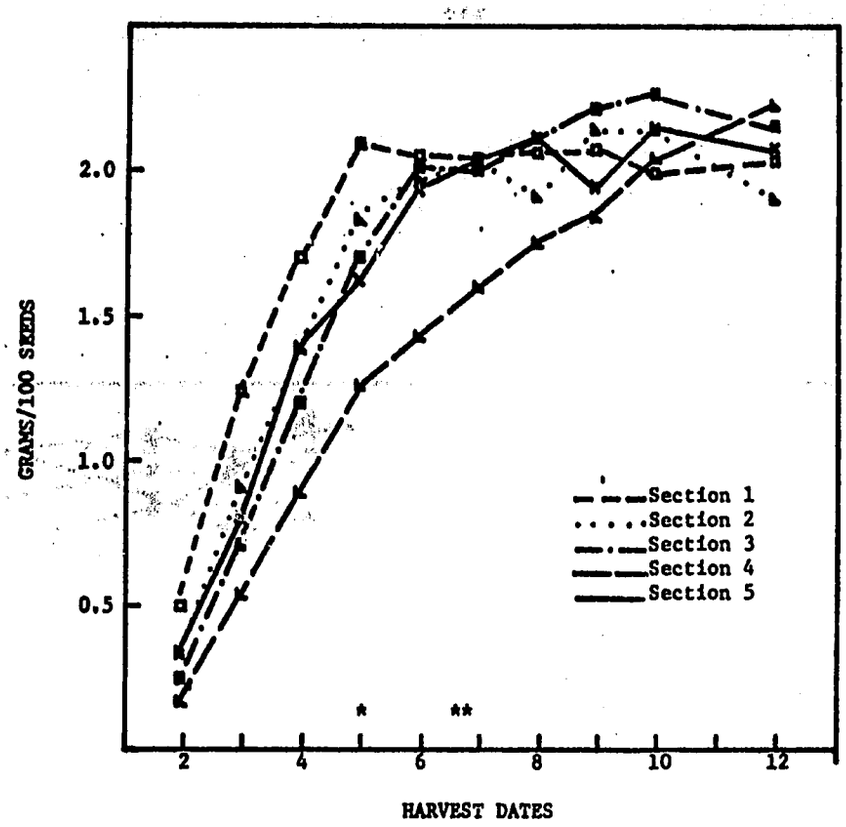

Figure 4. Mean dry seed weight per hundred seeds of RS671 studied for panicle development at Mead, Nebraska, in 1975. Asterisks represent black layer dates at the tip (*) and the base (**).

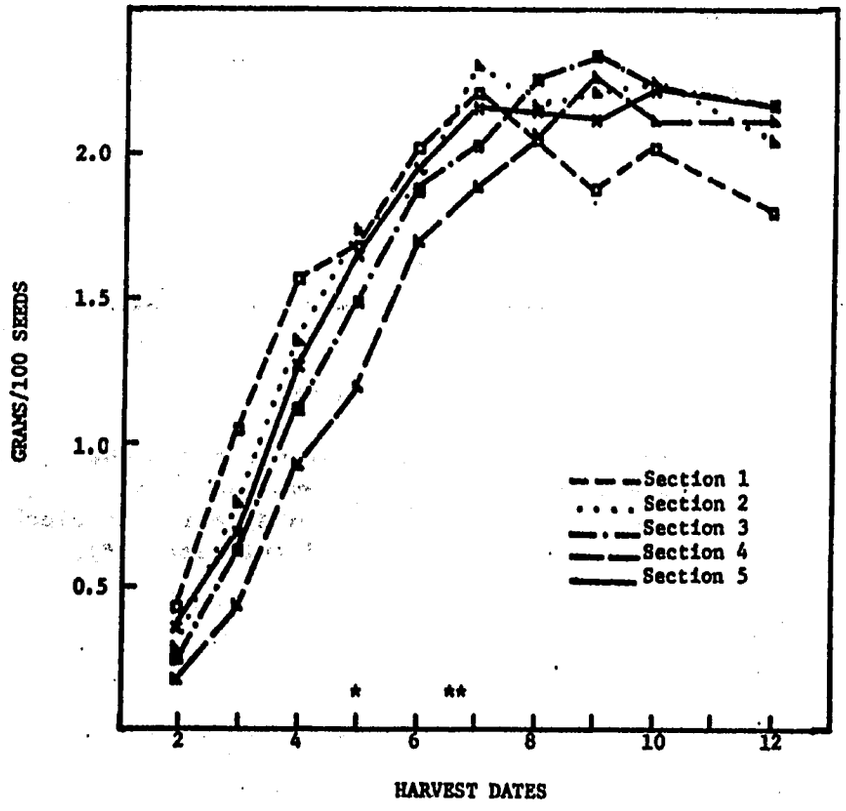

Figure 5 Mean dry seed weight per hundred seeds of RS633 studied for panicle development at Mead, Nebraska, in 1975. Asterisks represent black layer dates at the tip (*) and the base (**).

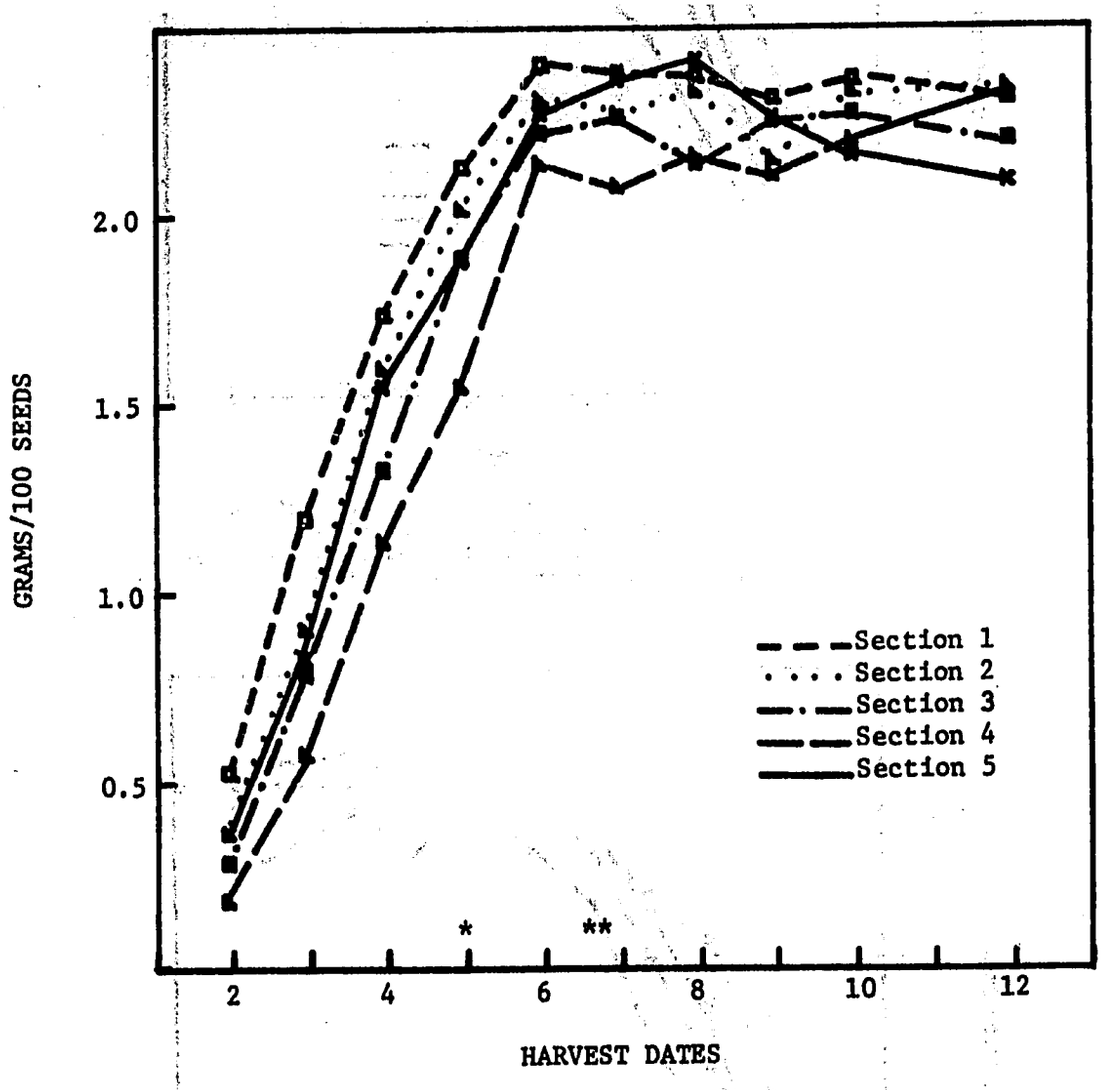

Figure 6. Mean dry seed weight per hundred seeds of Martin B studied for panicle development at Mead, Nebraska, in 1975. Asterisks represent black layer dates at the tip (*) and the base (**).

Table 7. Test of linearity of dry seed weight per hundred seeds in three genotypes for sections one to four from harvest dates two to five.

Source	d.f.	Mean Square RS671	RS633	Martin B
Rep	7	0.074	0.011	0.008
Section	3	2.508*	1.477*	1.665*
Error a	21	0.031	0.018	0.034
Date	3	11.663*	9.661*	14.656*
Date linear	1	34.885*	28.639*	43.864*
Date deviate	2	0.053	0.172*	0.053
Date x Section	9	0.089	0.079*	0.047
Date linear x Section	3	0.201*	0.118*	0.072
Date deviate x Section	6	0.033	0.060*	0.035
Error b	84	0.041	0.012	0.029

* Significant at the .05 level of probability.

Table 8. Test of linearity of dry seed weight per hundred seeds in three genotypes for sections one to four from harvest dates two to six.

Source	d.f	RS671	RS633	Martin B
Rep	7	0.077	0.035	0.021
Section	3	3.019*	1.538*	1.679*
Error a	21	0.037	0.047	0.026
Date	4	13.080*	12.669*	19.101*
Date linear	1	50.693*	50.090*	75.870*
Date quadratic	1	1.463*	0.426*	0.449*
Date cubic	1	0.115	0.001	0.058
Date deviate	1	0.048	0.158*	0.028
Date x Section	12	0.113*	0.076*	0.057
Date linear x Section	3	0.235*	0.024	0.017
Date quadratic x Section	3	0.214*	0.216*	0.169*
Date cubic x Section	3	0.003	0.053	0.020
Date deviate x Section	3	0.003	0.018	0.002
Error b	112	0.048	0.031	0.039

* Significant at the .05 level of probability.

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THE EFFECT OF INDUCED HIGH TEMPERATURES ON SORGHUM GRAIN DEVELOPMENT

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INTRODUCTION

One of the environmental stresses facing the sorghum producer is high temperature. Preliminary observations suggest that higher than normal air temperatures around a sorghum panicle can lead to reduced yields. It is reasonable to expect that genetic variability for tolerance to high temperature exists. The development of an appropriate selection technique to screen for heat tolerance might depend on knowing when the sorghum panicle is most vulnerable to high temperature.

Based on these thoughts the objective of this investigation was to attempt evaluating when the sorghum panicle is most vulnerable to a heat stress during grain filling.

LITERATURE

Endosperm Development in Grain Sorghum

Endosperm makes up most of the kernel in small grains. Bradbury *et al.* (3) reported the endosperm made up over 90% of the total weight for a kernel of wheat. Wolf *et al.* (16) reported 80 to 84% of the corn kernel is endosperm by weight. Freeman (5) suggested a figure around 82% for sorghum. These figures suggest that kernel development closely follows endosperm cell development in small grains for dry weight accumulation.

In sorghum for the first forty-eight hours after fertilization there is free nuclear division in the endosperm [Paulson (11), Sanders (13)]. During day three cell walls start to form at the base of the kernel. By day eight, cell division generally has stopped, cell number has been determined and starch formation is starting in each cell. On day nine two-thirds of the cells contain starch. Maximum endosperm size is reached about day 12. Any increase in the size of the grain after this period is due to the increase in embryo growth.

Heat Effects on Grain Sorghum Development

Most of the research concerned with high temperatures in grain sorghum are temperatures slightly above the optimum for the sorghum plant. High temperatures can hasten the time from planting to bloom and from bloom to physiological maturity as shown by Downes (4), Skerman (14), Fryer et al. (6), and Pasternak and Wilson (10). Fryer et al. (6) showed maturity could be hastened when day temperatures were about 70° F and night temperatures were greater than 70° F or below 60° F in sorghum for the first thirty days after emergence. Day temperatures below 70° F and night temperatures in the sixties generally retarded maturity. After the first thirty days sorghum maturity could be hastened when temperatures were above 80° F.

Skerman (14) compared sorghum yields with temperature over a number of years in Queensland, Australia. He found that when daily maximum temperatures were above 100° F for three or more consecutive days there was an adverse affect on grain sorghum yields. The heat waves, as he referred to them, were most destructive at the flowering period and were also destructive in the first month of grain fill.

Pasternak and Wilson (10) showed higher temperatures could accelerate anthesis. They claimed a heat stress, moist or dry, could reduce seed set. They also showed yield was lowered when heat stressed at or soon after the boot stage and they remarked that heat accompanied by low humidity can reduce yields in the field by ten to twenty percent.

Downes (4) studied the affect of various temperatures on different growth stages of grain sorghum. He used a temperature of 33° C during the day and 28° C at night for one treatment and for the second treatment he used a 27° C day and a 22° C night. The higher day-night temperatures, applied before bloom, and continued until maturity, reduced the number of florets which developed, and reduced the grain weight per panicle branch. The higher day-night temperatures applied at the time of panicle development retarded floral initiation and increased the number of leaves per plant. Downes' also did work on varying day and night temperatures which showed a high night temperature to have an adverse effect on grain yield while day temperature had little effect except at very high night temperatures.

