EFFECT OF NATURAL SELECTION ON GRAIN YIELD AND OTHER PLANT CHARACTERISTICS IN SELFED AND RANDOM MATING GRAIN SORGHUM POPULATIONS

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This work is dedicated to Eastern Mennonite College.

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CHAPTER I

INTRODUCTION

It is well understood that the stability of performance of a crop is determined by at least two factors: its adaptability, and its resistance to different environmental hazards such as insects, pathogens, drought, and cold. The overall objective of a plant breeder is governed by these two factors.

According to Webster (1965) the availability of only a narrow germplasm base has been the limiting factor for genetic advance in sorghum [Sorghum bicolor (L.) Moench] breeding. To broaden the germplasm base of sorghum, the conversion program, and the population breeding approach were initiated in the early sixties.

The discovery of male-sterile genes in sorghum made it possible to adopt cross-pollinated breeding techniques to sorghum. This discovery provided a method of developing random-mating populations (RMP), and of applying to sorghum some of the population improvement techniques involving recurrent selection.

As a contribution to the investigation of the potential of the population breeding approach in sorghum, several RMPs were initiated in the Oklahoma State University sorghum breeding program in the late sixties. Early and late maturing composite populations were used in this study.

The main objective of this investigation was to study the change in several grain and plant characteristics over 12 generations of random-mating. It is important to know the extent of changes over the 12 generations of advance of broad-based germplasm random-mating sorghum populations (germplasm pools) because of the implications toward maintenance of germplasm populations. To know the change over generations is important to breeders as it relates to the conservation of genes and gene frequencies in RMPs under conditions of natural selection. The other objectives were to compare the early with late maturing populations, and to compare the self-pollinated populations (SPP) with the cross-pollinated populations (CPP).

CHAPTER II

LITERATURE REVIEW

Male sterility

Duvick (1966) stated that genetic male-sterility (GMS), cytoplasmic-genic male-sterility (CMS), and self-incompatibility (SI) are the three genetically controlled systems that plant breeders are using to take advantage of hybrid vigor. According to him, roguing is necessary with GMS, environmental manipulation is required for self-incompatibility, and hand labor is needed for bud pollination. These systems (GMS and SI) are expensive, but with CMS there are fewer problems. Both GMS and CMS are being used in sorghum.

In 1935, Stephens (1937) discovered a male-sterile sorghum. The problem with this sorghum was that at best only half of the progeny were male-sterile. The other half were male-fertile and had to be removed by hand before they released pollen. In 1950, male-sterility, due to a cytoplasmic influence was found (Stephens and Holland, 1954).

The important difference between GMS and CMS is their mode of inheritance. Genetic male-sterility is inherited normally and the influence of the male is seen in the progeny, while the inheritance of the CMS is maternal. The GMS is caused by a single recessive gene, and it is used primarily in composites to ensure and enhance recombination. In sorghum CMS is the result of the introduction of kafir chromosomes into milo cytoplasm (Stephens et al. 1952), and it is being used in the commercial production of hybrid seed (Deosthale et al. 1972, Andrews et al. 1977, Poehlman 1977, House 1981). Arnon (1972), stated that neither the genetic factor of kafir nor the cytoplasmic factor of milo alone induces male-sterility, a combination of both is essential. Both, GMS and CMS have been used in sorghum RMP (Doggett 1968, 1970, 1972a, 1972b, Doggett and Eberhart 1968, Eckebil et al. 1977, House 1981, Ross 1973, 1978).

Ross and Gardner (1983) gave a detailed explanation about six male-sterile genes that can be used for sorghum RMP. Three of these genes, $\underline{ms}_1$, $\underline{ms}_3$, and $\underline{ms}_7$, are preferred because they impart higher male sterility and high receptiveness. The $\underline{al}$ and $\underline{ms}_2$ genes have undesirable characteristics, while $\underline{ms}_c$ can be used only in R-type populations. According to Nath (1982), $\underline{ms}_3$ and $\underline{ms}_7$ are stable in their expression of sterility over different environments.

Population Breeding

The bulk hybrid method, mass selection, recurrent selection, and population improvement have been reported as methods of population breeding (Frey 1983). The bulk method consists of creation of a population by hybridization, growing the progeny in bulk for six or more generations, and then making selections. This method requires less detailed work in early generations which permits the growing of a larger sample of the segregating population than the pedigree system. The bulk method has been used in both self- and cross-pollinated crops (Frey 1983). Mass selection is the oldest method of plant improvement in which selection is on the basis of phenotype. Recurrent selection is used for quantitatively inherited traits by which the frequencies of favorable genes are increased in populations of plants. It is cyclic, and there are at least two phases with each cycle: selection of plants that possess favorable genes, and crossing among the selected plants. Recurrent selection depends upon massive crossing among the selected genotypes in each cycle. The dependence of massive crossing has limited its use in self-pollinated crops where male-sterility has not yet been discovered (Hallauer 1981). According to Frey (1983)

> ...population of plants are dynamic gene pools (1) to which new sources of germplasm are added when feasible, (2) in which the frequencies of favorable alleles are progressively increased via recurrent selection, (3) in which genetic recombination is enhanced by massive hybridization among selected genotypes, and (4) from which cultivars, inbreds, or parental lines can be extracted at any stage (p. 81).

Need of Population Breeding Method

The classical method of improving sorghum and other self-pollinated crops consists of crossing two lines and selecting segregates from the F_2 and more advanced generations, that possess the desired combinations of traits. Some weaknesses of this method have been identified. Gardner (1972) indicated that the stepwise procedure of dealing with only two lines at a time would be too slow and would not allow for enough recombinations to make efficient use of abundant exotic germplasm. Doggett (1972a) pointed out three weaknesses of the classical method: (1) it is inadequate for quantitative traits such as yield, which are generally under the control of a large number of genes, (2) linkage groups are difficult to break up, because relatively few crosses are made, (3) this method produces pure lines and puts too much stress on uniformity.

Some of the factors which favor the population breeding approach are: the necessity of avoiding genetic vulnerability (Doggett 1972a, Frey 1983, Gardner 1972, House 1981, Webster 1972), the importance of variability in plant breeding (Andrews et al. 1977, Foster et al. 1980), and the shortage of hybrid seed industry technology in developing countries (Gardner 1972, Nath 1982).

Development of Random-mating Populations

Doggett (1970), Nath (1982), Ross et al. (1971), and Ross and Gardner (1983) outlined the steps involved in the development of a population. Some of the main steps are: selection of component parents, incorporation of a GMS gene, and effective recombination among parents. The main methods which have been used to establish sorghum RMPs are: (1) backcrossing male-sterility into component lines and intermating the derived backcrosses, then blending the seed and allowing them to cross-pollinate, (2) blending seeds of desirable lines and F_1 hybrids, the F_1 hybrid will segregate in F_2 for male-sterility thereby providing the mechanisms for random-mating.

Nordquist et al. (1973) backcrossed $\underline{ms}_3$ into eight B- lines and 30 R-lines to form NP2B and NP3R, respectively. After backcrossing the derived lines were allowed to segregate and random-mate.

Concerning the use of the population breeding method in sorghum Ross (1973, p. 32-33) raised two questions: "...How many generations of random-mating are necessary before the populations can be used?....Is field random-mating really random?..." Many sorghum breeders (Andrews et al. 1977, Doggett 1970, Ross 1965) used three generations (after a population is initiated) of random-mating. According to Gardner (1972) more than three random-matings may be required to approach gametic equilibrium. The study reported by Ross and Hookstra (1983) indicated that S_1 families taken in three different years from the same base populations produced similar means, variance, and heritability, suggesting that nonrandom-mating is not a serious factor in the employment of population breeding in sorghum.

Selection Methods in Population Breeding

Several cyclic breeding methods which have been used successfully for improvement of maize (Zea mays L.) populations (Sprague and Eberhart 1977) have been applied to sorghum. The schemes which have been used in sorghum are: mass selection, S_1 family selection, half-sib family selection (HS), full-sib family selection (FS), and reciprocal recurrent selection (RRS) (Gardner 1972, Ross et al. 1971, Ross and Gardner, 1983). Mass selection in sorghum was proposed for improving yield (Doggett 1968). It has been used for yield (Lothrop et al. 1985a), and for grain protein (Ross et al. 1981, Ross and Hookstra, 1983, Peterson and Weibel 1982). Atkins (1980) used grided mass selection to develop IAP3BR(M), a large-seeded sorghum random-mating population. Jan-orn et al. (1976) compared HS, FS and S_1 family testing in NP3R sorghum RMP. This study showed that the genetic variance among S_1 families was consistently smaller than additive variance which was estimated from HS and FS families. The effectiveness of S_1 family selection for improving grain yield has been reported (Doggett 1972b). Eckebil et al. (1977) compared the S_1 testing method in three sorghum RMPs of different genetic backgrounds, and concluded that more genetic variance was exhibited by the broad based population than by the narrow based.

Use of Random-mating Populations

The main goal of any plant breeding program is the production of superior cultivars. A broad genetic base is of fundamental importance in obtaining variation for characteristics such as drought resistance. Several sorghum RMPs which have been developed in the United States have been evaluated at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), and have shown promise for drought resistance (Garrity et al. 1982). The usefulness of RMPs as germplasm has been proposed (Miller 1979). Relative to the use of RMPs to maintain germplasm, six different germplasm pools (Burton 1976) of pearl millet, Pennisetum americanum (L.) K. Schum were advanced in isolation three to five generations. A comparison of the last generation with the first showed that advanced germplasm pools narrowed phenotypic variability. Extraction of superior sorghum lines from populations and their utilization in breeding programs at ICRISAT and other countries have been reported (Nath 1982).

Otte et al. (1984) compared sorghum hybrids made with inbreds selected from an RMP with hybrids made with elite component inbred lines. This study showed that parental lines can be selected from a sorghum RMP that will produce suitable hybrids. Kwolek et al. (1986) studied the effectiveness of mass selection for large seed. They used a grain sorghum population, IAP3BR(M), which was developed as a source of large-seeded sorghum genotypes. Their study revealed that mass selection for large seed increased 100-kernel weight by 2.4% per generation, but selecting for larger seed decreased grain yield, seeds per panicle, and panicles per plant. Kofoid et al. (1978) compared the performance of four Nebraska RMPs with population crosses and with two F_1 hybrids over five environments. The population crosses showed the greatest stability, while the hybrids were the least stable. Ross and Nordquist (1980) compared seven RMPs with four hybrids over 16 environments. Their study indicated greater stability among the RMPs than among the hybrids, but mean yield levels of the populations were lower than those of the hybrids.