Similar day-night relationships have been found in other crops. Peters *et al.* (12) found higher temperatures to be associated with earlier senescence and maturity in wheat, corn, and soybeans. High air temperatures at night reduced corn yields forty per cent, wheat fifty per cent and soybeans ten per cent. However, the data may have limited value. Wheat research by Asana and Asini (1), Asana and Williams (2), Hoshikawa (7) and Wardlaw (15) suggested temperatures above 30° C, applied during grain yields eleven to sixteen per cent and could hasten maturity. Starch formation can be reduced, as pointed out by Wardlaw (15), when heat stress

is applied toward the end of the filling period. Hoshikawa (7) suggested this is due to starch granular number and size being reduced. Hubik and Hlavoc (8) reported that wheat requires low temperatures during the first third of grain fill, higher temperatures for the second third, and again low temperatures are required for the last third of grain fill for optimal yields.

Nagata and Ebata (9) found development of the rice grain to be hastened when high temperatures were applied at the beginning of grain fill but depressed development when applied later. High temperatures applied throughout the ripening period accelerated starch accumulation but the starch content becomes insufficient to fill starch cells in the late period of ripening causing reduced seed size.

MATERIALS AND METHODS

This experiment was conducted to observe when the most critical time period would be to apply a heat stress to a sorghum panicle. The genotype used was RS671 which is an open-pedigree hybrid.

This experiment was planted June 5 in a completely randomized block design using fifteen replications. Panicles were selected at random from twenty rows 30.5 m (100 ft) long and 76.2 cm (30 in) apart. A stand count at the end of the year showed approximately 175,000 plants/ha (70,000 plants/A). The plot was irrigated in order to separate the moisture from the temperature variable.

The experiment was fertilized with 100 lbs. of N. Weeds were controlled using atrazine and propachlor. Greenbugs were controlled with Diazinon and Cygon.

The heat treatment was effected by applying a clear plastic bag 39 cm (15.4 in) long and 15 cm (5.9 in) wide to the head. The bag was held on the panicle with a twisted wire at the base applied loosely enough around the peduncle to allow drainage of transpirational water after it condensed in the bag. The bag effected a temperature elevation around the panicle to some point relative to temperatures surrounding the bag and the amount of sunlight passing through the bag. Several panicles were monitored with thermocouples hooked into a Hewlett Packard data logger. In both plastic covered and uncovered panicles the thermocouples were placed on a panicle branch halfway down the panicle on the north side next to the rachis. Temperatures were recorded hourly from 600 hours to 2200 hours. Table A1, in the appendix, shows the daily maximum, minimum, and average temperatures in the plastic covered and the untreated panicle.

The bagging treatment did raise panicle temperature appreciably and did effect a heat treatment. However, bagging also introduced an abnormal gaseous environment in terms of carbon dioxide, oxygen, and water vapor around the panicle. These effects are confounded with the heat treatment. While the treatment is spoken of as a heat treatment for discussion purposes these confounding effects are recognized.

The experimental unit was a single panicle of sorghum. All panicles were tagged at tip bloom on August 13th.

Bags were applied at five different stages during the filling period. For each application there were four removal times. These were set up so four days after each application one set of bags were removed, eight days after being applied another set were removed and likewise at

twelve and sixteen days. The application dates were set up to be applied two days apart and would start at five days after tip bloom (just after base bloom).

To allow for cooler days where little heat was applied and the plants grew slower, total radiation readings were used to determine the application and removal dates. An average sunny day in August, at Mead, Nebraska, would give a reading of 485 langleys/day on a total radiation sensor. If a two day interval were needed between application dates, 970 langleys were accumulated before the next application took place and the removals, 4 days apart were allowed to collect about 1940 langleys. Table A2 in the appendix, shows the sequence of applications and removals and the actual dates they took place. By September 9, the panicles were at fifty per cent black layer at the tip and all remaining bagged panicles were removed.

All panicles were harvested and allowed to air dry. Panicles were then threshed with a mechanical head thresher and separated into three seed size groups. Seed size one was the large grains that would not pass through a screen with a 0.357 cm (9/64 in) round holes. Medium sized grains that would pass through a 0.357 cm screen but not a 0.278 cm (7/64 in) screen were designated seed size two. Seed size three was any grain passing through the 0.278 cm screen.

Data collected were for total weight of the grain in the panicle before separation into seed sizes and seed number of the total panicle. Total grain weight, seed number, and seed weight per hundred seeds were also taken in each of the three seed size classes. All data presented are means of the treatments divided by means of fifteen check panicles that remained untreated so that values are expressed as percent of the check.

RESULTS AND DISCUSSION

Table 1 shows the analyses of variance for total grain weight and seed number for the whole panicle. Figures 1 and 2 show trends in seed number and panicle weights as influenced by treatments. Tables 2, 3, and 4 show the analyses of variance for all three seed sizes for the traits of total weight, seed number and seed weight. Tables 6, 7, and 8 show the means of the traits expressed as percentages of the check and also significant differences in Duncan's Multiple Range Test.

Figure 1 shows the mean total weight of the grain in the whole panicle as related to treatment length. There were significant differences in applied and removal dates on the mean total weight and there was a significant interaction in application and removal dates (Table 1). Figure 1 generally shows a trend that the treatments applied later and the longest stressed periods were most effective in reducing total panicle grain weight. Applications one and two resulted in continued decreasing weights throughout all treatment periods. Least effective was application five which was reached at the very end of the grain fill period and which apparently was a less sensitive stage for stress to influence assimilate accumulation in the grain as compared to earlier stages. The literature [Paulson (11), Sanders (13), Wardlaw (15), Hoshikawa (7) and Nagata and Ebata (9)] would suggest that cell number and cell size were possibly influenced by early applications of heat stress. Starch granular number and size were influenced with later applications and longer treatment periods of heat stress.

Figure 2 shows the mean seed number of the whole panicle as related

to removal interval. Again application five apparently had no affect on seed number. Applications three and four show little change in seed number regardless of removal date. Seed number resulting from applications one and two, however, decline throughout the entire filling period. The data appear to show that a short duration stress aborts more seeds about 9 days after anthesis than earlier. This apparent abortion of grain may have resulted from losing grains too small to be caught in the thresher and passed on through and were lost. This point will require further experimental verification.

The stressed panicles were divided into three seed sizes. The largest grain found generally at the base of the head, had a trend to decrease in total weight with the removal periods due to the fact there were fewer large grains. The large grains were generally heavier than the check or untreated heads. The medium sized grain tended to decrease in seed size with the longer heat stresses on the earlier application dates. Generally when the last three stages of stress were applied the seed number was set immediately and seed size differed very little with the longer stress periods. This would suggest that heat treatments at the mid to latter end of the grain fill will put an upper limit on starch accumulation as was suggested by Wardlaw (15), Hoshikawa (7) and Nagata and Ebata (9). The small grain proved to increase in total weight with longer periods of stress due to the fact that there was an increase in the number of grains falling into the small grain category.

The data suggest that short periods of high temperatures falling at about seven to nine days after tip bloom, can be as harmful as

stress applied at earlier dates of the grain fill period and left on for twelve to sixteen days. At this particular stage the cellular expansion is drawing to a finish and starch formation is starting [Paulson (11), Sanders (13)]. Therefore, if these data were used for a selection technique, the time to apply a heat stress would be between days seven and nine and the stress length could be left on a plant for any length of time.

Table 1. Analyses of variance for the total grain weight and seed number of the whole panicle studied in the temperature experiment at Mead, Nebraska, in 1975.

Source	d.f.	Mean Square: Total Grain Weight of the Whole Panicle	Mean Square: Seed Number of the Whole Panicle
Applied	4	4348.708*	13113.083*
Removal	3	15609.623*	6125.985*
Applied x Removal	12	998.914*	1488.999*
Error	280	247.574	185.303

* Significant at the .05 level of probability.

Table 2. Analyses of variance for the total grain weight of the three grain size classifications studied in the temperature experiment at Mead, Nebraska, in 1975.

Source	d.f.	Mean Square: Total Weight Seed Size One	Mean Square: Total Weight Seed Size Two	Mean Square: Total Weight Seed Size Three
Applied (A)	4	11648.980*	7253.022*	36458.478*
Removal (R)	3	33098.853*	10039.422*	14859.527*
A x R	12	730.364	4512.946*	1643.083
Error	280	1044.747	348.228	1185.829

* Significant at the .05 level of probability.

Table 3. Analyses of variance for the seed number of the three grain size classifications studied in the temperature experiment at Mead, Nebraska, in 1975.

Source	d.f.	Mean Square Seed Number Seed Size One	Seed Number Seed Size Two	Seed Number Seed Size Three
Applied (A)	4	11294.036*	13632.877*	187512.974*
Removal (R)	3	25358.065*	5434.582*	50477.405*
A x R	12	492.491	4337.869*	3993.204
Error	280	793.491	356.086	2792.888

* Significant at the .05 level of probability.

Table 4. Analyses of variance for the seed weight per hundred seeds of the three grain size classifications studied in the temperature experiment at Mead, Nebraska, in 1975.

Source	d.f.	Seed Weight Seed Size One	Seed Weight Seed Size Two	Seed Weight Seed Size Three
Applied (A)	4	391.806*	5556.933*	15757.668*
Removal (R)	3	789.727*	2288.868*	2595.996*
A x R	12	228.920*	129.622*	581.245*
Error	280	79.695	57.256	88.252

* Significant at the .05 level of probability.

Table 5. Means, expressed as a per cent of the check, of the total grain weight and seed number of the whole panicle studied in the temperature experiment at Mead, Nebraska, in 1975.1/

Application	Removal	Means expressed as a Per Cent of the Check: Total Grain Weight of the Whole Panicle	Seed Number of the Whole Panicle
1	1	91.72f	89.84e
1	2	68.70cde	64.17bcd
1	3	50.39abc	50.65ab
1	4	38.72a	41.49a
2	1	92.04f	88.18e
2	2	71.96de	70.91d
2	3	52.07abc	55.02abcd
2	4	44.00ab	51.77abc
3	1	73.84de	65.07bcd
3	2	73.26de	66.15bcd
3	3	50.85abc	55.62abcd
3	4	50.35abc	55.74abcd
4	1	67.69cde	68.00bcd
4	2	62.28bcde	63.59bcd
4	3	57.14abcd	70.27cd
4	4	50.64abc	62.57bcd
5	1	93.35f	99.30e
5	2	78.43ef	90.99e
5	3	79.25ef	103.29e
5	4	71.96de	91.31e

1/ Means followed by the same letter are not significantly different at the .05 level of probability using Duncan's Multiple Range Test. Comparisons are made only within each subdivision of the table. Subdivision is defined as one column.

Table 6. Means, expressed as a per cent of the check, of the total grain weight of the three grain size classifications studied in the temperature experiment at Mead, Nebraska, in 1975.1/

Application	Removal	Means expressed as a per cent of the check: Total Weight Seed Size One	Total Weight Seed Size Two	Total Weight Seed Size Three
1	1	76.78cdef	104.74j	88.86cdef
1	2	60.35abcd	75.27ghi	76.11bcd
1	3	43.66a	52.99bcde	90.58cdefg
1	4	37.95a	35.88a	83.07bcde
2	1	70.75bcde	112.65j	62.00abc
2	2	55.01abc	86.25i	74.91bcd
2	3	36.56a	62.96defg	82.71bcde
2	4	39.06a	44.14ab	95.24defg
3	1	99.34fg	54.19bcde	46.05a
3	2	85.22def	64.50efg	54.46ab
3	3	43.10a	53.81bcde	97.57defg
3	4	41.90a	55.47bcdef	77.28bcd
4	1	90.11ef	46.12abc	97.54defg
4	2	79.91cdef	44.97abc	90.12cdefg
4	3	48.35ab	60.13cdefg	114.69fg
4	4	47.58ab	47.89abcd	118.80g
5	1	118.62g	70.56fgh	107.63efg
5	2	84.13def	70.48fgh	117.24fg
5	3	71.17bcde	80.80hi	147.34h
5	4	70.67bcde	66.84efgh	150.74h

1/ Means followed by the same letter are not significantly different at the .05 level of probability using Duncan's Multiple Range Test. Comparisons are made only within each subdivision of the table. Subdivision is defined as one column.

Table 7. Means, expressed as a per cent of the check, of the seed number of the three grain size classifications studied in the temperature experiment at Mead, Nebraska, in 1975.1/

Application	Removal	Means expressed as a per cent of the check: Seed Number Seed Size One	Seed Number Seed Size Two	Seed Number Seed Size Three
1	1	73.18cdef	100.49gh	87.96abcd
1	2	55.06abcd	68.55de	73.43abc
1	3	40.57a	51.10abc	92.32abcde
1	4	34.87a	37.24a	101.28bcde
2	1	68.80bcdef	104.19h	60.12ab
2	2	51.82abc	82.15ef	75.65abc
2	3	36.23a	62.67cd	83.94abc
2	4	37.83a	49.68abc	128.67def
3	1	91.17fg	50.29abc	54.47a
3	2	77.69def	59.52bcd	62.12ab
3	3	40.86a	54.02bcd	132.62ef
3	4	40.76a	57.60bcd	109.11cde
4	1	79.85ef	47.68abc	160.23fg
4	2	72.28cdef	45.10ab	156.78fg
4	3	46.98ab	68.43de	186.94gh
4	4	45.89ab	51.63abc	214.72hi
5	1	109.01g	84.63f	160.80fg
5	2	82.52ef	84.14f	177.48gh
5	3	74.59cdef	103.24h	231.25i
5	4	67.08bcde	87.06fg	229.40i

1/ Means followed by the same letter are not significantly different at the .05 level of probability using Duncan's Multiple Range Test. Comparisons are made only within each subdivision of the table. Subdivision is defined as one column.

Table 8. Means, expressed as a per cent of the check, of the seed weight per hundred seeds of the three grain size classifications studied in the temperature experiment at Mead, Nebraska, in 1975.1/

		Means expressed as a per cent of the check		
Application	Removal	Seed Weight Seed Size One	Seed Weight Seed Size Two	Seed Weight Seed Size Three
1	1	105.21bcde	103.21ef	101.20g
1	2	113.36fg	108.41f	105.12g
1	3	110.58cdefg	102.17ef	98.78g
1	4	110.84cdefg	94.40d	83.59f
2	1	106.37bcdef	106.87f	103.07g
2	2	109.31bcdefg	103.76ef	98.86g
2	3	101.98b	98.59de	99.27g
2	4	103.88bcd	87.13c	75.07e
3	1	111.24defg	107.42f	85.58f
3	2	113.58fg	107.01f	87.87f
3	3	107.00bcdef	97.74de	73.82de
3	4	105.83bcdef	95.27d	71.76cde
4	1	114.88g	94.36d	61.71ab
4	2	112.36efg	98.05de	58.04a
4	3	105.87bcdef	86.78c	61.91ab
4	4	103.34bc	87.31c	57.97a
5	1	111.03cdefg	81.42abc	69.79cde
5	2	106.21bcdef	82.32bc	66.98bcd
5	3	94.47a	77.37ab	65.07abc
5	4	106.08bcdef	76.17a	68.45bcde

1/ Means followed by the same letter are not significantly different at the .05 level of probability using Duncan's Multiple Range Test. Comparisons are made only within each subdivision of the table. Subdivision is defined as one column.