CHAPTER III

MATERIALS AND METHODS

Remnant seed of 12 generations of four grain sorghum populations was used in this study. The populations were designated early sterile, early fertile, late sterile, and late fertile. The sterile and fertile populations were designated cross-pollinated populations (CPP) and self-pollinated populations (SPP), respectively. These populations were developed in the Oklahoma State University sorghum breeding program beginning in 1968.

In 1967, 44 late and 11 early maturing lines were selected on the basis of their general adaptability. These lines had been developed and commonly used in the Oklahoma State University breeding program. Equal measures of seed from each line within each group were mixed to form the late and early maturing composites (populations). Some entries were F_1 hybrids which segregated in F_2 for cytoplasm-genic male-sterility thereby providing the mechanism for the random-mating. In 1968 the two composites were planted in isolation near Lake Carl Blackwell, Oklahoma. During anthesis the sterile panicles in the two composites were tagged. Tall plants were rogued before they shed pollen. Approximately 200 panicles were harvested from each population. Tagged panicles were harvested to provide seed for the CPP, while the SPP was formed by harvesting a sample of good fertile panicles from the same composites.

Brown-seeded panicles were not harvested, because of their undesirable characteristic. An equal amount of seed from each panicle within each population was blended. In 1969, the blended seed of the four populations was planted. During this and succeeding years, the same procedures were followed in terms of isolation, tagging, roguing, harvesting, and blending. As for 1969, the source seed for each year was the blended seed of the previous year. Eleven random-matings were accomplished near Lake Carl Blackwell from 1968 through 1978 followed by five more at Perkins from 1979 through 1983. Remnant seed of each generation was kept in cold storage. Due to some crop failures, only 12 of the 16 generations were used in this study.

Seed of the 12 generations of the four populations was planted at Perkins, Oklahoma on a Teller loam (fine-loamy, mixed, Thermic Udic Argiustolls) and at Goodwell, Oklahoma on a Richfield clay loam (fine Montmorillontic, Mesic Argiustolls), in 1984 and in 1985 crop seasons. Preplant nitrogen fertilizer was applied at the rate of 134 kg/ha at Perkins in both years. At Goodwell the rate was 177 and 168 kg/ha in 1984 and 1985, respectively. A split-plot design with three replications was used. The main plots were represented by maturity (early or late), and the sub-plots by generations and fertility (sterile or fertile). Each replication consisted of one plot of each generation of each population. Plots consisted of a single row 10.7 x 0.91 m at Perkins, and 10.7 x 0.76 m at Goodwell. Excess seed was planted in each plot to assure a uniform stand. Seedlings in the row were thinned to about 15 cm apart. Prior to harvest, the center 3 m of each row was marked for data collection.

Data were obtained and analyzed for the following traits:

1. Days to midbloom - number of days between planting and the date approximately 50% of plants in a row had started blooming.
2. Plant height - height in cm of 5 random plants from soil level to the tip of the panicle.
3. Test weight - measure of specific gravity of the grain in kg/mc
4. Kernel weight - weight in g of 100 typical whole kernels.
5. Percent protein of the grain - estimated on dry weight basis from a 20 gm sample by the Technicon InfraAlyzer TM^{400} (Watson et al. 1976) using the near infrared reflectance (NIR) calibrated by Kjeldahl values.
6. Grain yield - grain weight in kg/ha.

The data from the four environments (Perkins 1984 and 1985, and Goodwell 1984 and 1985) were analyzed separately. The change in each trait over the 12 generations was examined for each of the four populations (early SPP, early CPP, late SPP, and late CPP). Because generations were equally spaced, the sum of squares for generations were partitioned into linear, quadratic, cubic, and residual components utilizing orthogonal polynomials. Regression equations were fitted using means of 3 replications, for the components which were significant at 0.05 level of probability. An R^2 value was associated with each regression equation. The R^2 value discloses the proportion of the variation which can be explained by the regression line. The mean of each trait was plotted against the generation.

Analyses of variance were conducted separately on the SPP and CPP to compare the early and late populations, and on the early and late populations to compare the SPP and CPP.

CHAPTER IV

RESULTS AND DISCUSSION

Grain Yield

The trend analyses (Table I) indicated that a significant change occurred in grain yield during the 12 generations for the early SPP at Goodwell in 1984 and at Perkins in 1985, for the early CPP at Perkins in 1985, for the late SPP at both locations in 1984, and for the late CPP at Goodwell in 1985.

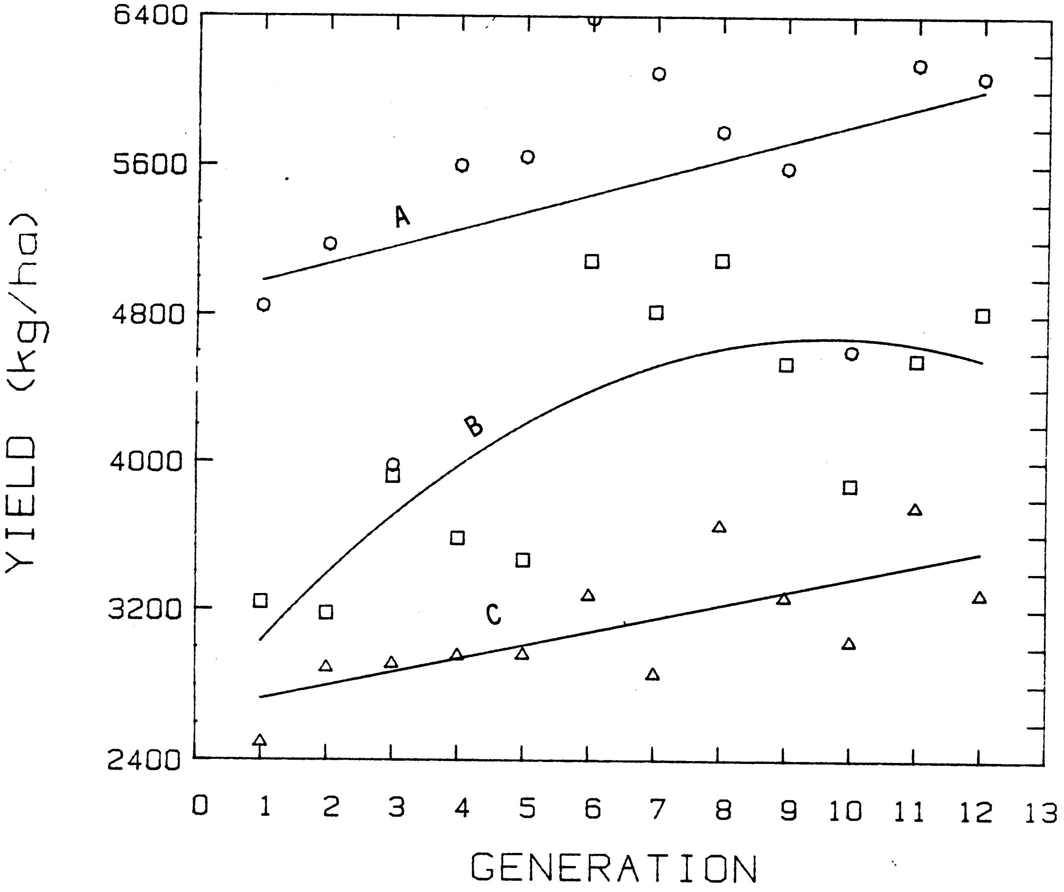
The yield increase per generation for the early CPP at Perkins in 1985 and the late SPP at Goodwell in 1984 were about 71 and 93 kg/ha, respectively (Figure 1). For the late CPP at Goodwell in 1985, the yield decreased after the 10th generation. The trends for the early SPP at Goodwell in 1984 and at Perkins in 1985 (Figure 2) were similar, showing a gain in yield during the early generations followed by a decline for more than 5 consecutive generations, and again showing gain during the last 2 or 3 generations. The late SPP at Perkins in 1984 showed an opposite trend compared to the early SPP at Perkins in 1985. In general, the early SPP was the only population which showed a similar trend in more than one environment.

TABLE I

ANALYSES OF GENERATION EFFECTS USING ORTHOGONAL POLYNOMIALS FOR GRAIN YIELD AT GOODWELL AND PERKINS, OKLAHOMA IN 1984 AND 1985

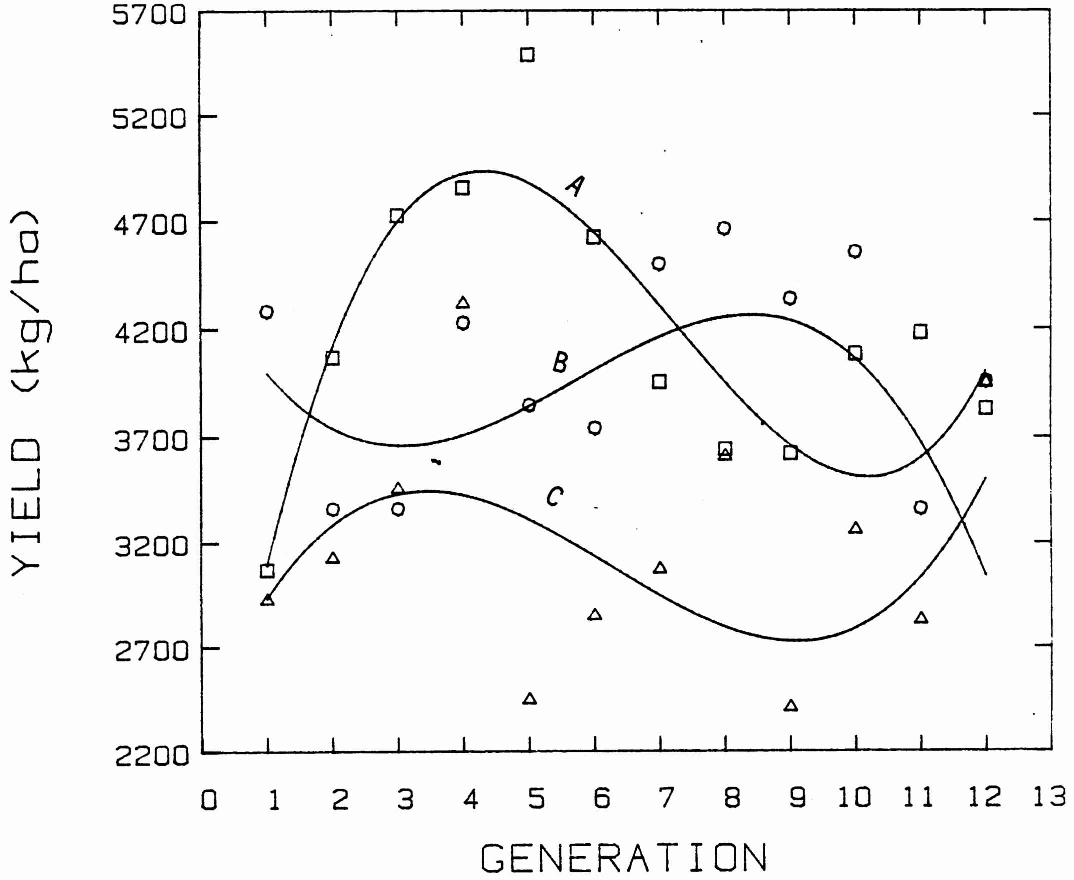
		Mean square ($x10^2$)			
		Goodwell		Perkins	
Source	df	1984	1985	1984	1985
		Early SPP			
Replication	2	7592	22827**	5164	20318**
Generation	11				
linear	1	2748	6164	1798	100
quadratic	1	33239*	8433	2252	3313
cubic	1	69977**	2032	272	23062*
residual	8	4514	3228	2817	10172
Error	22	7836	3780	3898	3477
		Early CPP			
Replication	2	7367	2093	7985**	14635*
Generation	11				
linear	1	3499	8574	3240	21893**
quadratic	1	456	4	1962	1257
cubic	1	94	7278	1470	51
residual	8	6872	9872	1953	2221
Error	22	2989	6132	1518	3059
		Late SPP			
Replication	2	8337	1270	2211	55816*
Generation	11				
linear	1	37289*	7283	3799	16591
quadratic	1	10921	7403	6665	16918
cubic	1	3448	2281	20457*	1619
residual	8	14721	2361	5710	8552
Error	22	8784	3916	4391	13069
		Late CPP			
Replication	2	6395	3347	8088	22192
Generation	11				
linear	1	32183	79273**	466	39351
quadratic	1	12064	19745*	63	31
cubic	1	2057	95	898	19143
residual	8	12772	8895	1680	10525
Error	22	8617	3104	4193	14149

*,** Significant at the 0.05 and 0.01 probability level, respectively. NS is nonsignificant.



A. Late SPP at Goodwell in 1984,
y=4887 + 93x, R^2=22%
B. Late CPP at Goodwell in 1985,
y=2626 + 424x -22x^2, R^2=58%
C. Early CPP at Perkins in 1985,
y=2656+71x, R^2=53%

Figure 1. Average Grain Yield Trends of selected SPP and CPP Over 12 Generations.



A. Early SPP at Perkins in 1985,
$y=2328+746x-150x^2+8x^3$, $R^2=25\%$,

B. Late SPP at Perkins in 1984
$y=4478+612x+137x^2-8x^3$, $R^2=40\%$,

C. Early SPP at Goodwell in 1984,
$y=1543+1837x-304x^2+14x^3$, $R^2=74\%$

Figure 2. Average Grain Yield Trends of selected SPP Over 12 Generations.

Yield differences between maturities were significant in two of the four environments for both the SPP and CPP (Table II). At Goodwell, the late maturing populations yielded more than the early populations for the SPP in 1984 and for the CPP in both years. But at Perkins in 1984 the early populations of the SPP showed a yield advantage (Table III).

The differences between the SPP and CPP were significant in one of the four environments for both early and late populations (Table IV). In 1984 at Goodwell, the early SPP yielded more than the early CPP, while in 1985 at Goodwell the late CPP showed a yield advantage over the late SPP (Table V). In general, little yield loss or gain occurred in the CPP, indicating that natural selection in continuous random-mating did not change the gene frequency for grain yield.

Test Weight

The trend analyses (Table VI) indicated that a significant change occurred in test weight during the 12 generations for the early SPP and CPP in two of four environments, for the late SPP in one environment, and for the late CPP in three environments.

The regression lines in Figure 3 showed that the trend of the early CPP at Perkins in 1984 and 1985 was different. The early CPP at Perkins in 1985, and the early SPP at Goodwell in 1985 showed a decrease of approximately two and three kg/mc in test weight per generation, respectively. The late CPP showed an increase in test weight of about 2 to 5 kg/mc per generation at three of the four environments (Figure 4).

TABLE II

ANALYSES OF VARIANCE OF GRAIN YIELD AS INFLUENCED BY MATURITY AT GOODWELL AND PERKINS, OKLAHOMA IN 1984 AND 1985

		Mean Squares ($x10^4$)			
		Goodwell		Perkins	
Source	df	1984	1985	1984	1985
		Self-pollinated population			
Replication	2	5	114	71	47
Maturity (M)	1	3119*	327	360**	1160
Error a	2	154	127	3	203
Generation (G)	11	145	28	42	100
M x G	11	137	43	52	93
Error b	44	83	38	42	46
		Cross-pollinated population			
Replication	2	135	41	67	52
Maturity (M)	1	6044**	280*	29	1348
Error a	2	2	14	94	100
Generation (G)	11	70	180	16	133
M x G	11	119	61	18	33
Error b	44	58	46	29	41

*,** Significant at the 0.05 and 0.01 probability level, respectively.

TABLE III

MEANS FOR GRAIN YIELD OF THE EARLY AND LATE POPULATIONS GROWN AT GOODWELL AND PERKINS, OKLAHOMA IN 1984 AND 1985

	Grain Yield			
	Goodwell		Perkins	
Maturity	1984	1985	1984	1985
	kg/ha			
	Self-pollinated population			
Early	4177	4067	4463	3195
Late	5493	3641	4016	3997
LSD (0.05)	1260	NS	178	NS
	Cross-pollinated population			
Early	3341	3788	4233	3120
Late	5173	4183	4106	3986
LSD (0.05)	148	374	NS	NS

TABLE IV

ANALYSES OF VARIANCE OF GRAIN YIELD AS INFLUENCED BY TYPE OF POLLINATION AT GOODWELL AND PERKINS, OKLAHOMA IN 1984 AND 1985

		Mean squares (x 10^3)			
		Goodwell		Perkins	
Source	df	1984	1985	1984	1985
		Early maturity			
Replication	2	1446	1933*	1252**	2495**
Pollination (P)	1	12587**	1402	955	101
Generation (G)	11	957	712	210	685
P x G	11	863	537	237	668
Error	46	520	498	262	356
		Late maturity			
Replication	2	30	380	606	419
Pollination (P)	1	1847	5287**	147	3
Generation(G)	11	1517	1323**	525	1299**
P x G	11	1374	550	308	928
Error	46	895	339	431	531

*,** Significant at 0.05 and 0.01 probability levels, respectively.

TABLE V

MEANS FOR GRAIN YIELD OF THE SELF-POLLINATED POPULATIONS (SPP) AND CROSS-POLLINATED POPULATIONS (CPP) GROWN AT GOODWELL AND PERKINS, OKLAHOMA IN 1984 AND 1985

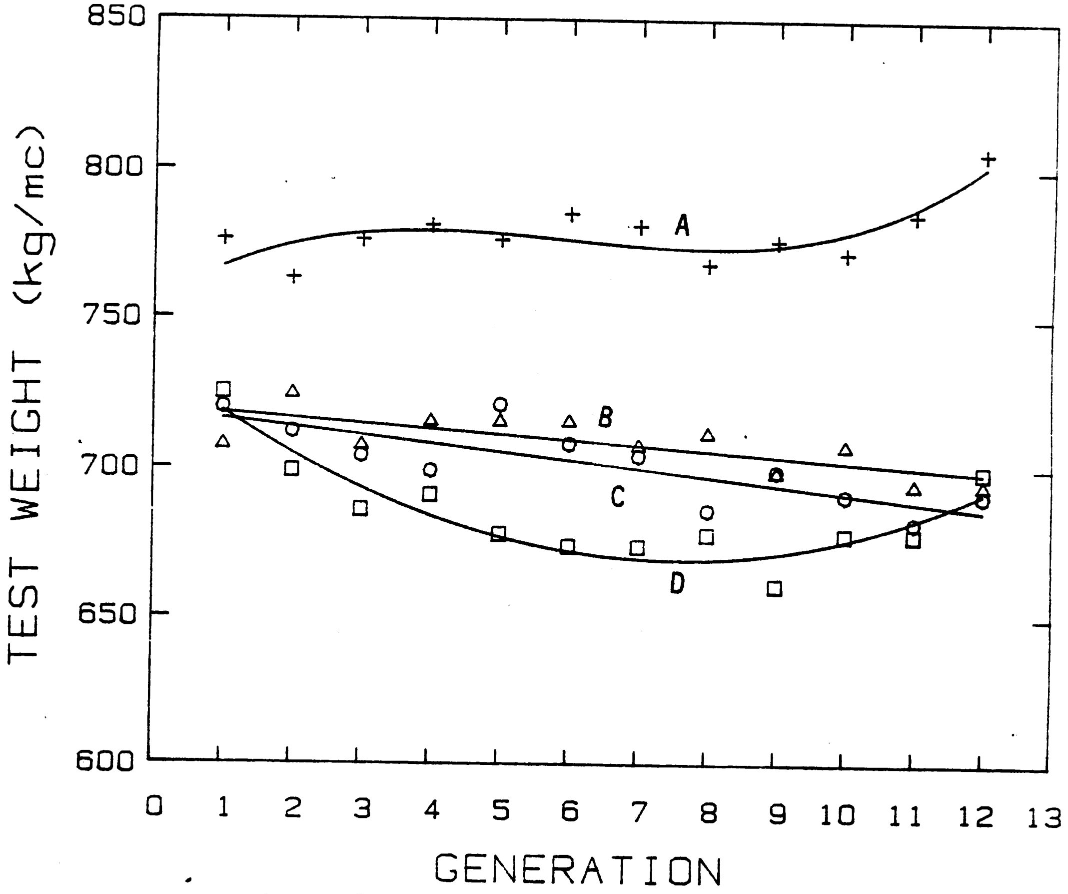
Type of Pollination	Grain Yield			
	Goodwell		Perkins	
	1984	1985	1984	1985
	- - - - - - kg/ha		- - - - - -	
	Early maturity			
SPP	4176	4067	4463	3195
CPP	3341	3788	4232	3120
LSD(0.05)	342	NS	NS	NS
	Late maturity			
SPP	5493	3641	4016	3998
CPP	5173	4183	4106	3986
LSD(0.05)	NS	276	NS	NS