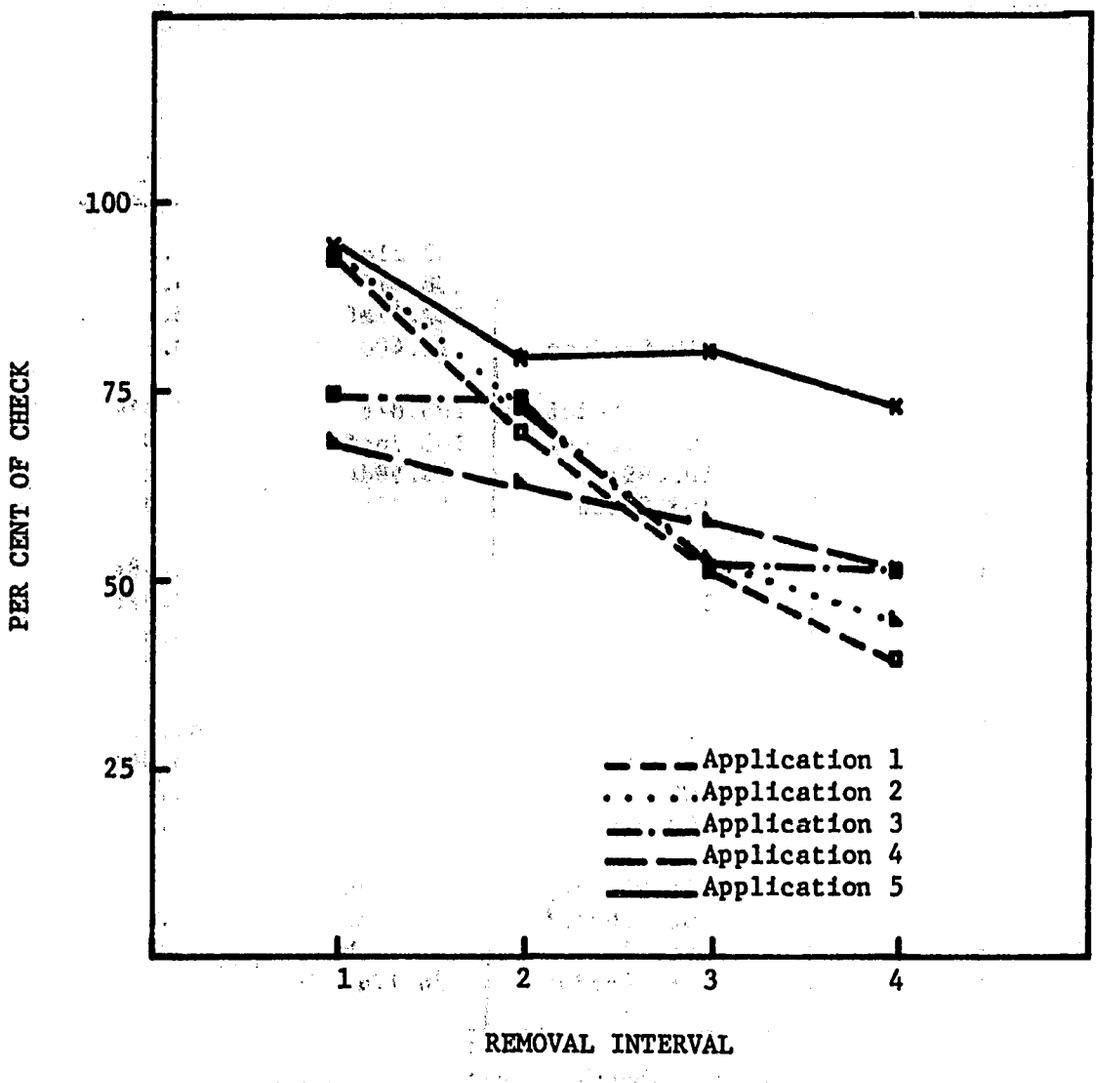

Figure 1. Mean total weight of the whole panicle, expressed as a per cent of the check, under different temperature treatments of RS671 at Mead, Nebraska, in 1975.

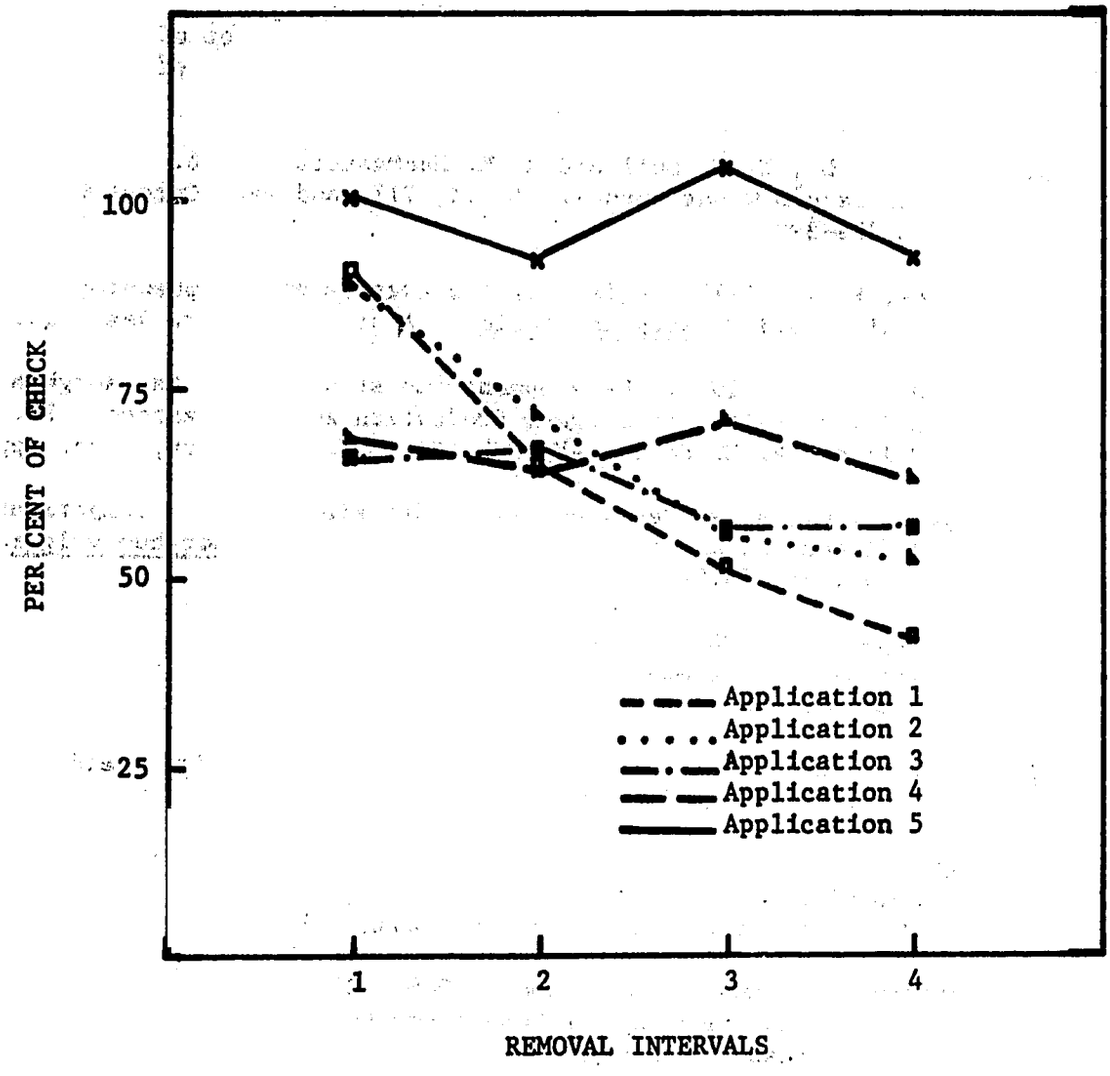

Figure 2. Mean seed number of the whole panicle, expressed as a per cent of the check, under different temperature treatments of RS671 at Mead, Nebraska, in 1975.

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APPENDIX

Table A1. Maximum, minimum and average daytime temperatures of the plastic covered and untreated panicles in the temperature experiment at Mead, Nebraska, in 1975. Tip bloom was August 13.

Days After Tip Bloom	Covered Panicles (°C)			Open Panicles (°C)		
	Max.	Min.	Ave.	Max.	Min.	Ave.
6	44	23	34	37	23	28
7	46	23	38	37	23	32
8	47	22	39	36	22	32
9	49	24	40	40	24	34
10	48	30	37	39	30	33
11	48	29	40	39	29	35
12	48	17	35	32	17	26
13	45	11	33	33	11	27
14	47	21	36	35	21	31
15	36*	23*	28*	27*	20*	24*
16	42	19	30	29	19	25
17	41	20	31	29	20	25
18	42	18	31	31	18	25
19	43*	17*	34*	34*	17*	27*
20	44*	24*	37*	33*	24*	31*
21	28	16	21	22	16	18
22	21	17	19	18	17	17
23	37	12	25	27	13	20
24	37	13	27	27	13	21
25	39	13	28	27	13	21
26	37	12	26	25	12	20

* Estimates due to partial loss of readings. Days not listed are unavailable due to equipment failure.

Table A2. A listing of dates for the application and removal of heat treatments at Mead, Nebraska, in 1975. Bloom at the tip was August 13.

Days After Tip Bloom	Treatments 1/				
3	A1				
5		A2			
7	A1R1		A3		
9		A2R1		A4	
11	A1R2		A3R1		A5
13		A2R2		A4R1	
15	A1R3		A3R2		A5R1
18		A2R3		A4R2	
20	A1R4		A3R3		A5R2
25		A2R4		A4R3	
27			A3R4		A5R3
27				A4R4	
27					A5R4

1/ Applications are abbreviated A and removals R. Using A3R2 as an example, this means the heat stress was applied with the third set of applications and removed with the second set of removals for that application period.

RELATIONSHIP BETWEEN LABORATORY AND FIELD OBSERVATIONS OF SORGHUM SEEDLINGS GROWN UNDER COLD TEMPERATURES

L. Mendoza-Onofre, J. D. Eastin, C. Y. Sullivan, W. M. Ross

In high-altitude and/or upper-latitude areas, sorghum plantings are limited by several factors among which cold temperature is one of the more relevant (Stoffer, 1962). In areas like Nebraska, soil and air temperatures during early spring plantings are often sub-optimal for seed germination and seedling growth (Kramer and Ross, 1970). Therefore, poor stands, complete loss of stands due to killing temperatures after seedling emergence, and poor seedling growth are often experienced. Cultural and genetic approaches to improving responses to moderate adverse temperatures in early plantings could be legitimately pursued. Breeding programs have been initiated to detect cold-tolerant genotypes in several species, and those genotypes could be used in different crop production situations (Namken, et al, 1974).

It is difficult to expect that selecting for cold tolerance in one specific growth stage could accomplish all desirable characteristics required for different crop production situations. However, screening for cold tolerance in the germination and seedling stages and testing the selected genotypes under different environmental conditions in order to detect those that better fit the desired situation could be a reasonable approach.

In doing this, the first problem arises when large numbers of genotypes are available for screening. Looking for a fast, simple and reliable technique should be of the greatest priority.

MATERIALS AND METHODS

Field Planting

Six hundred ninety-three S_1 progenies developed from sorghum populations NP8BR and NP10BR were planted April 22, 1975, on the Agronomy Farm, Lincoln, Nebraska. This is an early planting date since most farmers plant from mid-May to early June. The purpose of this early planting was to test under cold temperatures in the early growth stage so selection could be applied.

Each S_1 progeny was planted in single rows. Each row was 15 feet long and 30 inches apart. RS 626 and MS-83 were planted as checks each 20 rows. The latter is a line reported to have some cold tolerance in previous early planting observations[1/], while RS 626 is a commercial hybrid. Only one replication was planted.

Soil temperature at 2 inches deep was continuously recorded during the first 19 days after planting by placing three tempscribe instruments in the field. The maximum and minimum values are given in Table 1. As an average, over the first 19 days, the minimum temperature was 10° C and the maximum was 23° C.

The first evaluation was done 19 days after planting. Visual grades were given to each one of the S_1 progenies, according to the relative seedling growth and number of seedlings emerged from each S_1 row in relation to those of the checks immediately preceding them. Both checks, at that time, behaved the same. Grades from 1 to 5 were given.

1/ Personal communication by Dr. G. Robison (Dekalb Ag. Research, Inc.)

Table 1. Maximum and minimum soil temperatures two inches deep at Lincoln, NE from April 22 to May 10, 1975.1/

Date		Maximum °C	Minimum °C
April	22	17.0	----
	23	21.7	9.7
	24	19.3	11.0
	25	23.0	8.3
	26	19.0	13.0
	27	19.0	16.7
	28	16.0	9.0
	29	22.0	7.0
	30	20.7	6.0
May	1	21.0	4.0
	2	15.7	8.0
	3	22.3	7.0
	4	26.7	7.7
	5	28.0	12.3
	6	28.0	16.7
	7	30.0	13.3
	8	29.0	11.0
	9	27.0	12.7
	10	30.7	10.3
	Mean	22.9	10.2

1/ Average of three observations

Grades from 1 to 5 were given. Grade 1 represents seedling number and seedling growth similar to that of the checks, and grade 5 represents very poor seedling development or no seedlings at all. A second evaluation of the same material was done 5 days later by the same procedure.