TABLE VI

ANALYSES OF GENERATION EFFECTS USING ORTHOGONAL POLYNOMIALS FOR TEST WEIGHT AT GOODWELL AND PERKINS, OKLAHOMA IN 1984 AND 1985

		Mean square			
		Goodwell		Perkins	
Source	df	1984	1985	1984	1985
			Early SPP		
Replication	2	262	14	13	971
Generation	11				
linear	1	56	3339**	303	2471*
quadratic	1	931	3	483	5501**
cubic	1	317	2	281	12
residual	8	755	238	288	165
Error	22	794	114	169	379
			Early CPP		
Replication	2	5	336	87	41
Generation	11				
linear	1	1233	43	1024**	1413*
quadratic	1	205	224	400	405
cubic	1	168	22	1011*	32
residual	8	537	232	171	115
Error	22	351	376	143	222
			Late SPP		
Replication	2	998	128	96	1339
Generation	11				
linear	1	2533**	60	799	2724
quadratic	1	166	815	422	3873
cubic	1	10	30	57	618
residual	8	170	528	712	1148
Error	22	356	315	207	1520
			Late CPP		
Replication	2	290	60	179	165
Generation	11				
linear	1	178	1344*	4462**	10195**
quadratic	1	30	2	197	405
cubic	1	213	13	207	195
residual	8	280	345	401	1081
Error	22	385	246	752	447

*,** Significant at the 0.05 and 0.01 probability level, respectively. NS is nonsignificant.



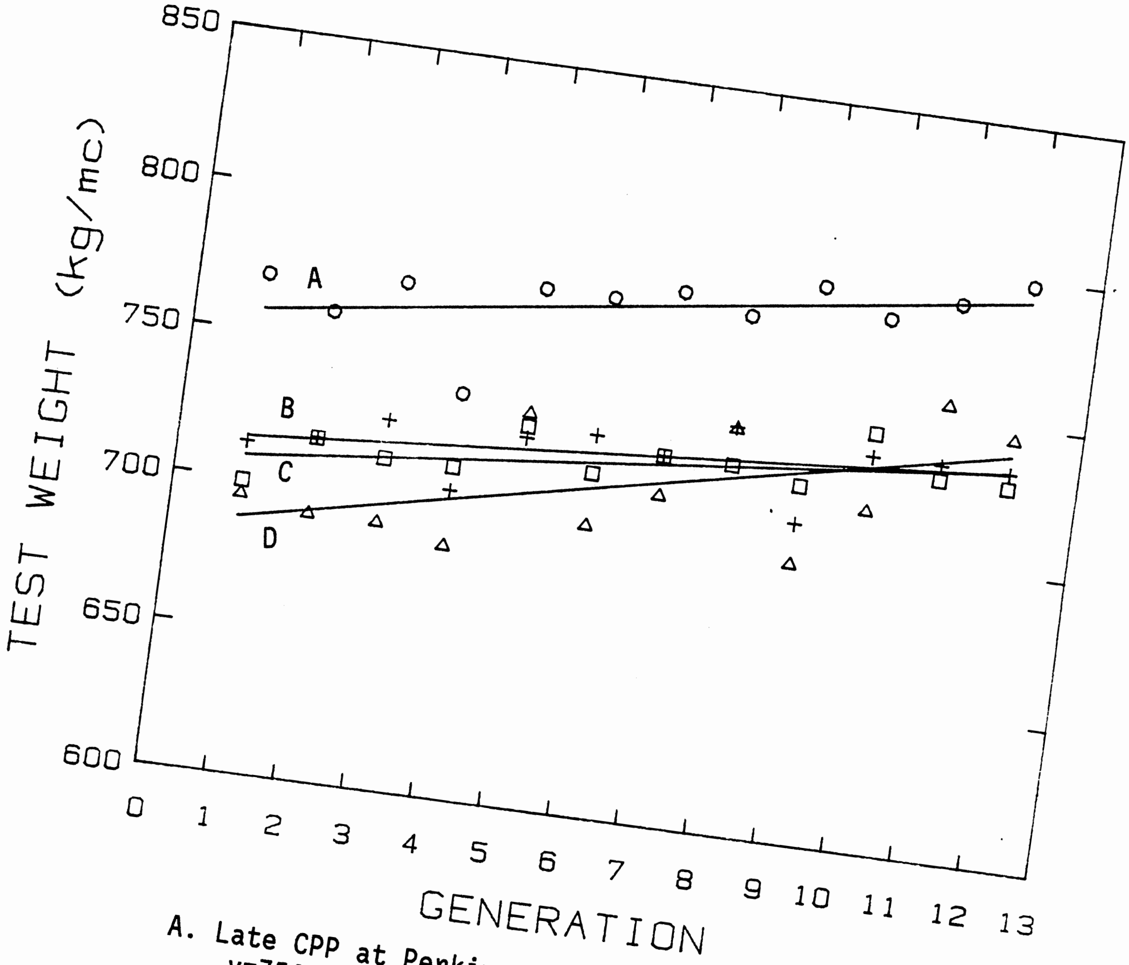
A. Early CPP at Perkins in 1984,
$y=754+16x-3.01x^2+0.17x^3$, $R^2=63\%$

B. Early CPP at Perkins in 1985,
$y=720-1.81x$, $R^2=52\%$

C. Early SPP at Goodwell in 1985,
$y=719-2.76x$, $R^2=63\%$

D. Early SPP at Perkins in 1985,
$y=735-17x+1.15x^2$, $R^2=85\%$

Figure 3. Average Test weight Trends of selected SPP and CPP Over 12 Generations.



A. Late CPP at Perkins in 1984,
$y=754+3.21x$, $R^2=54\%$
B. Late CPP at Goodwell in 1985,
$y=712+1.83x$, $R^2=34\%$
C. Late SPP at Goodwell in 1984,
$y=705+2.44x$, $R^2=63\%$
D. Late CPP at Perkins in 1985,
$y=682+4.83x$, $R^2=52\%$

Figure 4. Average Test weight Trends of selected SPP and CPP Over 12 Generations.

Overall this indicated that continuous natural selection had little effect on test weight of this population.

The analyses of variance (Table VII) showed that test weight was significantly influenced by maturity only at Goodwell in 1984 for the CPP. In this environment the test weight of the late population was higher than the early maturing ones (Table VIII). In general, the late maturing populations produced grain of slightly greater weight per volume.

The test weight of the SPP and CPP were significantly different for both early and late populations at three of the four environments (Table IX). The CPP produced grain of greater weight per volume than the SPP (Table X). This could be due to the fact that the seeds of the CPP were smaller, which increased the number of kernels per volume.

100-Kernel Weight

Table XI shows that a significant change occurred in 100-kernel weight for the early SPP and CPP at both locations in 1984, for the late SPP at Goodwell and for the late CPP at Perkins in 1984.

The weight of 100 kernels decreased for the early SPP at both location in 1984, for the early CPP at Perkins in 1984, and for the late SPP at Goodwell (Figure 5), suggesting that the kernel weight of these populations was reduced during the continuous random mating. Other studies (Kwolek et al.1986, Lothrop et al. 1985b) have indicated an increase for this trait in RMPs when selection was done for kernel weight. Since selection for this trait was not applied in either the

TABLE VII

ANALYSES OF VARIANCE OF TEST WEIGHT AS INFLUENCED BY MATURITY AT GOODWELL AND PERKINS, OKLAHOMA IN 1984 AND1985

		Mean squares			
		Goodwell		Perkins	
Source	df	1984	1985	1984	1985
		Self-pollinated population			
Replication	2	671	85	21	37
Maturity (M)	1	10638	389	517	2659
Error a	2	590	58	90	2273
Generation (G)	11	544	499*	543**	1219
M x G	11	494	444*	397*	1118
Error b	44	575	214	188	949
		Cross-pollinated population			
Replication	2	113	90	154	21
Maturity (M)	1	14723**	113	230	331
Error a	2	181	306	113	186
Generation (G)	11	411	302	770	665*
M x G	11	368	268	310	1355**
Error b	44	368	311	447	334

*,** Significant at 0.05 and 0.01 probability levels, respectively.

TABLE VIII

MEANS FOR TEST WEIGHT OF THE EARLY AND LATE POPULATIONS GROWN AT GOODWELL AND PERKINS, OKLAHOMA IN 1984 AND 1985

	Test Weight			
	Goodwell		Perkins	
Maturity	1984	1985	1984	1985
	- - - - - kg/mc - - - - -			
	Self-pollinated population			
Early	697	701	761	685
Late	721	697	767	697
LSD (0.05)	NS	NS	NS	NS
	Cross-pollinated population			
Early	706	721	779	709
Late	735	724	775	713
LSD (0.05)	14	NS	NS	NS

TABLE IX

ANALYSES OF VARIANCE OF TEST WEIGHT AS INFLUENCED BY TYPE OF POLLINATION AT GOODWELL AND PERKINS, OKLAHOMA IN 1984 AND 1985

		Mean squares			
		Goodwell		Perkins	
Source	df	1984	1985	1984	1985
		Early maturity			
Replication	2	99	113	71	617
Population (P)	1	1438	6659**	5523**	10327**
Generation (G)	11	233	319	359*	610*
P x G	11	971	354	293	489
Error	46	555	245	151	304
		Late maturity			
Replication	2	802	99	255	1084
Population (P)	1	3149**	12940**	1325	4659**
Generation (G)	11	384	449	946*	2445**
P x G	11	228	392	422	813
Error	46	376	272	459	959

*,** Significant at 0.05 and 0.01 probability levels, respectively.

TABLE X

MEANS FOR TEST WEIGHT OF THE SELF-POLLINATED POPULATIONS (SPP) AND CROSS-POLLINATED POPULATIONS (CPP) GROWN AT GOODWELL AND PERKINS, OKLAHOMA IN 1984 AND 1985

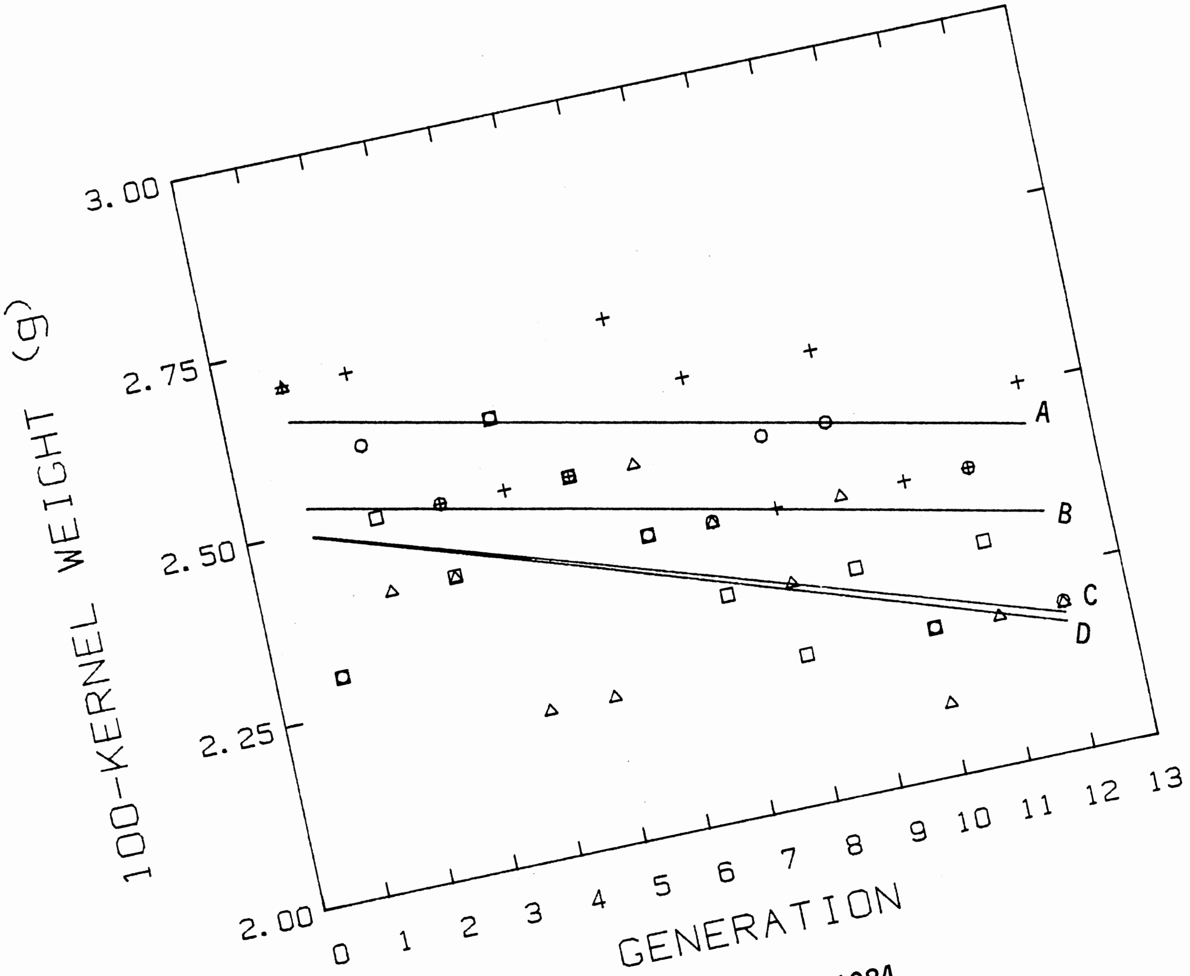
Type of Pollination	Test Weight Goodwell 1984	Goodwell 1985	Perkins 1984	Perkins 1985
	- - - - - kg/mc	- - - - -		
		Early maturity		
SPP	721	697	767	697
CPP	735	724	775	713
LSD (0.05)	9	7	NS	NS
		Late maturity		
SPP	697	701	761	685
CPP	706	721	779	709
LSD (0.05)	NS	7	6	8

TABLE XI

ANALYSES OF GENERATION EFFECTS USING ORTHOGONAL POLYNOMIALS FOR 100-KERNEL WEIGHT AT GOODWELL AND PERKINS, OKLAHOMA IN 1984 AND 1985

		Mean square		
		Goodwell	Perkins	
Source	df	1984	1984	1985
		Early SPP		
Replication	2	0.1144*	0.2178**	0.0119
Generation	11			
linear	1	0.4407*	0.1805*	0.0042
quadratic	1	0.0924	0.1137	0.0117
cubic	1	0.0610	0.0174	0.0414
residual	8	0.0228	0.0313	0.0415
Error	22	0.0320	0.0329	0.0159
		Early CPP		
Replication	2	0.0975**	0.0253	0.0203
Generation	11			
linear	1	0.1259*	0.2976**	0.0098
quadratic	1	0.2671**	0.0321	0.0008
cubic	1	0.0217	0.1504	0.0020
residual	8	0.0249	0.0553	0.0180
Error	22	0.0181	0.0135	0.0209
		Late SPP		
Replication	2	0.2019**	0.1525	0.0203
Generation	11			
linear	1	0.1364*	0.0642	0.0028
quadratic	1	0.0025	0.0540	0.0011
cubic	1	0.0014	0.0217	0.0183
residual	8	0.0345	0.0493	0.0208
Error	22	0.0232	0.0613	0.0466
		Late CPP		
Replication	2	0.1108*	0.0578	0.0233
Generation	11			
linear	1	0.0189	0.0246	0.0431
quadratic	1	0.0046	0.0043	0.0068
cubic	1	0.0001	0.3536**	0.0070
residual	8	0.0388	0.0342	0.0266
Error	22	0.0260	0.0284	0.0315

*,** Significant at the 0.05 and 0.01 probability level, respectively. NS is nonsignificant.



A. Late SPP at Goodwell in 1984,
y=2.67-0.019x, R^2=35%

B. Early SPP at Perkins in 1984
y=2.55-0.019x, R^2=26%

C. Early SPP at Goodwell in 1984
y=2.52-0.02x, R^2=48%

D. Early CPP at Perkins in 1984
y=2.52-0.029x, R^2=38%

Figure 5. Average 100 Kernel Weight Trends of selected SPP and CPP Over 12 Generations.

SPP or CPP during the 12 generations, observing this type of trend could be expected. Figure 6 shows that for the late CPP at Perkins in 1984, an increase of 100-kernel weight was detected during the early and later generation. This might indicate the inconsistency of this trait for this population during the random mating due to seasonal variation. For the early CPP at Goodwell in 1984 a decrease of this trait was detected between the 2nd and 8th generation.

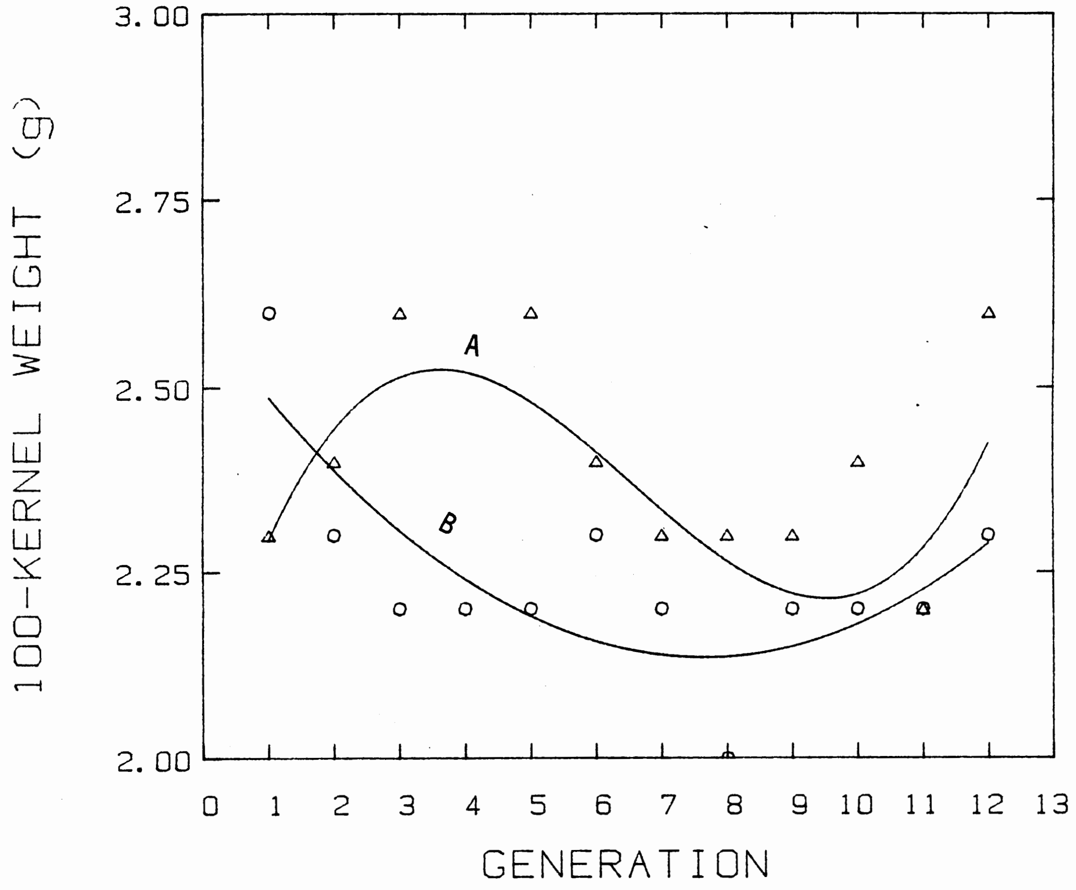
There was a significant difference between the early and late maturing populations at Goodwell for both the SPP and CPP (Table XII). The late population weighed about 0.2 and 0.4 g more than the early for the SPP and CPP, respectively (Table XIII). This could be also due to the longer period of grain filling of the late maturing populations.

The analyses of variance (Table XIV) showed that there was a significant difference between the SPP and CPP for the early and late maturing population at Goodwell in 1984, and for the late at Perkins in 1985. The kernels of the SPP were slightly heavier than those of the CPP except in the late maturing populations in 1984 at Goodwell (Table XV), indicating that kernels from male-sterile panicles (CPP) suffered a slight reduction in seed size.