Laboratory Planting

On July 29, 1975, the same 693 S_1 progenies were planted under laboratory conditions. In order to evaluate germination and seedling growth of this number of genotypes, a fast, inexpensive and simple technique was required. The more promising technique appeared to be a modification of a procedure reported by Myhill and Konzak (1967).

The procedure used follows: 30 seeds of each S_1 were placed between two wet regular weight seed germination papers 12 x 4 cm dimensions. A steel blue anchor seed germination blotter paper 12 x 2 1/2 cm dimensions was placed in between for supporting the seeds. These "sandwiches" were placed in slots cut in racks as indicated by Myhill and Konzak. Figures 1 to 4 shows the general procedure.

This planting arrangement was similar to the field planting. Each S_1 was placed in one slot and each 20 slots both checks (RS 626 and MS-83) were planted. In this way, only 22 genotypes were placed in each rack. In this planting, it was feasible to put in a uniform number of seeds of each genotype while the same was not done in the field planting.

As soon as each rack was completed, it was placed in a growth chamber in which temperature and humidity were controlled. The temperature cycle over the 24 hours period within the growth chamber was the average of the soil temperature cycle that occurred in the field during the first 19 days. Relative humidity was maintained at 90%.

Table 2 shows the temperatures used at 3-hour intervals during the 24-hour cycle.

Visual grades were given 13 days after planting by using the same criteria as used in the field planting.

On September 12, a second replication was planted under laboratory conditions. The procedure was the same as in the first replication, except that visual grades were given 16 days after planting.

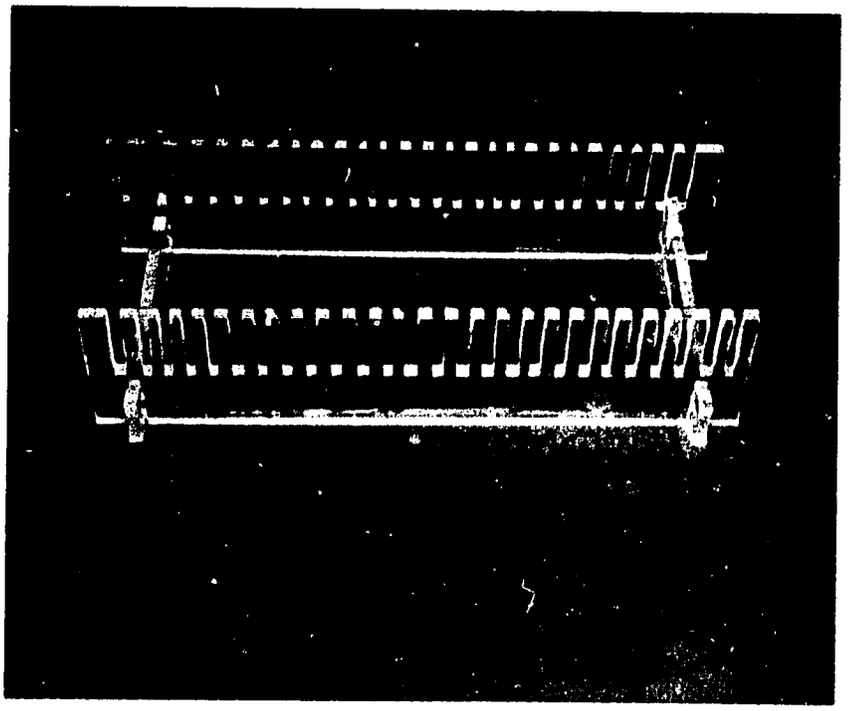

Fig. 1. Polyethylene rack for supporting seeds.

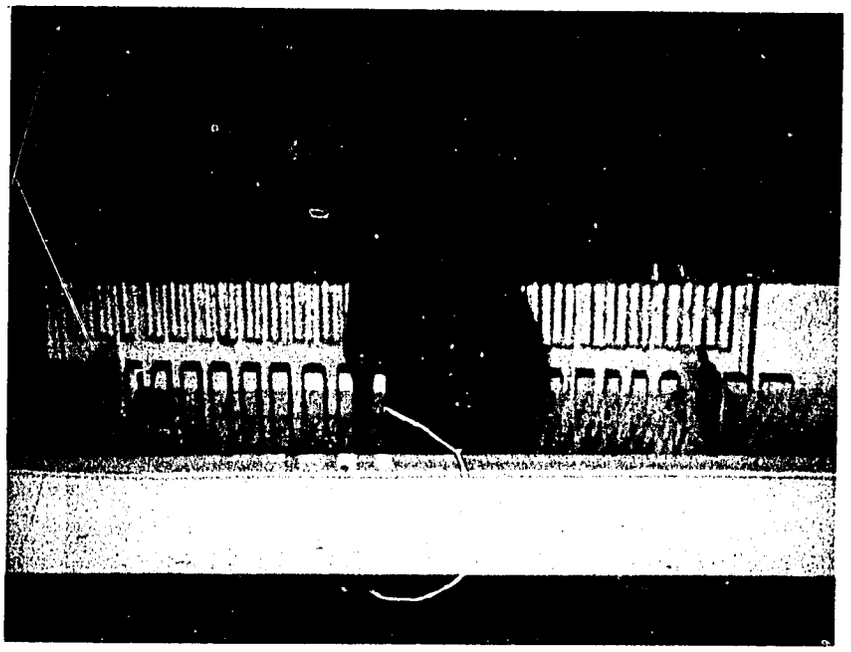

Fig. 2. Rack being filled out with blotter "sandwiches" of seeds.

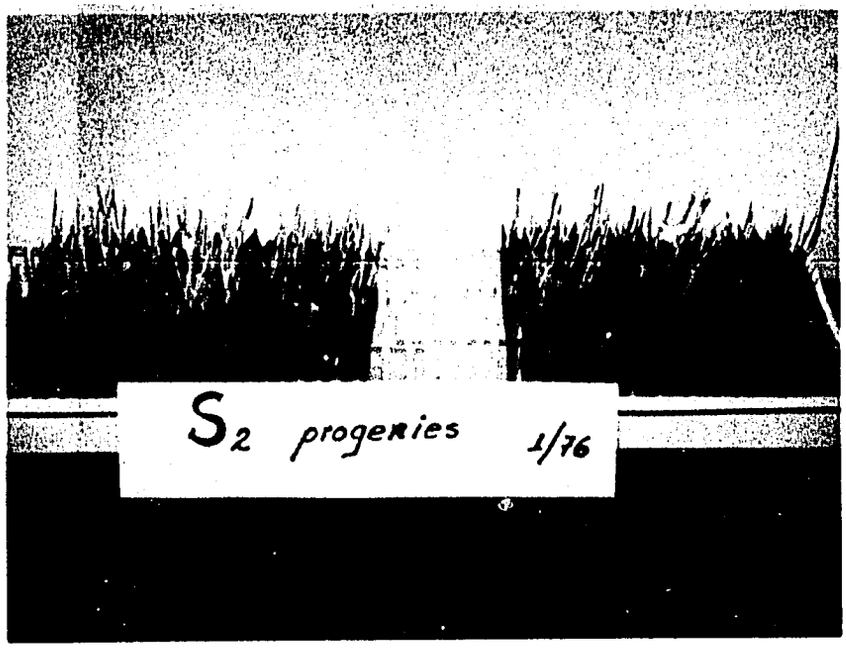

Fig. 3. General aspect of a plastic tray containing two sets of S_2 progenies

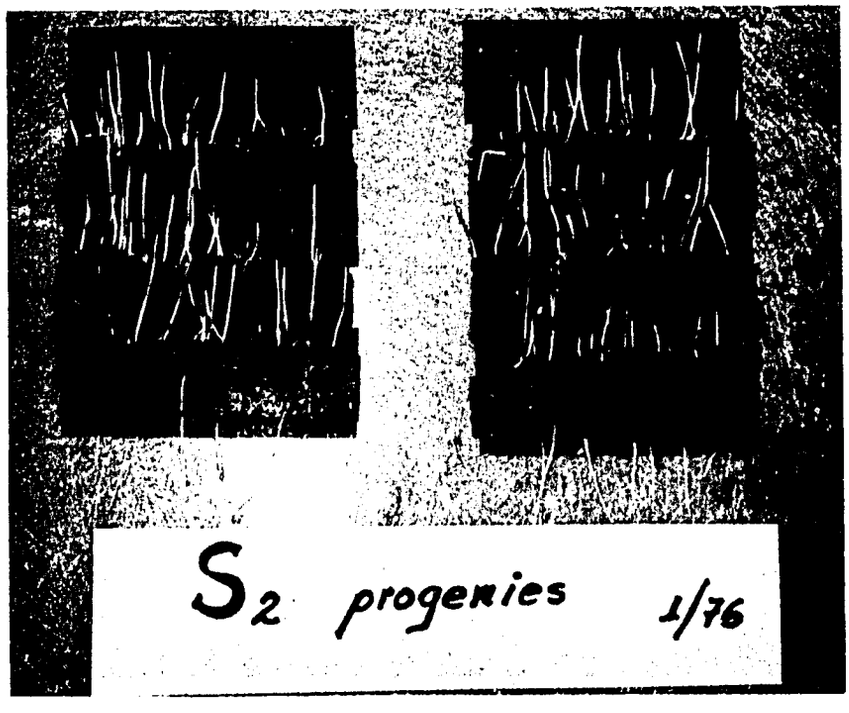

Fig. 4. Relative growth of S_2 progenies

Table 2. Daily soil temperature cycle two inches deep at Lincoln, NE from April 22 to May 10, 1975[2/]

Time (hours)	Temperature (°C)
3	10
6	10
9	15
12	20
15	22
18	18
21	14
24	12

2/ Average of the first 19 days after planting.

RESULTS AND DISCUSSION

Correlation analysis was performed with four sets of data. Two of those sets (FG-1 and FG-2) were visual grades given under field conditions corresponding to two different days in which genotypes were graded in the same replication. The other two sets of data correspond to the two replications planted under laboratory conditions (GCH-1 and GCH-2).

Results are given in Table 3.

Table 3. Correlation coefficients between field and laboratory visual grades, Lincoln, NE, 1975[3/]

Grade:	FG-2	GCH-1	GCH-2
FG-1	0.83**	0.62**	0.55**
FG-2		0.62**	0.54**
GCH-1			0.67**

3/ 693 observations.

** Significant at the 1% probability level.

From the correlation coefficient values it is noticed that the number of days from planting to the day in which grades are given has influence upon the grades and, therefore, affect the correlation values. In this context, FG-1 and FG-2 are grades given to genotypes of the same replication but FG-2 was given 5 days after FG-1. A close value of r=1 should be expected. The observed departure from r=1 could be interpreted as random errors due to failure in assigning grades in the field, but a differential rate of seedling growth among genotypes in that 5 days interval should also be considered.

The above consideration also applies to laboratory observations. GCH-2 grades were given 3 days after GCH-1, but in this case, grades belong to two different replications. Therefore, the effect of grading at different dates is confounded with replications. An obvious conclusion is that the grades must be assigned at the same number of days after planting in all replications.

CONCLUSIONS

Taking into account the following factors: 1) that comparisons among genotypes are much easier to do in the growth chamber than in the field; 2) that under laboratory conditions there is control over the number of seeds being planted; 3) that growth chamber temperatures were kept very similar to those occurring under field conditions; 4) that large numbers of genotypes were involved and 5) that visual grades ranged from 1 to 5, we conclude that this laboratory technique has good correlation with field observations and is to be considered a useful tool in screening genotypes for cold tolerance in the germination and seedling growth stage during the early phases of breeding programs.

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WHOLE PLANT RESPIRATION IN GRAIN SORGHUM

Jerry D. Eastin, Ian Brooking and A. O. Taylor

Sorghum hybrids were grown at three different day/night temperatures (29/17, 29/22 and 29/27 C) from panicle initiation until differentiation of florets (about 2 weeks) before whole plant (minus roots) respiration was run at 10, 15, 21 and 27 C (five replications). Table 1 contains results.

Table 1. Respiration rates in two sorghum hybrids taken from 3 pretreatment temperatures. Measurements were made at 10, 15, 21 and 27 C. Means are from 5 replications.

	Mg CO_2 evolved/g dry wt/hr	LSD .05	LSD .01
Respiration temperature			
10	0.50	.127	0.168
15	0.92		
21	1.74		
27	3.23		
Pretreatment temperature			
29/17	1.73	.101	.147
29/22	1.51		
29/27	1.55		
Hybrids			
CK 60 x 7078	1.41	.089	.118
CT[1/] x 156	1.78		

1/ CT - cold tolerant A line (SJ7) from Northrup King

Points of interest in Table 2 are significance in hybrids, respiration temperatures, pretreatment temperatures and the hybrid x respiration temperature interaction. The LSD's in Table 1 suggest large real differences between every temperature. Also (Table 1) plants grown at 29/17 respired more rapidly than plants taken from the 29/22 and 29/17 pretreatments. Therefore, previous history does influence respiration rate.

Table 2. Analysis of variance for whole plant respiration in two sorghum hybrids (CK60 x 7078 and SJ7 x 156) from 3 pretreatment temperatures (29/17, 29/22 and 29/17 C) run at 10, 15, 21, and 27 C.

Source	DF	SS	MS	F
Blocks	4	4.111	1.028	16.849 **
Hybrids (A)	1	4.144	4.144	67.934 **
Pretreatment Temp (B)	2	1.125	0.562	9.223 **
Respiration Temp (C)	3	129.796	43.265	709.266 **
A x B	2	0.090	0.045	0.736
A x C	3	1.672	0.558	9.139 **
B x C	6	0.614	0.102	1.679
A x B x C	6	0.040	0.007	0.110
Error	92	5.616	0.061	
Total	119	147.208		

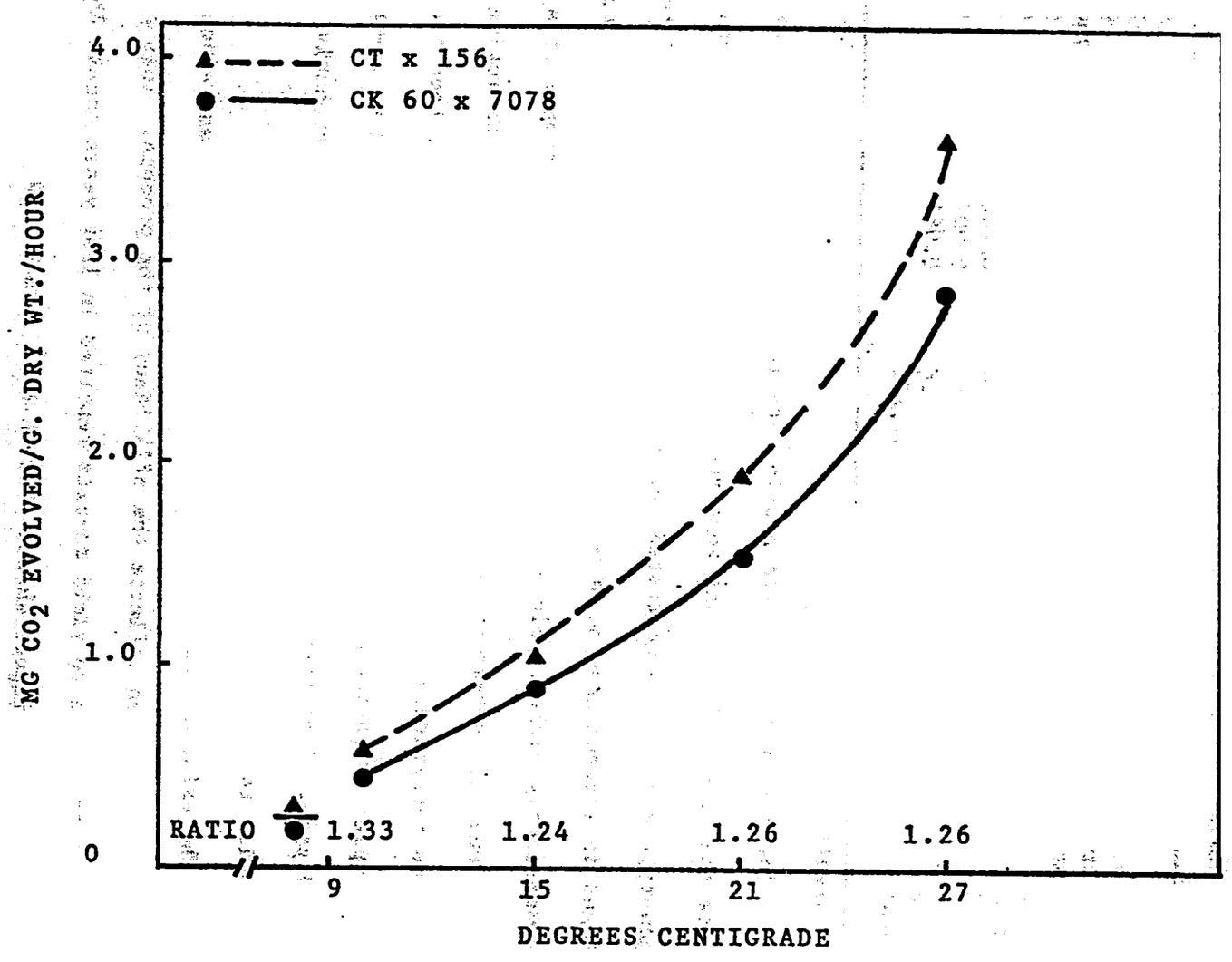
** Significant at .01 level

The differences between hybrids are more readily visualized in Figure 1. Note that the cool tolerant genotype respires about 25% faster than the temperate genotype over the range tested which spans most of the night temperatures to be found in sorghum growing areas. Some night temperatures in the tropics may be consistently higher. Since respiration is coupled to a number of synthetic processes, it is reasonable to expect that if respiration is moving 25% faster at some temperature in one genotype compared to the other, then the associated or coupled synthetic activities likely are also proceeding at a similar more rapid pace. Therefore, the respiration rate differences probably reflect metabolic rate differences in general.

The existence of such genotype differences is important since the pace of a process often reflects the efficiency of the process. This generalization appears to relate to yield results reported in last years Annual Report (1). Table 1 of that report showed that CK 60 x 7078 peaked in yield at about 29/22 C while CT x 156 peaked near 29/17 C which suggests first that they have different

FIGURE 1. TEMPERATURE INFLUENCE ON RESPIRATION IN SORGHUM

(15 PLANT AVERAGE, 1973)



temperature optima. Second, the percent yield reduction with a 5 C increase in night temperature over their respective optima was 25% in both cases. Regardless of where the temperature optima is for a genotype, moving it to a higher temperature environment than that to which it is adapted, will cause significant yield reductions. The importance of placing the proper temperature reaction genotype to the prevailing temperature environment of an area is clear.

Table 3 contains respiration rates by genotype. Data illustrate the marked effect of temperature on respiration. Note that approximately a 6 fold increase in respiration occurs when going from 10 C to 27 C. Stated differently, about an average 15% respiration increase per degree C elevation occurs.

These results suggest sorghums vary widely in their temperature optima and possess at least 25% respiration rate differences over a wide range of temperatures. These differences appear to relate quite directly to yield responses at different temperatures. The data probably at least partially explain the relatively low yields common to certain warm night areas of the tropics. Some effort is being given to developing a screening test for temperature typing sorghum in terms of cool, temperate and tropical adaptation.

Table 3. Respiration rates (mg CO_2 evolved/g dry wt/hr).

	CK60 x 7078		SJ7 x 156		
Temperature	CO_2 evolved	% increase/1 C	CO_2 evolved	% increase/1 C	Ave % increase
10	0.43		0.57		
15	0.82	18.1 (10-15C)	1.02	15.8	17.0
21	1.54	14.6 (15-21)	1.94	15.0	14.8
27	2.84	14.1 (21-27)	3.60	14.3	14.2
Overall Ave	1.41	15.6	1.78	15.0	15.3

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ENERGY QUANTITIES AND TIME PERIODS ASSOCIATED WITH SORGHUM GROWTH STAGES

J. D. Eastin, R. M. Castleberry, M. D. Clegg, C. Y. Sullivan and J. W. Maranville

We have arbitrarily divided sorghum development into the vegetative (GS_1), panicle development (GS_2) and grain filling stages (GS_3). Sorghum tolerates appreciable stress during GS_1 without suffering much yield loss. However, GS_2 is a more sensitive and critical period since seed number potential is set then. Seed number generally correlates positively with yield. Grain filling is obviously a critical period also. This investigation was conducted to check the time periods spent in each growth stage, the growing degree units (GDU) associated with the time and a combination GDU - solar energy factor[1/] (STU) association with days in each respective growth stage. The bearing of these parameters on yield will be considered.

Twenty hybrids were grown for 2 years at Mead, NE, in 3 replications under irrigated (240,000 plants/ha) and dryland (20,000 plants/ha) conditions. Fertility levels were adequate. Growing degree units were calculated according to the following formula using 12, 15, and 18 C base temperatures.

$$\text{GDU} = \frac{\text{Daily max} + \text{min}}{2} - \text{Base temperature}$$

$$\text{Solar-Thermal Units} = \text{GDU} \times \text{Langleys}$$

1/ Caprio, Joseph M. 1971. The Solar-Thermal Unit Theory in Relation to Plant Development and Potential Evapotranspiration. Circular 251. Montana Agr. Expt. Sta., Montana State University. Bozeman, Montana

Total energy is in Ly/day and PAR is photosynthetically active radiation in microeinsteins/sq. cm.

Table 1 contains days in growth stages and energy data by genotype. Conditions at Mead, NE., are such that GS_3 days exceed days in other growth stages by 15 to 28%. PAR received is about the same in GS_2 and GS_3 but was on the order of 16% less than that received during GS_1. Similarly total Langley's received during GS_2 and GS_3 were about 18% less than in GS_1. Average radiation values per day show GS_1 to be the highest and GS_3 to be the lowest.

Table 2 GDU and STU values reflect the fact that GS_2 days are warmer and generally longer than GS_1 and GS_3 days. GS_3 days are particularly cooler and likely have a higher percentage of cloudy days. GDU's required for GS_2 and GS_3 are about equal and exceed necessary GS_1 GDU by 10%.

Irrigated yields (Table 3) exceeded dryland yields only by 10.3%. Irrigated kg/ha/day (dry matter accumulation rate) exceeded dryland values by 7.6%. Presumably dryland environmental stresses reduced metabolic efficiency by 7.6% which is almost enough to account for the average yield reduction of 10.3%.

Table 4 shows relationships between GDU and STU and agronomic characters in 1972. The r value for yield and GS_3 days is significant in both cases. From 23 to 48% of the variability in yield related to variability in GS_3 days. Surprisingly seed number does not correlate with yield. Seed number does correlate generally with different energy value expressions during GS_2 when seed number potential is set.

Table 5 illustrates relationships between GDU and STU and agronomic characters in 1973 during which year the GS_3 period was longer and cooler.

Irrigated yields related significantly to all GS_3 energy expressions with r values of about 0.5. The unusually cool GS may relate to the absence of correlation between yield and GS_3. While data for 1973 do not show a meaningful association between yield and GS_3 days this association was significant in 1972 and also in tests from previous years.

Knowledge of the general requirement of 260 to 300 GDU (15 C base), about 1400 STU, or about 500 Langleys for the respective growth stages should be useful in evaluating where sorghum culture may be possible in LDC's if limited climatological data for the area in question are available. Also some estimation of adapted maturity class should be possible.

Table 1. Days, photosynthetically active radiation ($\mu e/cm^2$), and Langleys for each growth stage (GS) for 20 genotypes averaged over 4 experiments in 2 years.

Genotype	Days			PAR x 10^2			Langleys		
	GS_1	GS_2	GS_3	GS_1	GS_2	GS_3	GS_1	GS_2	GS_3
820[1]	44.5	34.7	46.2	2325	1690	1684	25401	18105	18341
E59[2]	40.2	37.0	47.1	2087	1824	1776	22685	19726	19292
828[1]	44.3	35.0	47.0	2302	1718	1717	25196	18367	18679
E57[2]	39.8	35.4	45.9	2068	1733	1790	22582	18691	19399
Nb 691	42.6	35.5	49.7	2223	1737	1801	24274	18649	19560
C42C[2]	38.7	34.0	45.9	2004	1660	1852	22246	17598	19963
833[1]	42.8	34.3	47.5	2231	1670	1790	24377	17940	19412
Nb 635	36.3	37.4	48.5	1878	1839	1900	20831	19560	20503
Nb 634	36.8	36.9	48.7	1902	1818	1912	21056	19369	20649
Acco R109	39.0	36.6	46.4	2040	1781	1789	22160	19328	19405
C42Y[2]	38.2	33.9	44.6	1994	1639	1836	21957	17560	19794
RS 626	35.3	34.3	39.7	1841	1668	1697	20405	17865	18118
Exel 808	39.5	37.0	47.0	2049	1823	1791	23532	19486	19445
RS 671	39.7	36.3	44.5	2058	1786	1717	22564	19153	18598
266[3]	35.7	38.2	43.3	1856	1866	1757	20522	19924	18991
222G[3]	40.7	34.8	46.1	2127	1682	1810	23158	18199	19644
845[1]	39.5	36.3	45.7	2049	1785	1763	22697	18917	19105
F64[2]	44.2	34.3	46.8	2296	1682	1733	25133	17991	18846
RS 625	34.0	35.6	38.5	1783	1726	1662	19677	18545	17753
233[3]	32.7	34.2	40.8	1708	1658	1797	18903	17802	19209
Ave	39.4	35.6	45.5	2048	1740	1774	22499	18636	19190
Ave/day				52.0	49.9	39.0	571	524	422

1 Pioneer
2 Dekalb
3 Northrup King

Table 2. Growing degree units (GDU) at base 15 C and solar thermal units (STU) for respective growth stages in 20 sorghum hybrids.

Genotype	GDU			STU x 10^2		
	GS_1	GS_2	GS_3	GS_1	GS_2	GS_3
820[1]	301	280	261	1695	1471	1161
E59[2]	254	304	279	1404	1643	1272
828[1]	300	281	263	1678	1488	1170
E57[2]	251	286	297	1394	1525	1386
Nb 691	278	291	278	1560	1541	1238
C42C[2]	244	274	314	1377	1433	1487
833[1]	281	276	284	1572	1459	1297
Nb 635	234	292	308	1322	1529	1454
Nb 634	237	293	305	1328	1543	1433
Acco R109	243	299	294	1353	1591	1366
C42Y[2]	237	277	313	1342	1445	1503
RS 626	224	276	298	1287	1434	1450
Exel 808	249	302	285	1390	1609	1314
RS 671	250	295	286	1393	1575	1329
266[3]	227	298	305	1291	1554	1447
222G[3]	262	285	286	1471	1510	1330
845[1]	251	293	290	1414	1544	1347
F64[2]	298	274	269	1670	1450	1209
RS 625	212	291	290	1219	1515	1416
233[3]	203	279	310	1174	1450	1531
Ave	263	287	290	1425	1513	1352
Ave/day	6.68	8.06	6.37	36.17	42.50	25.70

1 Pioneer
2 Dekalb
3 Northrup King

Table 3. Total grain yield (kg/ha) and kg/ha/GS_3 day for sorghum hybrids from irrigated and dryland plots for 2 years.

Genotype	Irrigated		Dryland		Overall	
	kg/ha	kg/ha/GS_3 day	kg/ha	kg/ha/GS_3 day	kg/ha	kg/ha/GS_3 day
820[1]	8147	172	7455	165	7801	169
E59[2]	8409	177	7933	170	8171	174
828[1]	9171	195	8016	171	8594	183
E57[2]	8275	176	7050	158	7663	167
Nb 691	8848	174	8021	165	8435	170
C42C[2]	8879	192	7269	159	8074	176
833[1]	8437	176	7980	170	8209	173
Nb 635	8622	175	7711	161	8167	168
Nb 634	9019	185	7811	161	8415	173
Acco R109	8395	178	8206	180	8301	179
C42Y[2]	8206	177	7338	171	7772	174
RS 626	8421	210	6973	178	7697	194
Exel 808	8259	173	8293	179	8276	176
RS 671	8813	196	7946	181	8379	188
266[3]	8571	194	7822	184	8197	189
222G[3]	7822	165	7460	166	7641	166
845[1]	8663	186	8093	181	8378	183
F64[2]	7988	168	7543	163	7766	166
RS 625	7809	204	6604	171	7207	187
233[3]	8576	209	7625	188	8100	199
Ave	8467	184	7657	171	8062	177

[1] Pioneer
[2] Dekalb
[3] Northrup King

Table 4. The regression of mean yield and seed number on mean GDU, STU, Langleys, PAR and days for 1972 irrigated and dryland sorghum. Means are from 3 replications.