Protein Percentage

The trend for protein percentage during the 12 generations showed significant change for the early SPP and CPP at both locations in 1984, and for the late CPP at Perkins in 1985 (Table XVI).

The early CPP showed a similar trend in two of the three environments (Figure 7). The grain protein of this population



A. Late CPP at Perkins in 1984,
$y=2.04+0.31x-0.06x^2+0.003x^3$, $R^2=56\%$
B. Early CPP at Goodwell in 1984,
$y=2.60-0.12x+0.01x^2$, $R^2=62\%$

Figure 6. Average 100 Kernel Weight Trends of selected CPP Over 12 Generations.

TABLE XII

ANALYSES OF VARIANCE OF 100-KERNEL WEIGHT AS INFLUENCED BY MATURITY AT GOODWELL AND PERKINS, OKLAHOMA IN 1984 AND 1985

		Mean squares (x 10^{-5})		
		Goodwell	Perkins	
Source	df	1984	1984	1985
		Self-pollinated population		
Replication	2	3051**	3347	1167
Maturity (M)	1	7200*	14	4014
Error a	2	1125	33680	2556
Generation (G)	11	706**	4984	2428
M x G	11	379	4984	2832
Error b	44	2759	4711	3126
		Cross-pollinated population		
Replication	2	20791**	6542	2681
Maturity (M)	1	288000**	2347	347
Error a	2	42	1764	1681
Generation (G)	11	3803	5064*	1529
M x G	11	4818*	9287**	2347
Error b	44	2205	2092	2620

*,** Significant at 0.05 and 0.01 probability levels, respectively.

TABLE XIII

MEANS FOR 100-KERNEL WEIGHT OF THE EARLY AND LATE POPULATIONS GROWN AT GOODWELL AND PERKINS, OKLAHOMA IN 1984 AND 1985

	100-Kernel weight		
	Goodwell	Perkins	
Maturity	1984	1984	1985
	- - - - - g - - - - - - -		
	Self-pollinated population		
Early	2.35	2.43	2.81
Late	2.55	2.42	2.76
LSD (0.05)	0.11	NS	NS
	Cross-pollinated population		
Early	2.23	2.34	2.73
Late	2.63	2.38	2.72
LSD (0.05)	0.02	NS	NS

TABLE XIV

ANALYSES OF VARIANCE OF 100-KERNEL WEIGHT AS INFLUENCED BY TYPE OF POLLINATION AT GOODWELL AND PERKINS, OKLAHOMA IN 1984 AND 1985

		Mean squares (x 10^{-4})		
		Goodwell	Perkins	
Source	df	1984	1984	1985
		Early maturity		
Replication	2	1935**	788	5
Pollination (P)	1	2689**	1089	200
Generation (G)	11	706*	773**	260
P x G	11	559*	577*	236
Error	46	248	293	190
		Late maturity		
Replication	2	2943**	1335	435
Pollination (P)	1	1089*	356	1606*
Generation (G)	11	390	378	272
P x G	11	292	704	145
Error	46	243	462	374

*,** Significant at 0.05 and 0.01 probability levels, respectively.

TABLE XV

MEANS FOR 100-KERNEL WEIGHT OF THE SELF-POLLINATED POPULATIONS (SPP) AND CROSS-POLLINATED POPULATIONS (CPP) GROWN AT GOODWELL AND PERKINS,OKLAHOMA IN 1984 AND 1985

Type of Pollination	100-Kernel Weight		
	Goodwell	Perkins	
	1984	1984	1985
	- - - - - g - - - - - - -		
	Early maturity		
SPP	2.35	2.42	2.76
CPP	2.23	2.34	2.73
LSD (0.05)	0.07	NS	NS
	Late maturity		
SPP	2.54	2.43	2.81
CPP	2.63	2.38	2.72
LSD (0.05)	0.07	NS	0.09

TABLE XVI

ANALYSES OF GENERATION EFFECTS USING ORTHOGONAL POLYNOMIALS FOR PROTEIN PERCENTAGE AT GOODWELL AND PERKINS, OKLAHOMA IN 1984 AND 1985

		Mean square		
		Goodwell	Perkins	
Source	df	1984	1984	1985
		Early SPP		
Replication	2	1.82**	3.08**	4.58**
Generation	11			
linear	1	0.04	0.33	0.07
quadratic	1	1.19*	1.72	1.36
cubic	1	1.06	2.53*	0.04
residual	8	0.07	0.84	0.34
Error	22	0.17	0.43	0.48
		Early CPP		
Replication	2	1.89**	0.03	0.65
Generation	11			
linear	1	3.26**	6.41**	0.01
quadratic	1	0.70	0.03	0.19
cubic	1	0.04	0.12	0.98
residual	8	0.18	0.44	0.35
Error	22	0.20	0.55	0.42
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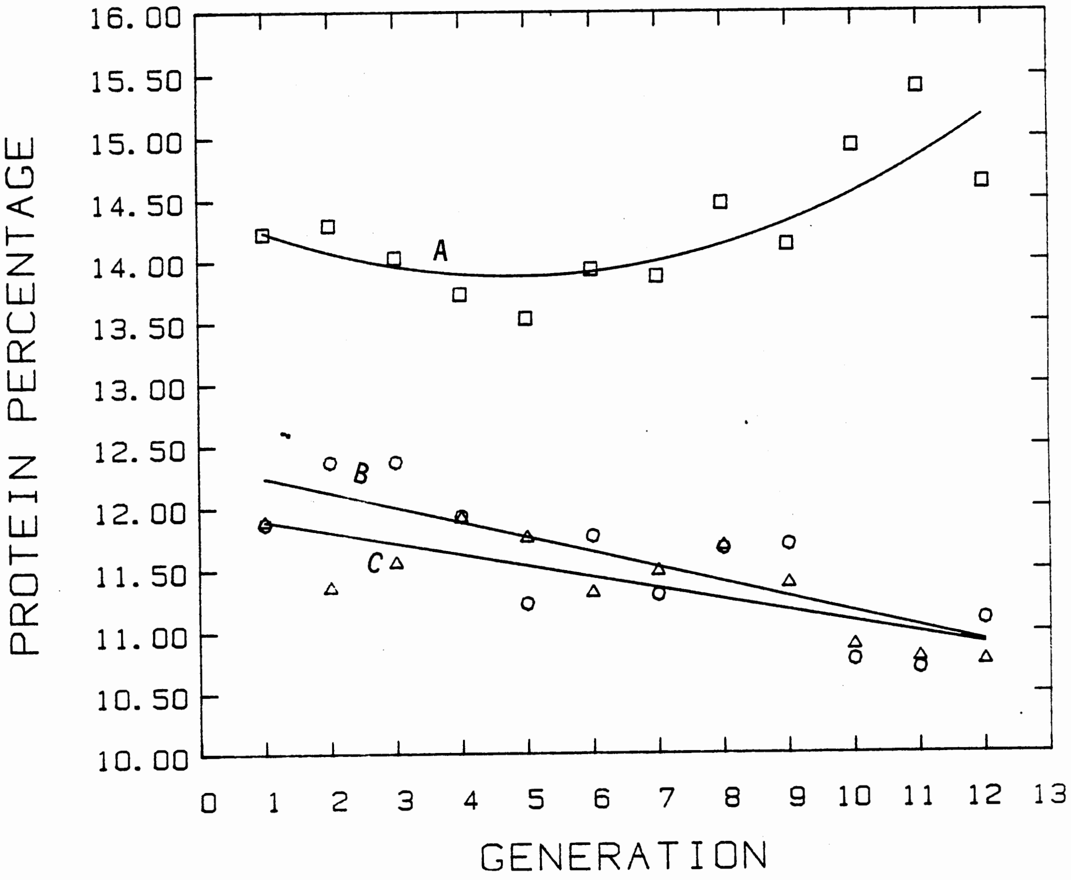
		Late SPP		
Replication	2	4.13**	3.76	2.44
Generation	11			
linear	1	2.67	0.01	0.49
quadratic	1	0.15	1.82	0.03
cubic	1	0.08	3.15	0.07
residual	8	0.16	0.81	1.13
Error	22	0.17	1.58	0.75
		Late CPP		
Replication	2	2.15**	0.16	0.22
Generation	11			
linear	1	0.63	0.49	3.37
quadratic	1	0.01	0.75	2.52*
cubic	1	0.01	4.12	0.77*
residual	8	0.13	1.51	0.32
Error	22	0.27	1.27	0.56

*,** Significant at the 0.05 and 0.01 probability level, respectively. NS is nonsignificant.



A. Late CPP at Perkins in 1985,
$y=14.45-0.24x+0.03x^2$, $R^2=64\%$
B. Early CPP at Perkins in 1984,
$y=12.36-0.12x$, $R^2=64\%$
C. Early CPP at Goodwell in 1984,
$y=11.98-0.09x$, $R^2=60\%$

Figure 7. Average Protein Percentage Trends of selected CPP Over 12 Generations.