	GDU_1 1/	GDU_2	GDU_3	STU_1	STU_2	STU_3	Langleys	PAR 2/	Days	Seed #
Irrigated										
Yield					GS_3					
r^2	.00946	.00110	.00623	.01128	.01363	.00396	.11054	.06875	.23337*	.13954
r	.0973	.0332	.0789	.1062	.1167	.0629	.3325	.2622	.4831	.3736
					GS_2					
r^2	.07748	.05611	.02300	.08730	.07188	.04444	.11333	.12409	.10398	
r	.2784	.2369	.1517	.2955	.2681	.2108	.3366	.3523	.3225	
Seed #										
r^2	.29753	.32300	.32614	.41551	.42355	.40829	.27435	.17466	.13978	
r	.5455*	.5683**	.5711**	.6446**	.6508**	.6390**	.5238*	.4179	.3739	
Dryland										
Yield	GDU_1	GDU_2	GDU_3	STU_1	STU_2	STU_3	Langleys	PAR	Days	Seed #
					GS_3					
r^2	.00148	.00396	.00011	.07998	.09033	.04892	.18431	.08752	.47823	.09404
r	.0385	.0629	.0105	.2828	.3005	.2212	.4293	.2958	.6915**	.3067
					GS_2					
r^2	.39866	.35797	.25511	.40572	.36655	.28083	.43797	.43274	.39471	
r	.6314**	.5983**	.5051*	.6370**	.6054**	.5299*	.6618**	.6578**	.6283**	
Seed #										
r^2	.15769	.16136	.15788	.21394	.21450	.20293	.15400	.11695	.09660	
r	.3971	.4017	.3973	.4625*	.4631**	.4505*	.3924	.3420	.3108	

1/ Numbers 1, 2 & 3 following GDU and STU notations indicate 12, 15 and 18 C temperature bases used in calculations.
2/ Microeinsteins/cm^2.

Table 5. The regression of mean yield and seed number on mean GDU, STU, Langleys, PAR and days for 1973 irrigated and dryland sorghum. Means are from 3 replications.

	GDU_1 1/	GDU_2	GDU_3	STU_1	STU_2	STU_3	Langleys	PAR 2/	Days	Seed #
Irrigated										
Yield					GS_3					
r^2	.32829	.26203	.21650	.24208	.22253	.21226	.20064	.20768	.00112	.00005
r	.5730**	.5119*	.4653*	.4920*	.4717*	.4607*	.4479*	.4557*	.0335	.0071
					GS_2					
r^2	.14031	.14684	.15823	.19405	.19900	.20643	.17284	.14653	.11387	
r	.3746	.3832	.3978	.4405	.4461*	.4543*	.4157	.3828	.3374	
Seed #										
r^2	.03699	.04127	.04603	.06751	.07250	.08174	.04946	.05798	.02225	
r	.1923	.2032	.2145	.2598	.2693	.2859	.2224	.2408	.1492	
Dryland										
	GDU_1	GDU_2	GDU_3	STU_1	STU_2	STU_3	Langleys	PAR	Days	Seed #
Yield					GS_3					
r^2	.02953	.04130	.04911	.02837	.03358	.03922	.02547	.02331	.05841	.22451
r	.1718	.2032	.2216	.1684	.1832	.1980	.1596	.1527	.2417	.4738*
					GS_2					
r^2	.06450	.06641	.06474	.04053	.04140	.04273	.03714	.04799	.05733	
r	.2540	.2577	.2544	.2013	.2035	.2067	.1927	.2191	.2394	
Seed #										
r^2	.10210	.10388	.10150	.08462	.08603	.08853	.07889	.10302	.09484	
r	.3195	.3223	.3186	.2909	.2933	.2975	.2809	.3210	.3080	

1/ Numbers 1,2 & 3 following GDU and STU notations indicate 12, 15 & 18 C temperature bases used in calculations.
2/ Microeinsteins/cm^2.

SELECTION FOR PROTEIN IN GRAIN SORGHUM

W. M. Ross, J. W. Maranville, and K. D. Kofoid

In 1970 combine-height S_1's having agronomic acceptability were selected from KP1BR at Mead, Nebraska, and this new population was later designated NP7BR. Each S_1 head was threshed, the grain weighed, 1000-kernel weight calculated, and protein (Udy) determined. The upper and lower 15% of 547 heads were composited as high and low protein subpopulations. The selected populations were sent to Puerto Rico during the winter of 1970-71, but little seed was set on the antherless male steriles so recombination was repeated in the states. Thereafter, selection was done in even years and recombinations made in odd years to the present time.

Data collected on the heads used in each cycle of each subpopulation are summarized in Table 1 . The 1975 season involved recombination, and new selections will be made in 1976. For reasons to be presented, the experiment soon will be modified, but meanwhile an analysis of progress to date is attempted.

Since different years are involved, and yield levels are related to protein levels, it is hardly valid to compare one year to the next with respect to absolute protein values in high or low groups. Perhaps a better indication of progress is to look at the difference between highs and lows on a population basis or on a selection basis to see if the differences are increasing. These percentage differences are summarized as follows:

	Populations	Selections
1970	--	3.34
1972	0.70	3.95
1974	2.62	5.47

It is apparent that two contrasting groups are emerging through male mass selection, but the low group may be progressing at a faster rate. More conclusive evidence can be attained only when successive cycles of material are compared in the same year.

The influence of yield is readily observed in that the high protein heads have generally been lower yielding and have had a lower seed number than the low protein heads. As a result, protein yields have been changed relatively little, and unless this can be done, the breeding must be deemed ineffective. Seed weight also has been slightly in favor of the low protein groups.

Correlations among the several characters made on the high and low selections are listed in Tables 2 and 3 for each successive cycle. The data in both tables are similar in that grain yield is highly correlated with seed number and protein yield. In the case of the low protein group, yield is not correlated with protein percent while in the high group it seems to be increasingly more negative. In either group protein percent has little relation to seed number or seed weight.

Though the above data are of interest, quantitative data on progenies are of more value. In 1975 200 S_1 familes were taken from the 1972 and 1974 subpopulations and yield tested in two replications at Mead. Two other populations of similar material selected for yield were also planted. On set was families from the first recombined cycle of Eckebil's NP7BR thesis material, and the other was NP9BR, which also traced to KP1BR but was selected in Arizona under a limited water regime. Yield, kernel weight, and percent protein are available for each of the S_1's used and will be available on the progenies. Meanwhile the preliminary agronomic data are given in Table 4. As might be expected the NP7BR population selected for yield only was the highest yielding. Even the population selected in Arizona performed well in Nebraska. Also as expected

the low protein populations in both cycles outyielded the high protein populations. No apparent yield differences were noted between cycles in either group, but the 1974 families in each case seemed to be earlier. The experiment will be repeated in 1976.

The need for progeny testing becomes apparent when one considers data reconstructed from Eckebil's research. Though his primary interest was in yield, protein analyses were available on both the S_1's and on the S_1 progenies of NP7BR used in his study. The S_1 progenies were yield tested in 1972 and 1973, and these results were correlated with the same data from the S_1's (Table 5). Unfortunately, the parent-offspring relationship is almost nil as determined by simple correlation. However, the correlation between years using progeny data is quite good.

For these reasons and because NP7BR carries the antherless gene which gives poor seed set during recombination and which induces biases in yield trials, if uncorrected, new protein breeding materials are being developed. Selections have been made in broad-based Purdue populations for shorter, earlier types, and these ultimately will be blended with the best protein selections from NP7BR. Improvement then will be undertaken on a family testing basis using both yield and protein as selection criteria.

Table 1. Agronomic and protein data on populations and selections

Year and population 1/	No. heads	Grain yd., g/head		Kernel wt., g/M		Seed no./head		Protein, %		Protein yd.	
		Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
1970 base	547	44.5	13.74	23.9	4.02	1903	623.1	12.2	1.10	5.4	1.61
high sel.	86	36.5	11.34	23.2	4.65	1612	525.8	14.1	0.53	5.1	1.59
low sel.	91	48.7	12.81	24.0	3.86	2063	598.5	10.7	0.37	5.2	1.38
1972 high pop.	289	69.7	21.39	21.9	4.22	3212	907.7	11.9	1.16	8.2	2.37
low pop.	487	66.6	16.12	23.3	3.97	2904	731.6	11.2	0.88	7.4	1.79
high sel.	47	52.6	14.70	20.2	4.69	2683	744.3	13.8	0.71	7.2	1.94
low sel.	62	68.4	16.58	22.1	3.52	3140	809.6	9.9	0.32	6.8	1.68
1974 high pop.	243	39.8	12.27	21.0	4.31	1936	579.1	12.7	1.16	5.0	1.38
low pop.	295	44.9	13.20	21.5	3.85	2121	607.0	10.1	0.98	4.5	1.31
high sel.	52	32.0	8.70	19.6	4.72	1701	489.4	14.4	0.77	4.6	1.18
low sel.	55	48.0	12.29	21.8	3.29	2211	498.4	8.9	0.42	4.3	1.09

1/ S_1's taken from isolation in years indicated at Mead, Nebraska; selections recombined in 1971, 1973, and 1975.

Table 2. Correlation data on high protein selections from successive cycles grown at Mead, Nebraska.

Trait 1/		Kernel weight per 1000	Seed no. per head	Protein, %	Protein yield (gr. yd. x % protein)
Grain yield	1970	0.237*	0.771**	-0.066	0.993**
	1972	0.432**	0.613**	-0.291*	0.987**
	1974	0.357**	0.529**	-0.347*	0.985**
Kernel weight	1970		-0.402**	-0.206	0.216*
	1972		-0.418**	-0.416**	0.386**
	1974		-0.579**	-0.116	0.367**
Seed no.	1970			0.109	0.781**
	1972			0.122	0.649**
	1974			-0.196	0.508**
Protein	1970				0.048
	1972				-0.140
	1974				-0.186

1/ In 1970, n = 84 of 547 or 15.4%.
In 1972, n = 47 of 289 or 16.3%.
In 1974, n = 52 of 243 or 21.4%.

* Significant at the 5% level.
** Significant at the 1% level.

Table 3 . Correlation data on low protein selections from successive cycles grown at Mead, Nebraska.

Trait[1/]	Kernel weight per 1000	Seed no. per head	Protein, %	Protein yield (gr. yd. x % protein)
Grain yield 1970	0.136	0.822**	-0.026	0.991**
1972	0.293*	0.795**	0.072	0.992**
1974	0.493**	0.797**	-0.069	0.979**
Kernel weight 1970		-0.429**	-0.046	0.140
1972		-0.324**	0.295*	0.332**
1974		-0.111	-0.109	0.470**
Seed no. 1970			-0.036	0.813**
1972			-0.139	0.761**
1974			0.024	0.793**
Protein 1970				0.103
1972				0.195
1974				0.132

1/ In 1970, n = 91 of 547 or 16.6%.
In 1972, n = 62 of 487 or 12.7%.
In 1974, n = 55 of 295 or 18.6%.

* Significant at the 5% level.
** Significant at the 1% level.

Table 4. Yield and days to bloom of 200 S_1 families each from successive cycles of protein selection compared with related material selected for yield. 1/

Year, source and population	Yield, kg/ha	Bloom, days
1974 NP7BR - Eckebil	3010 a	67 b
1974 NP9BR - Arizona	2801 b	67 b
1974 low protein	2672 bc	67 b
1972 low protein	2612 c	69 a
1974 high protein	2409 d	66 c
1972 high protein	2365 d	69 a

1/ Planted 6/7/75 at Mead, Nebraska, in two replications of single-row plots.

Table 5 . Correlation data of S_1's and their progenies.1/

Trait	1970 S_1's versus			
	1972 progenies	1973 progenies	Mean	1972 vs. 1973
Grain yield per head	0.310	0.086	0.064	0.651**
Kernel weight per 1000	0.050	0.061	0.059	0.751**
Seed no. per head	0.008	0.051	0.029	0.683**
Protein, %	-0.035	0.030	-0.003	0.655**
Protein yield	0.020	0.058	0.043	0.661**

1/ Based on 200 random S_1's selected from NP7BR at Mead, Nebraska, in 1970 and grown in two-replications of single-row plots at Mead in 1972 and 1973.

** Significant at the 1% level.

SORGHUM BREEDING AND GENETICS

W. M. Ross and K. D. Kofoid

Sorghum Random-Mating Populations

Development and use of random-mating populations make up a major effort in the breeding program at Nebraska in addition to a conventional line and hybrid phase. Many inquiries are made about the constitution of these populations, their use, and availability. The populations which we have developed are listed in Table 1 for reference and may be used to complement some of the studies which follow.

A numbering system has been adopted so that some degree of uniformity exists among the states which are working with populations. The designation consists of three basic parts: state prefix, number and suffix. The suffixes B, R, and BR refer to the type of germplasm that went into the composite and the expected use of lines that can be obtained through inbreeding.

It is anticipated that relatively few of the populations will be formally released, but they are available to public agencies in this country and abroad so long as seed supply is available. Newer populations carrying greenbug resistance, better grain quality, or other desirable attributes should be more valuable than some of the first developed populations. As with lines, recurrent selection procedures are being used to improve populations either through routine breeding and selection or through experiments which involve family testing. The latter furnish much needed information in the area of quantitative genetics and, at the same time, have considerable practical application to sorghum breeding in the lesser developed countries as well as to the commerical breeding programs in the developed nations.

Table 1. Random-mating populations developed by USDA, ARS-University of Nebraska.

Population	Male-sterile gene	No. lines	Brief description
NP1BR[1/]	ms_c, ms_3	20	Basic grain and forage varieties, selected for shortness and earliness.
NP2B[1/]	ms_3	9	Improved U. S. B lines and varieties.
NP3R[1/]	ms_3	31	Improved U. S. R lines and varieties.
NP4BR	ms_3	19	Similar to NP1BR, less selected.
NP5R	ms_3	140	NP3R x conversion lines and introductions.
NP6B	ms_3	32	NP2B x conversion lines and introductions.
NP7BR	al	218	KP1BR source, protein selections.
NP8BR	ms_3	98	Martin ms_3 x conversion lines[2].
NP9BR	al	218	KP1BR source, drought tolerance, cooperative with Arizona.
NP10BR	ms_3	360	NP3R x CIMMYT lines, cold tolerance.
NP11BR	al	218	KP1BR source, corn borer resistance, cooperative with Iowa.
NP12B	ms_3	48	NP2B x yellow B lines.
NP13R	ms_3	231	NP3R x yellow R lines.
NP14B[2/]	ms_3	-	NP6B[2] x greenbug resistant bulk, cooperative with Kansas.
NP15R[2/]	ms_3	-	NP5R[2] x greenbug resistant bulk, cooperative with Kansas.
NP16BR	ms_3	-	NP8BR x NP10BR, cold tolerance.
NP17R	ms_3	-	Short, early selections from Purdue protein populations.
NP18B	ms_3	-	Short, early selections from Purdue protein populations.

1/ Released and registered in Crop Science.

2/ Release anticipated under a regional number (RP).

Evaluation of Base Populations for Yield

Plant breeding methods based on population improvement can be successful only if two conditions are met: 1) the populations themselves must be high yielding and/or possess other attributes of importance so that effort is not wasted on working with germplasm of little value, and 2) sufficient variability must exist in the populations so that improvement is possible.

The yield levels of several base (unselected) random mating populations have been evaluated at Mead, Nebraska, for a period of time (Table 2), and the data are of considerable interest. Entries were not uniform for the period as new populations were added in 1974, but five populations were tested for 4 years. RS 626 and RS 671 were included as checks.

The 1972-75 period represents two distinct sets of climatic conditions in that 1972-73 was extremely favorable for sorghum production with adequate moisture while 1974-75 was characterized by heat and drought stress. The populations common to both periods performed relatively better in relation to the checks in 1972-73 than in 1974-75 indicating that the variable germplasm did not have any unusual buffering capacities as is often surmised. Yield levels of NP3R and NP5R were virtually equal to the checks in 1972-73, and the 4-year average yield of these two populations (about 90% of the checks) is encouraging.

Populations NP4BR, NP6B, and NP8BR were added in 1974 and seem to be even higher yielding than NP3R and NP5R. More base populations will be tested in 1976, particularly those carrying greenbug resistance and yellow endosperm. NP1BR, NP2B, and NP7BR are obviously low yielding for reasons of either rigid selection during development or because of a narrow germplasm base. Of these, only NP7BR is being used in experiments (protein selection), and that study is relatively short-termed.

In the 4-year analysis a population x year interaction (P x Y) existed as might be expected, but populations (P) themselves were relatively more important. A comparison of P with P x Y mean squares from the analysis of variance gave a ratio of 10.9 to 1, and the variance component ratios (σ_p^2 vs. σ_{py}^2) were 3.3 to 1, which is still of considerable magnitude. These data indicate that a preliminary yield test of an unselected population for a period of 2 years (or perhaps two locations in 1 year) might be a prudent step prior to the launching of full-scale family tests.

Table 2. Yields of populations and checks grown at Mead, Nebraska, 1972-75.1/

Population	Yield, kg/ha				Avg. yield, kg/ha			% yield of RS 626		
	1972	1973	1974	1975	1972-73	1974-75	1972-75	1972-73	1974-75	1972-75
NP1BR	4698	4572	2255	4148	4635	3201	3918	84.6	68.7	77.3
NP2B	5325	4187	2513	4248	4756	3381	4068	86.9	72.6	80.3
NP3R	5762	5372	2616	4822	5567	3719	4643	101.7	79.8	91.6
NP4BR	--	--	2965	4928	--	3947	--	--	84.7	--
NP5R	5633	5397	2368	4363	5515	3366	4440	100.7	72.2	87.6
NP6B	--	--	3184	5014	--	4099	--	--	88.0	--
NP7BR	4720	3923	1640	3531	4322	2585	3453	78.9	55.5	68.1
NP8BR	--	--	3037	4837	--	3937	--	--	84.5	--
RS 626	5368	5583	4162	5157	5476	4660	5068	100.0	100.0	100.0
RS 671	5855	5512	3023	5387	5683	4205	4944	103.8	90.2	97.6
Mean	5337	4935	2776	4643	5136	3710	4362			
LSD (.05)	595	610	270	542	770	577	524			
CV (%)	9.5	10.5	8.4	10.1	10.0	9.9	9.8			

1/ Six replications were grown each year in a RCB design; harvested plot area was two rows x 4.5 m x .76 m or two x 6 m x .76 m.

Comparisons of NP3R Subpopulations

The NP3R base population is considered to be the 1971 Mead source after one random mating at Mead in 1970 and two more in Puerto Rico during the winter of 1970-71. In 1971 and the years following, NP3R was planted under both irrigated and nonirrigated isolated conditions at Mead and maintained through half-sib selection. In 1971 the base population was maintained separately from the dryland block, but this was not done subsequently since they were handled the same.

In 1971 male mass selection was practiced in the base block of NP3R through selection of S_1's. These were recombined during the winter for subsequent mass selection, and a cycle per year has been accomplished to date.

The several sources of NP3R from three consecutive seasons were yield tested at Mead in 1974 and 1975 to see if any gains had been made through mass selection and to see if unconscience selection had been practiced in the dryland and irrigated subpopulations. Checks were added for yield comparisons, and the data were analyzed as a randomized complete block with the checks and as a split plot design without them. Data are presented in Table 3.

Several conclusions can be made from the experiment:

1) Three random matings did not materially effect the population's performance though two of them had been made in Puerto Rico.
2) Subsequent random mating under dryland conditions did not change the performance from the initial random matings except some effort was made to reduce tall height mutants and tall segregates. Maturity may also possibly have been shortened.
3) Propagation under either dryland or irrigation made no difference in performance under dryland testing conditions. Irrigated yield tests were not made.

4) Mass selection apparently was ineffective in increasing yield while undesirable shifts to late maturity and taller height were apparent.

Mass selection was somewhat more severe in 1975, but if future yield tests continue to show no gains, the breeding method will be dropped in lieu of more successful systems like S_1 progeny testing which is already being used with NP3R.

NP3R was also grown under dryland and irrigation in 1974 and 1975, and tentative plans are to select S_1's from both subpopulations in 1976, yield test them in 1977 under both dryland and irrigation, and employ drought-heat tests in cooperation with C. Y. Sullivan.

Table 3. Mean agronomic data from various groups and sources of NP3R and checks grown at Mead, Nebraska, 1974-75.1/

Population and source	Bloom, days	Height, cm	Yield, kg/ha
NP3R-RM1, Mead 1970	61 a	100 a	3044 a
-RM2, P.R. 1970	62 a	104 a	3096 a
-RM3, P.R. 1971	62 a	104 a	3016 a
Mean2/	62 (b)	103 (b)	3052 (a)
NP3R-mass sel., P.R. 1971-72	66 a	116 a	3198 a
-mass sel., P.R. 1972-73	66 a	117 a	3080 a
-mass sel., P.R. 1973-74	67 a	117 a	3073 a
Mean	66 (a)	117 (a)	3117 (a)
NP3R-dryland, Mead 1971	60 a	97 a	3089 a
-dryland, Mead 1972	60 a	95 a	2973 a
-dryland, Mead 1973	60 a	95 a	3043 a
Mean	60 (d)	96 (d)	3035 (a)
NP3R-irrig., Mead 1971	61 a	97 a	3247 a
-irrig., Mead 1972	61 a	97 a	3047 a
-irrig., Mead 1973	60 a	99 a	3134 a
Mean	61 (c)	98 (c)	3143 (a)
NP3R-base check	60 c	101 a	3012 b
RS 626 - hybrid check	68 b	95 a	4097 a
RS 671 - hybrid check	75 a	96 a	3153 b
CV (%) excluding checks	0.9	3.3	11.4
CV (%) including checks	1.3	4.1	11.8
LSD (.05) RCB analysis	5.3	11.4	449.1

1/ Six replications grown each year in a modified split-plot design. Harvested plot area was two rows x 4.5 m x .76 m.

2/ For mean comparisons, use DMR in ( ). Other DMR comparisons are within sets of three.

Family Testing Schemes with NP3R and NP5R

Jan-orn (Ph.D. Dissertation, 1973) compared full-sib (FS), half-sib (HS), and S_1 family testing using NP3R while Eckebil (Ph.D. Dissertation, 1974) compared NP3R, NP5R, and NP7BR using S_1 testing. The two experiments were continued into second cycle testing but were consolidated through the dropping of NP7BR and one set of NP3R S_1's. The NP3R S_1's traced to the same material, were handled essentially the same way, and for practical purposes were considered equal. NP7BR is inheritently low yielding, carries the anterless gene, is being used in a protein study, and does not warrant further experimentation in this long-term study.

The highest 20% yielding families in each of the four populations of the combined experiment were genetically recombined in Puerto Rico during the winter of 1973-74. The new populations (or subpopulations) from first cycle tests were yield tested as bulks in Nebraska in 1975 when the second cycle family tests were also conducted. The bulk population tests (Table 4) help establish the realized or actual yield gains in relation to the predicted gains from the first cycle of family testing.

Gains in NP3R were within expectations if the NP3R base population is interpreted to be in a class different from the three family populations. These gains were from 36 to 62% of that expected which is not unreasonable considering the usually inflated broad-sense heritabilities which were in the prediction equation. Broad-sense heritability allows all families to be compared together as narrow-sense or true heritability based on additive genetic variance is not available from S_1's alone as with NP5R. The gains seem to be significant when yields are related to RS 626. While the base NP3R averaged 81% of the check hybrid, improved populations ranged from 84 to 87% of RS 626. If these levels can be maintained, eventual elite subpopulations of NP3R should approach RS 626. This must be demonstrated

experimentally, however.

Gains were not so high or perhaps nonexistent with NP5R with only a 2.9% increase. This was only 10% of the expected gain. Several reasons may account for the relatively poor performance of the selected NP5R. First, limited seed was obtained from Puerto Rico after recombination and may not have represented a good sample. This was apparent from the large number of tall plants in the isolation block at Mead in 1974 where it was difficult to find new S_1's of proper stature for the second cycle family tests. Secondly, the predicted genetic advance from Eckebil's study was considerably higher for NP5R (28.8%) as compared with NP3R (16.6%). However, a lower predicted gain would only aid relative, and not actual, gains. Future tests may help resolve these unexpected results since NP5R is known to have a moderately high yield potential and ample variability for improvement.

Two hundred families were made from each of the four populations in 1974 for family tests in 1975. These tests were grown at Mead and Goehner, Nebraska, using the blocks in replications experimental design of Eckebil's research. The second location was made possible through the courtesy of Dr. R. F. Koenig, former graduate student and now plant breeder with Funk's International Seed Co.

Better experimental conditions existed at Mead than at Goehner as reflected by the C. V.'s and DMR values required for significance (Table 5). Entries within populations often interacted with locations as did populations themselves. However, the HS and FS means were in a class apart from the S_1's with the S_1's yielding about 88% of the FS and HS families. This level is normal and can be attributed to inbreeding depression.

The mean yield of NP5R S_1 families was below that of NP3R families but at the same relative level as in the first cycle of testing. At Mead in 1972 and 1973, Eckebil's NP5R families averaged about 92% of his NP3R S_1's; at Mead

in 1975 the relationship was about 94%. This indicates that the yield potential of NP5R at least has been maintained.

Table 5 shows that application of moderate pressure for height and maturity when making up families was fairly effective. NP5R from the first cycle recombination in Puerto Rico was somewhat tall while the families tested were relatively shorter. Only HS families at Mead tended to be taller than the other three. Maturities of all four populations were about the same without any apparent shifts. Deviations in maturity too far from RS 626 should be cause for concern as should heights which average too far above the check hybrids.

Table 6 summarizes family tests from two cycles. For the most part, the broad sense heritabilities and genetic advances for yield are similar in both cycles. The second cycle predictions for NP5R S_1's were down from the first cycle and more in line with NP3R S_1's. As in the first cycle the lowest gains are expected from HS families. The second cycle predictions were based on Mead data only due to the high experimental errors at the second location.

The highest yielding 20% families from the 1975 tests were sent to Puerto Rico for recombination, and families will be made in 1976 for testing in 1977. Bulk family testing can be done in 1976 or preferably in 1977 when the families are grown.

Table 4. Yields of recombined highest 20% yielding families from first cycle tests compared with base populations and checks at Mead, Nebraska in 1975. 1/

Population and source	Bloom, days	Ht., cm	Yield				
			kg/ha	kg inc.	% inc.	% real./ % pred.	% of RS 626
NP5R base	57	105	3688 cd	---	---	---	75
NP5R S_1	61	128	3793 cd	105	2.9	.10	77
NP3R base	56	108	3951 cd	---	---	---	81
NP3R S_1	61	111	4248 bc	297	7.5	.48 2/	87
NP3R HS	58	110	4123 bcd	172	4.4	.62	84
NP3R FS	59	112	4158 bcd	207	5.2	.36	85
RS 626	60	102	4908 a	---	---	---	100
RS 671	67	101	4535 ab	---	---	---	92

1/ Planted 6/12/75 in six replications of two-row plots.

2/ Mean of two sets.

Table 5. Mean agronomic data from second cycle family testing methods at two locations in Nebraska in 1975.[1/]

Population	Bloom, days			Height, cm			Yield, kg/ha		
	Mead	Goehner	Combined	Mead	Goehner	Combined	Mead	Goehner	Combined
NP5R S_1	60 a	63 a	61 a	109 c	122 a	115 a	3781 c	4645 c	4231 c
NP3R HS	57 c	63 a	60 a	124 a	120 a	122 a	4533 a	5404 a	4968 a
NP3R FS	58 b	62 a	60 a	114 b	122 a	118 a	4629 a	4972 b	4801 ab
NP3R S_1	60 a	62 a	61 a	115 b	123 a	119 a	4037 b	4663 c	4350 bc
Mean	59 b	63 a	61	116 b	122 a	119	4245 b	4921 a	4583
CV (%)	2.1	4.7	3.8	4.8	10.4	8.3	10.4	17.9	15.2

1/ Two replications were grown in a modified RCB design (blocks in replications) using 200 families from each population. Planting dates were 6-10 (rep. 1) and 6-12 (rep. 2) at Mead and 6-5 at Goehner. Harvested area was one row x 4.5 m x .76 m.