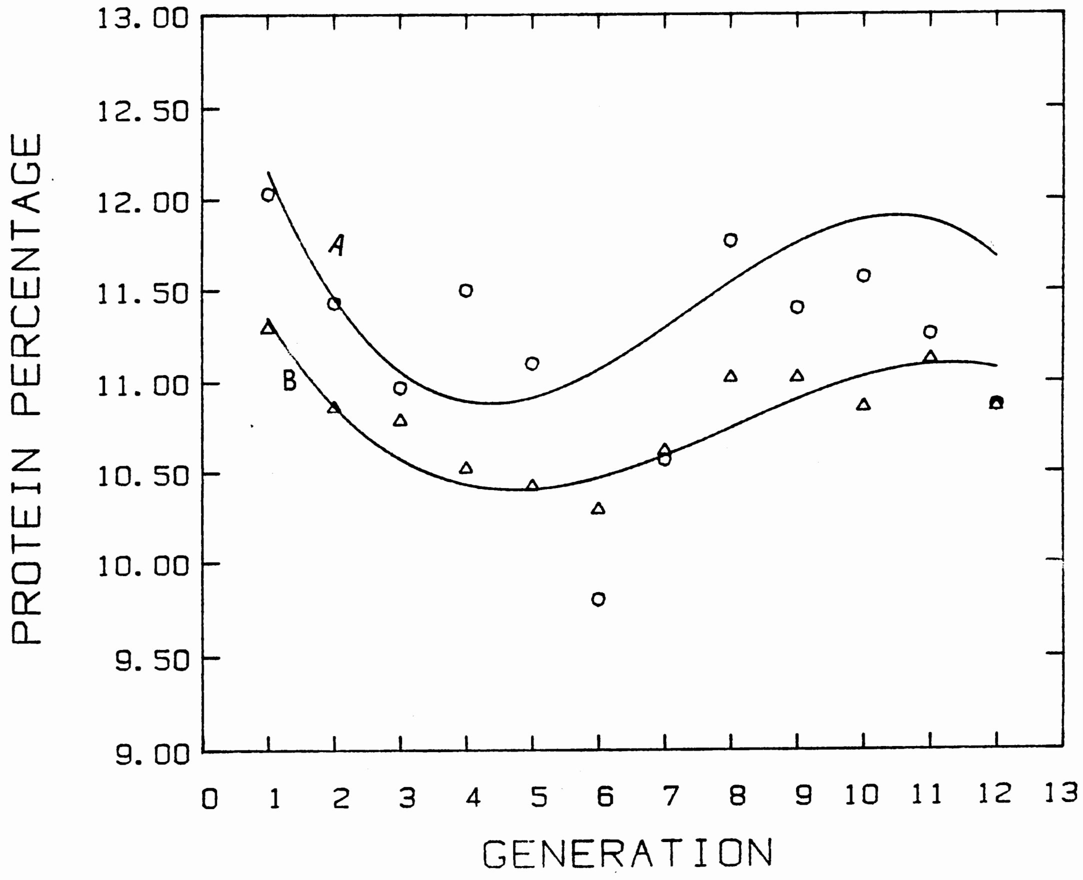
decreased, indicating that random mating had a negative effect on this trait (where there was no selection for protein). The protein percentage of the late CPP at Perkins in 1985 increased after the 6th generation (Figure 7). The early SPP showed a similar trend in 1984 at both locations (Figure 8), indicating that the expression of this trait was consistent in its response to the environment.

There was a significant difference between the early and late maturing populations in all environments for the CPP but in none of the environments for the SPP (Table XVII). The protein percentage of the early CPP was significantly higher than that of the late CPP in 1984 at both locations, but in 1985 at Perkins the protein percentage of the late CPP was higher than the early CPP (Table XVIII).

The difference between the CPP and SPP was significant in two of the three environments for both early and late populations (Table XIX). The grain protein of the CPP was higher than that of the SPP for the early and late maturing populations at Goodwell, and for the early at Perkins in 1984, but in 1985 at Perkins the late SPP produced higher protein percentage than the CPP (Table XX). In most cases the grain protein percentage of the CPP was higher than that of the SPP. This difference might be due to the fact that the seeds of the CPP were smaller and had a higher proportion of pericarp and germ to endosperm.

Plant Height

The analyses (Table XXI) revealed that the trend in plant height showed a significant change during the 12 generations for the late CPP in all environments, and for the late SPP in two environments.



A. Early SPP at Perkins in 1984,
$y=13.19-1.23x+0.20x^2-0.01x^3$, $R^2=38\%$
B. Early SPP at Goodwell in 1984
$y=12.03-0.80x+0.12x^2-0.01x^3$, $R^2=79\%$

Figure 8. Average Protein Percentage Trends of selected SPP Over 12 Generations.

TABLE XVII

ANALYSES OF VARIANCE OF PROTEIN PERCENTAGE AS INFLUENCED BY MATURITY AT GOODWELL AND PERKINS, OKLAHOMA IN 1984 AND 1985

		Mean squares		
		Goodwell	Perkins	
Source	df	1984	1984	1985
		Self-pollinated population		
Replication	2	5.69**	5.06**	0.18
Maturity (M)	1	2.76	0.41	54.60
Error a	2	0.25	1.79	6.84
Generation (G)	11	0.33	1.34	0.46
M x G	11	0.31	0.74	0.79
Error b	44	0.17	1.01	0.61
		Cross-pollinated population		
Replication	2	3.97**	0.15	0.10
Maturity (M)	1	3.78*	2.28*	35.14*
Error a	2	0.07	0.04	0.78
Generation (G)	11	0.21	1.47	0.42
M x G	11	0.43	1.04	0.78
Error b	44	0.24	0.91	0.49

*,** Significant at 0.05 and 0.01 probability levels, respectively.

TABLE XVIII

MEANS FOR PROTEIN PERCENTAGE OF THE EARLY AND LATE POPULATIONS GROWN AT GOODWELL AND PERKINS, OKLAHOMA IN 1984 AND 1985

	Protein Percentage		
	Goodwell	Perkins	
Maturity	1984	1984	1985
	- - - - - - - %	- - - - - - -	
	Self-pollinated population		
Early	10.82	11.19	13.14
Late	10.43	11.04	14.89
LSD (0.05)	NS	NS	NS
	Cross-pollinated population		
Early	11.41	11.56	12.87
Late	10.95	11.21	14.27
LSD (0.05)	0.27	0.21	0.89

TABLE XIX

ANALYSES OF VARIANCE OF PROTEIN PERCENTAGE AS INFLUENCED BY TYPE OF POLLINATION AT GOODWELL AND PERKINS, OKLAHOMA IN 1984 AND 1985

		Mean squares		
		Goodwell	Perkins	
Source	df	1984	1984	1985
		Early maturity		
Replication	2	3.71**	1.76*	4.00*
Pollination (P)	1	6.36**	2.49*	1.36
Generation (G)	11	0.32	1.02	0.37
P x G	11	0.44	0.93	0.38
Error	46	0.18	0.53	0.48
		Late maturity		
Replication	2	6.10**	2.41	2.05*
Pollination (P	1	5.01**	0.50	6.91**
Generation (G)	11	0.22	1.98	0.66
P x G	11	0.31	0.64	1.05
Error	46	0.22	1.43	0.65

*,** Significant at 0.05 and 0.01 probability levels, respectively.

TABLE XX

MEANS FOR PROTEIN PERCENTAGE OF THE SELF-POLLINATED POPULATIONS (SPP) AND CROSS-POLLINATED POPULATIONS (CPP) GROWN AT GOODWELL AND PERKINS, OKLAHOMA IN 1984 AND 1985

Type of Pollination	Protein Percentage Goodwell 1984	 Perkins 1984	 1985
	- - - - -	% - - - - -	
		Early maturity	
SPP	10.82	11.19	13.14
CPP	11.41	11.56	12.87
LSD (0.05)	0.20	0.34	NS
		Late maturity	
SPP	10.42	11.04	14.89
CPP	10.95	11.21	14.27
LSD (0.05)	0.22	NS	0.38

TABLE XXI

ANALYSES OF GENERATION EFFECTS USING ORTHOGONAL POLYNOMIALS FOR PLANT HEIGHT AT GOODWELL AND PERKINS, OKLAHOMA IN 1984 AND 1985

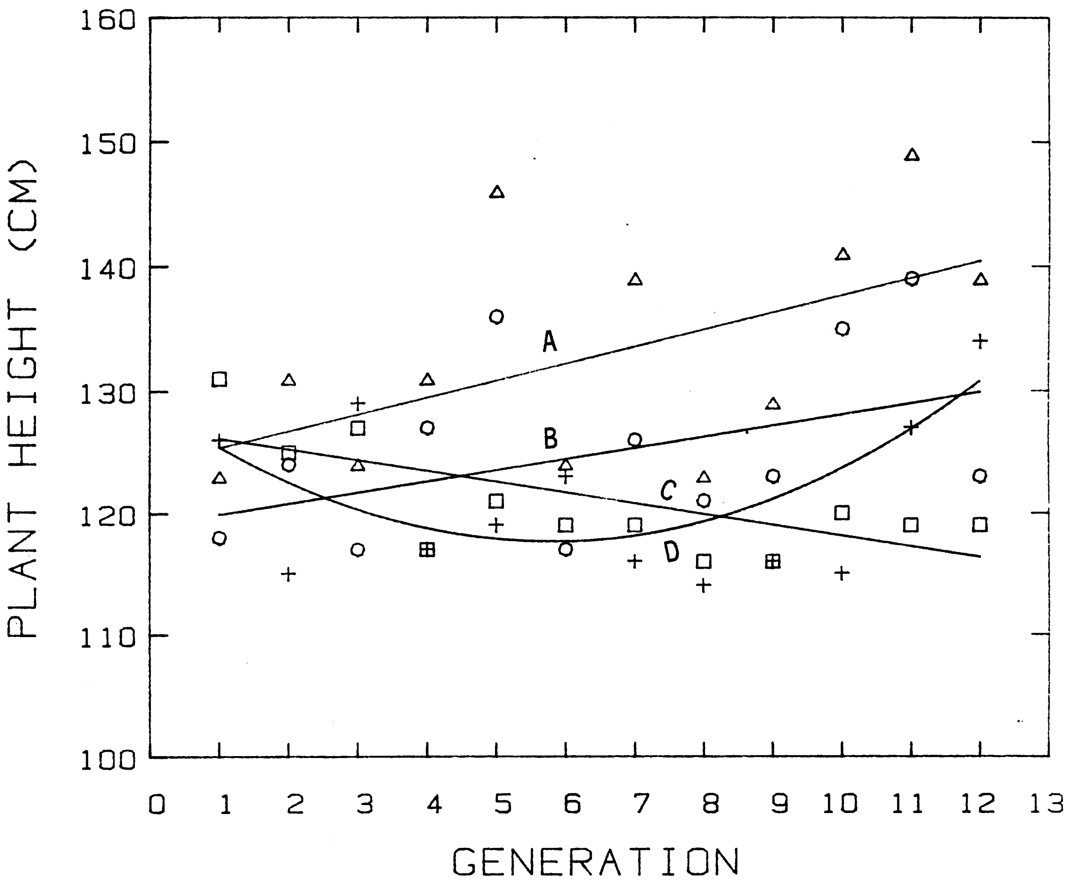
		Mean square			
		Goodwell		Perkins	
Source	df	1984	1985	1984	1985
			Early SPP		
Replication	2	6228.0**	2001.9**	290.9**	69.8
Generation	11				
linear	1	45.4	2.5	0.3	5.5
quadratic	1	8.4	0.1	32.6	15.8
cubic	1	27.3	13.2	17.6	42.6
residual	8	134.7	72.7	49.7	35.3
Error	22	132.1	57.5	34.3	58.1
			Early CPP		
Replication	2	6612.0**	444.1**	324.1**	25.4
Generation	11				
linear	1	550.6	10.8	137.6	87.7
quadratic	1	300.4	1.8	179.0	162.0
cubic	1	0.1	96.4	0.1	0.1
residual	8	49.5	76.8	18.3	49.9
Error	22	174.7	82.7	43.7	48.2
			Late SPP		
Replication	2	1112.4**	502.6**	226.8**	533.5**
Generation	11				
linear	1	433.0*	3.2	44.4	343.7*
quadratic	1	66.7	0.2	1.1	219.1
cubic	1	443.8*	62.6	4.4	6.0
residual	8	195.7	118.3	61.3	15.5
Error	22	88.4	189.1	27.2	55.0
			Late CPP		
Replication	2	5888.1**	3478.7**	407.0*	498.1**
Generation	11				
linear	1	953.3**	800.5*	75.9	339.3*
quadratic	1	5.3	12.2	432.3*	1.5
cubic	1	709.0**	150.8	134.1	3.0
residual	8	73.7	233.1	102.7	183.3
Error	22	80.9	121.5	87.7	75.9

*,** Significant at the 0.05 and 0.01 probability level, respectively. NS is nonsignificant.