Table 6 . Yields, predicted gains per cycle, and broad-sense heritabilities from two cycles of family testing for yield.

Cycle and population	Family type	Yield, kg/ha	Predicted gen. advance kg/h	Predicted gen. advance % of mean	Heritability 4/
First cycle					
NP5R 1/	S_1 (JPE)	5650	1628	28.8	.86
NP3R 1/	S_1 (JPE)	6150	1017	16.6	.74
NP3R 2/	S_1 (JJO)	4930	712	14.4	.69
NP3R 2/	HS (JJO)	5056	358	7.1	.53
NP3R 2/	FS (JJO)	5398	770	14.3	.74
Second cycle 3/					
NP5R	S_1	3780	572	15.1	.71
NP3R	S_1	4037	668	16.5	.76
NP3R	HS	4533	446	9.8	.61
NP3R	FS	4629	522	11.3	.68

1/ Mead, Nebraska, 1972 and 1973; JPE = Eckebil data.

2/ Mead and Lincoln, 1972; JJO = Jan-Orn data.

3/ Mead, 1975; second location data not used.

4/ Heritability is defined here as the ratio of family genotypic variance to family phenotypic variance, or

$$H = \frac{\sigma_F^2}{\sigma_F^2 + \sigma_{FL}^2/L + \sigma^2/RL}$$

where F, L, and R refer to families, locations (or years), and replications, respectively.

Full-sib Reciprocal Recurrent Selection

Jan-orn (Ph. D. Dissertation, University of Nebraska, 1973) found in NP3R that full-sib families yielded higher than half-sibs, which in turn were higher than S_1's. This fact plus the practical need to develop B and R populations that combine well with each other prompted a preliminary investigation of reciprocal full-sib crosses.

In 1973, bulk crosses were made between two B populations, NP2B and NP6B, and two R populations, NP3R and NP5R. The crosses, including reciprocals, the populations, and checks were yield tested at Mead, Nebraska, and Lafayette, Indiana, in 1974 and 1975 with the unanalyzed results presented in Table 7 .

Though yield levels were higher in Indiana than in Nebraska, performance of the entries was generally similar. At both locations NP6B was the highest yielding population while NP2B was the lowest. The two R populations tended to be equal at Mead, but NP3R was somewhat better at Lafayette. The crosses were more erratic though reciprocals apparently were equal. NP6B x NP3R did well at both locations while NP6B x NP5R was low at both locations. NP2B x NP5R did relatively well and was essentially equal to NP6B x NP3R. NP2B is a narrow-based population and was not expected to give such good results. Additional population crosses need to be studied for their combining ability potential.

Since both NP6B and NP5R were wide-based and high yielding in themselves, it was assumed that they might be suitable populations for a reciprocal recurrent study involving full-sib families. Crosses were made on a paired basis in 1974 prior to the known results of the 1974 bulk yield test for a family yield trial in 1975. Males used in the crosses became S_1's of the 1975 test. Had the population cross data been available, NP6B x NP5R might not have been chosen. However, 150 kg/h in the combined analysis may not be significant between crosses, and any cross may be suitable for study.

The data (Table 8) summarize 100 families in each group and point out the high yield of NP6B which averaged the same as the full-sib families. The mean of NP5R and NP6B S_1's together averaged 92.3% of the full-sib families which is about the same as found by Jan-orn in NP3R (91.3%). The full-sib families in this test were taller as expected which reflects hybrid vigor. Maturity differences were not great though perhaps real.

The experiment will be repeated in 1976, and further analyses will be made of the relation of the male parent to the full-sib family cross. Unfortunately, in sorghum the female parent cannot be propagated as with corn, but crosses can be made both ways since genetic steriles are used. If a suitable criterion is found, both B and R populations can be improved. Another method is to cross one male to several females, but this involves considerably more work, and fewer males can be sampled for making up a large scale yield test.

Table 7. Yield data from population crosses, populations, and checks at two locations, 1974-75.1/

Entry	Mead--yd., kg/ha			Lafayette--yd., kg/ha			Combined yield	
	1974	1975	Mean	1974	1975	Mean	Mean	% of RS626
NP2B x NP3R	2888	3745	3316	4452	8893	6672	4994	86.6
NP3R x NP2B	2920	3899	3410	5007	8577	6792	5101	88.4
Mean	2904	3822	3363	4729	8735	6732	5048	87.5
NP2B x NP5R	3105	3735	3420	4288	8183	6236	4828	83.7
NP5R x NP2B	2972	3837	3404	4437	8242	6340	4872	84.5
Mean	3038	3786	3412	4362	8212	6288	4850	84.1
NP6B x NP3R	3208	3774	3491	4638	9003	6820	5156	89.4
NP3R x NP6B	3210	3492	3351	4248	8604	6426	4888	84.7
Mean	3209	3633	3421	4443	8804	6623	5022	87.1
NP6B x NP5R	3127	3616	3372	4262	8437	6350	4861	84.3
NP5R x NP6B	2988	3296	3142	4460	8528	6494	4818	83.5
Mean	3058	3456	3257	4361	8482	6422	4840	83.9
NP2B	2192	3199	2696	3998	8934	6466	4581	79.4
NP6B	3073	3612	3342	4408	9317	6862	5102	88.4
Mean	2632	3406	3019	4203	9126	6664	4842	83.9
NP3R	2913	3472	3192	4613	8955	6784	4988	86.5
NP5R	2795	3588	3192	4305	8755	6530	4861	84.3
Mean	2854	3530	3192	4459	8855	6657	4924	85.4
RS 626	4005	4276	4140	5548	9244	7396	5768	100.0
RS 671	2872	4267	3570	3660	8396	6028	4799	83.2
Mean	3438	4272	3855	4604	8820	6712	5284	91.6

1/ Lafayette, Indiana, data furnished by D. L. Oswalt and K. S. Porter.

Table 8. Agronomic data on S_1 progenies and related full-sib reciprocal families at Mead, Nebraska in 1975. 1/

Group	Days, bloom	Ht., cm	Yd., kg/ha
NP6B	58 a	96 b	4748 a
NP5R	57 b	92 c	4219 b
NP6B x NP5R	56 c	105 a	4857 a
NP5R x NP6B	56 c	106 a	4849 a
CV (%)	1.5	5.6	10.1

1/ Planted 6/10/75 in two replications of single-row plots; 100 families or progenies tested in each group.

Performance of NP1BR Topcrosses

Seven cytoplasmic male-sterile seed stocks were interspersed in the isolation block of NP1BR for three years, 1971-73, and topcross seed was harvested every year from each sterile except Redlan which generally was late and set little seed. In 1974 and 1975 the three yearly sources of six topcrosses were yield tested along with the NP1BR base population and three F_1 hybrid checks. Objectives were to evaluate topcross performance among females and to determine if year-to-year variation existed in given female topcrosses.

Data in Table 9 show that within-year yield differences among females existed though of a low magnitude. The combined data did not reveal statistical yield differences though trends existed. The yield of NP1BR itself tended to decrease, and this is not accounted for since large numbers of half sibs were saved each year for maintenance without selection. Any drastic shifts in NP1BR likely would be accompanied by changes in maturity which would have resulted in a different spectrum of crosses to any or all females which in turn should have been reflected in the topcrosses. This was not apparent. Averages of all topcrosses by years was 1971 (3976 kg/ha), 1972 (3847), and 1973 (3844) which are nonsignificant.

The data indicate that CK60 and Wheatland are extremely good general combiners which also has been affirmed through F_1 hybrid programs of the past 20 years. However, more males were sampled here in one season than can be done with lines in a decade. Population topcrosses, then, may be a good way to evaluate new A-B lines from the breeding program for general combining ability.

Just as populations themselves differ in yielding ability, it is also likely that their topcrosses differ. It is suggested then that random mating populations not only be tested for yield potential through tests of the base

population themselves but also through one or two good topcrosses before embarking on family recurrent selection schemes were yield is of prime importance. Experiments need to be conducted for improving the yield of a random-mating population through family testing by crossing S_1's to CK60, Wheatland, or some other good tests like a sterile F_1, yield testing the topcrosses, and recombining the best males based on topcross performance. Such a breeding scheme would not be difficult to implement and would have certain advantage over RRS schemes in that: 1) extra crossed seed could be more easily obtained by pollinating an extra sterile tester, and 2) crosses would be identified by males only.

Table . Performance of NP1BR topcrosses at Mead, Nebraska, 1974-75.[1/]

Entry	Topcross	Source	Bloom, days			Ht., cm			Yd., kg/ha		
			1974	1975	Mean	1974	1975	Mean	1974	1975	Mean
1	Tx406 x NP1BR	1971	67 a	59 a	63 a	91 a	105 a	98 a	2537 a	5012 a	3775 a
2	"	1972	66 a	59 a	63 a	91 a	102 a	97 a	2485 a	4510 a	3498 a
3	"	1973	66 a	59 a	63 a	90 b	102 a	96 a	2207 a	4472 a	3339 a
Mean			66 d	59 c	63 b	91 b	103 bc	97 b	2410 b	4665 c	3537 a
4	Tx616 x NP1BR	1971	68 a	59 a	63 a	87 b	102 a	94 a	3149 a	4484 a	3994 a
5	"	1972	68 a	59 a	64 a	87 b	100 a	93 a	2912 a	4498 a	3905 a
6	"	1973	68 a	59 a	64 a	89 a	101 a	95 a	2932 a	4797 a	3864 a
Mean			68 c	59 c	64 b	88 b	101 bc	94 b	2997 a	4845 bc	3921 a
7	OK24 x NP1BR	1971	69 a	59 a	64 a	92 a	98 a	95 a	2732 a	5012 a	3872 a
8	"	1972	69 a	59 a	64 a	90 b	98 a	94 a	2673 a	4917 a	3795 a
9	"	197[illegible]	69 a	60 a	64 a	88 c	98 a	93 a	2578 a	5108 a	3843 a
Mean			69 bc	59 c	64 b	90 b	98 c	94 b	2661 b	5012 ab	3837 a
10	CK60 x NP1BR	1971	70 a	60 a	65 a	98 a	108 a	103 a	3063 a	5046 a	4045 a
11	"	1972	70 a	60 a	65 a	97 b	107 a	102 a	2930 a	5022 a	3976 a
12	"	1973	70 a	60 a	65 a	98 a	108 a	103 a	3179 a	5084 a	4132 a
Mean			70 b	60 b	65 b	98 a	108 a	103 a	3057 a	5051 ab	4054 a
13	Martin x NP1BR	1971	70 a	60 a	65 a	97 a	106 a	101 a	2939 a	4907 a	3932 a
14	"	1972	70 a	60 a	64 a	97 a	108 a	102 a	2966 a	4840 a	3903 a
15	"	1973	69 a	59 a	64 a	97 a	105 a	101 a	2889 a	4797 a	3843 a
Mean			70 b	60 b	64 b	97 a	106 ab	101 a	2931 a	4848 bc	3890 a
16	Wheatland x NP1BR	1971	75 a	64 a	69 a	97 a	102 a	99 a	3030 a	5448 a	4239 a
17	"	1972	76 a	64 a	70 a	93 c	102 a	98 a	2896 a	5118 a	4007 a
18	"	1973	75 a	64 a	70 a	95 b	101 a	98 a	2883 a	5199 a	4041 a
Mean			75 a	64 a	70 a	95 a	102 bc	98 ab	2936 a	5255 a	4096 a
19	NP1BR	1971	62	58	60	92	105	99	2752	4711	3732
20	"	1972	62	58	60	93	104	99	2422	4596	3509
21	"	1973	61	58	59	92	105	98	2342	4218	3280
Mean			62	58	60	92	105	99	2505	4508	3507
22	NB634	--	85	64	74	112	118	115	2112	5759	3936
23	NB635	--	85	64	74	110	116	113	2040	6012	4020
24	NB691	--	93	73	82	123	124	124	471	5730	3101
Mean			88	67	77	115	119	117	1542	5834	3688
Mean			71	61	66	96	105	100	2630	5002	3816
LSD (.05)			1.4	0.9	7.0	3.8	3.9	5.2	319	467	1188
CV (%)			1.8	1.3	1.6	3.5	3.3	3.4	10.6	8.2	9.2

1/ Planted 5/30/74 and 6/10/75 in six replications of two-row plots. Data analyzed as a RCB design including checks and as a split plot design without checks.

Yield of Twin-Seeded Sorghum

Interest has arisen in the past few years in twin-seeded sorghums that reputedly outyield normal types. A. J. Casady, ARS Agronomist, Manhattan, Kansas, developed an isogenic Combine Kafir-60 twin-seeded female line having PI 14610 as the nonrecurrent source of the dominant character. He made six pairs of isogenic hybrids using normal R lines which were then grown at Mead, Nebraska, and Manhattan, Kansas, in 1975. The Mead data are shown in Table 10 and preliminary results from Manhattan show essentially the same reults.

As determined by the analysis of variance, the mean of the normals significantly outyielded the mean of the twins. This was due,however, largely to two hybrids, RS 650 and 55MH19. Two more, KS 652 and 62MH248, tended to favor the normals while the other two, RS 610 and RS 702, were essentially equal.

Unless other sources of twin seed are being used which have more pronounced effects, there seems to be no practical plant breeding advantage with this character. It may, however, be of value in physiological studies dealing with seed development.

Table 10. Yields of isogenic and normal twin-seeded hybrids at Mead, Nebraska, 1975. 1/

Hybrid	Yield, kg/ha		
	Twin (T)	Normal (N)	Diff. (N-T)
KS 652	5573	6257	684
RS 610	5698	5500	-198
RS 702	5033	4680	- 353
RS 650	5268	6103	835
62MH248	5610	6292	682
55MH19	5568	6620	1052
Mean	5458	5909	451*

1/ Planted 6/12/75 in three replications of a split-plot design. Harvested area was 4.5 m from the center row of three-row plots.

* Significant at the 5% level.
CV = 8.4%.

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