The height increased by about 1 cm per generation for the late CPP at Goodwell and Perkins in 1985 (Figure 9), while the height of the late SPP at Perkins in 1985 decreased by about 1 cm per generation. The late SPP and CPP at Goodwell in 1984 showed a decrease in height from about the 5th generation till the 7th, and then increased after the 8th generation (Figure 10). The similarity of this type of trend between the late SPP and CPP might indicate that the application of the population breeding method using male-sterility did not affect plant height.

Table XXII shows that there was a significant difference between the late and early maturing populations in one and two of the four environments for the SPP and the CPP, respectively. The plants of the late populations were taller than those of the early (Table XXIII). The greater height of late-maturing sorghums has been reported (Poehlman, 1977).

There was a significant difference between the SPP and CPP for height in two and four environments in the early and late populations, respectively (Table XXIV). The plants of the early SPP were taller than those of the early CPP, but in the late maturing populations the plants of the CPP were taller (Table XXV), indicating the potential for an increase in plant height in a population breeding program which involved late maturing grain sorghum lines. One of the four dwarfing genes in sorghum has been reported to be unstable and reverts to tallness (Quinby, 1974). The difference in height between the CPP and SPP might be due to the expression of the mutant gene.



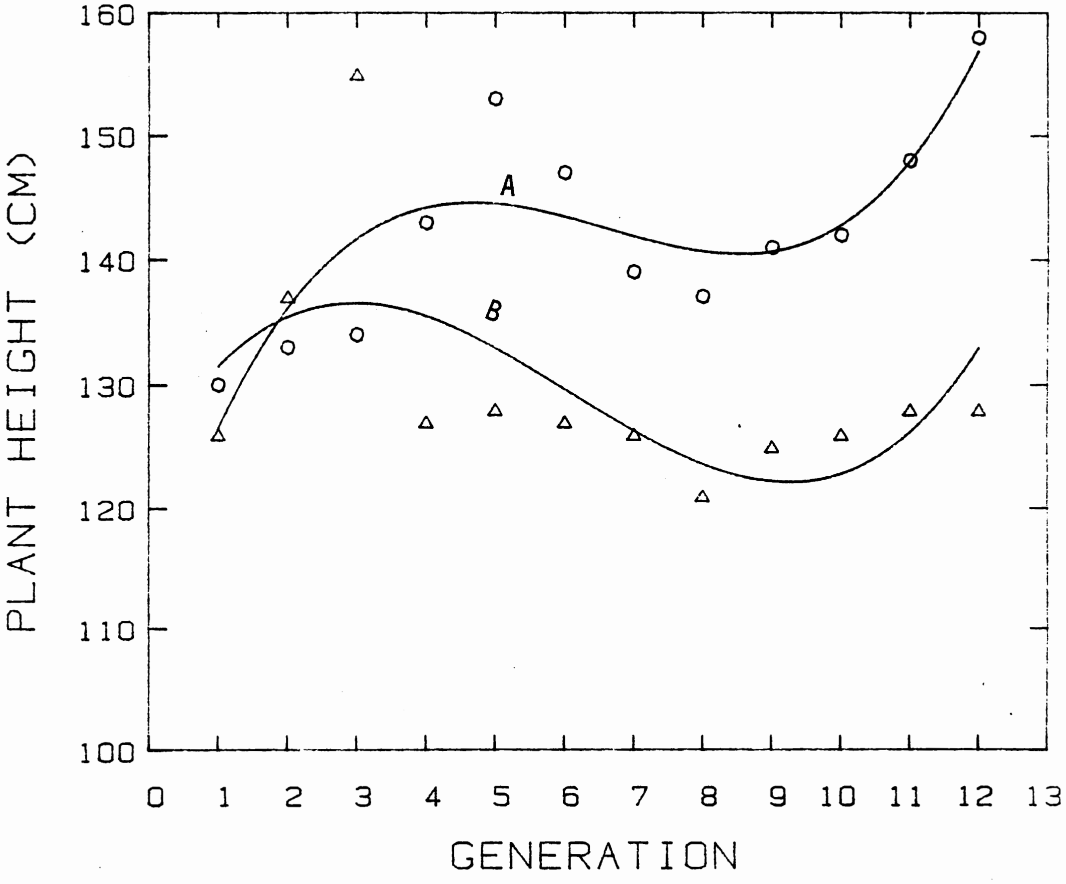
A. Late CPP at Goodwell in 1985,
$y=124+1.37x$, $R^2=29\%$

B. Late CPP at Perkins in 1985,
$y=119+0.91x$, $R^2=19\%$

C. Late SPP at Perkins in 1985,
$y=127-o.89x$, $R^2=49\%$

D. Late CPP at Perkins in 1984,
$y=129-3.93x+0.34x^2$, $R^2=36\%$

Figure 9. Average Plant Height Trends of selected SPP and CPP Over 12 Generations.



A. Late CPP at Goodwell in 1984,
$y=112+17x-3x^2+0.15x^3$, $R^2=75\%$
B. Late SPP at Goodwell in 1984,
$y=124+9x-2x^2+0.12x^3$, $R^2=38\%$

Figure 10. Average Plant Height Trends of selected SPP and CPP Over 12 Generations.

TABLE XXII

ANALYSIS OF VARIANCE OF PLANT HEIGHT AS INFLUNCED BY MATURITY AT GOODWELL AND PERKINS, OKLAHOMA IN 1984 AND 1985

		Mean squares			
		Goodwell		Perkins	
Source	df	1984	1985	1984	1985
		Self-pollinated population			
Replication	2	3318**	255	470**	117
Maturity (M)	1	917	35	925*	5017
Error a	2	4022	2248	48	486
Generation (G)	11	113	90	39	35
M x G	11	220*	56	51	60
Error b	44	110	123	31	57
		Cross-pollinated population			
Replication	2	2535**	903**	720**	304*
Maturity (M)	1	6982	5796	8128**	8734*
Error a	2	9965	3020	11	220
Generation (G)	11	223	120	131*	134
M x G	11	96	203*	44	89
Error b	44	128	102	66	62

*,** Significant at 0.05 and 0.01 probability levels, respectively.

TABLE XXIII

MEANS FOR PLANT HEIGHT OF THE EARLY AND LATE POPULATIONS GROWN AT GOODWELL AND PERKINS, OKLAHOMA IN 1984 AND 1985

	Plant Height			
	Goodwell		Perkins	
Maturity	1984	1985	1984	1985
	- - - - - - cm - - - - - -			
	Self-pollinated population			
Early	122	122	105	104
Late	129	120	113	121
LSD (0.05)	NS	NS	7	NS
	Cross-pollinated population			
Early	122	115	101	103
Late	142	133	122	126
LSD (0.05)	NS	NS	3	15

TABLE XXIV

ANALYSES OF VARIANCE OF PLANT HEIGHT AS INFLUNCED BY TYPE OF POLLINATION AT GOODWELL AND PERKINS, OKLAHOMA IN 1984 AND 1985

		Mean squares			
		Goodwell		Perkins	
Source	df	1984	1985	1984	1985
		Early maturity			
Replication	2	3338**	2024**	599**	7
Population (P)	1	62	754**	421**	4
Generation (G)	11	90*	63	36	63
P x G	11	96*	57	47	28
Error	46	35	85	38	55
		Late maturity			
Replication	2	5558**	3305**	548**	742**
Population (P)	1	2901**	2977**	1540**	425**
Generation (G)	11	152	112	97	86
P x G	11	282	238	85	142
Error	46	144	178	59	75

*,** Significant at 0.05 and 0.01 probability levels, respectively.

TABLE XXV

MEANS FOR PLANT HEIGHT OF THE SELF-POLLINATED POPULATIONS (SPP) AND CROSS-POLLINATED POPULATIONS (CPP) GROWN AT GOODWELL AND PERKINS, OKLAHOMA IN 1984 AND 1985

Type of Pollination	Plant Height			
	Goodwell		Perkins	
	1984	1985	1984	1985
	- - - - - cm - - - - - -			
	Early maturity			
SPP	115	122	105	104
CPP	113	115	101	104
LSD (0.05)	NS	4	3	NS
	Late maturity			
SPP	129	120	113	121
CPP	142	133	122	126
LSD (0.05)	6	6	4	4

Days to Midbloom

The trend in this trait during the 12 generations showed a significant change for the early SPP in all environments, for the early CPP in three environments, and for the late CPP in one environment (Table XXVI). Figure 11 showed that maturity increased by about 0.17 days per generation for the late CPP at Perkins in 1985. The trend of the early SPP at Perkins in both years was similar. Days to midbloom of these populations were increasing for the first few generations and declining during the later generations. The third-degree function reveals that the trend of this population at Goodwell in both years was similar (Figure 12). The similarity of the trends of the early SPP at each location indicates that the change in maturity of this population is somewhat consistent over generations. The early CPP at Goodwell and at Perkins in 1984 (Figure 12) showed somewhat opposite trends, suggesting the inconsistency of the population. In general, the early populations showed significant trends in more environments than the late. Plant selection can easily alter the maturity of RMPs of sorghum; hence, natural selection is more difficult to apply.

Table XXVII shows that there was a significant difference between the early and late maturing populations of the SPP and CPP in all environments. There were at least 8 days difference between the early and late (Table XXVIII). This difference was expected.

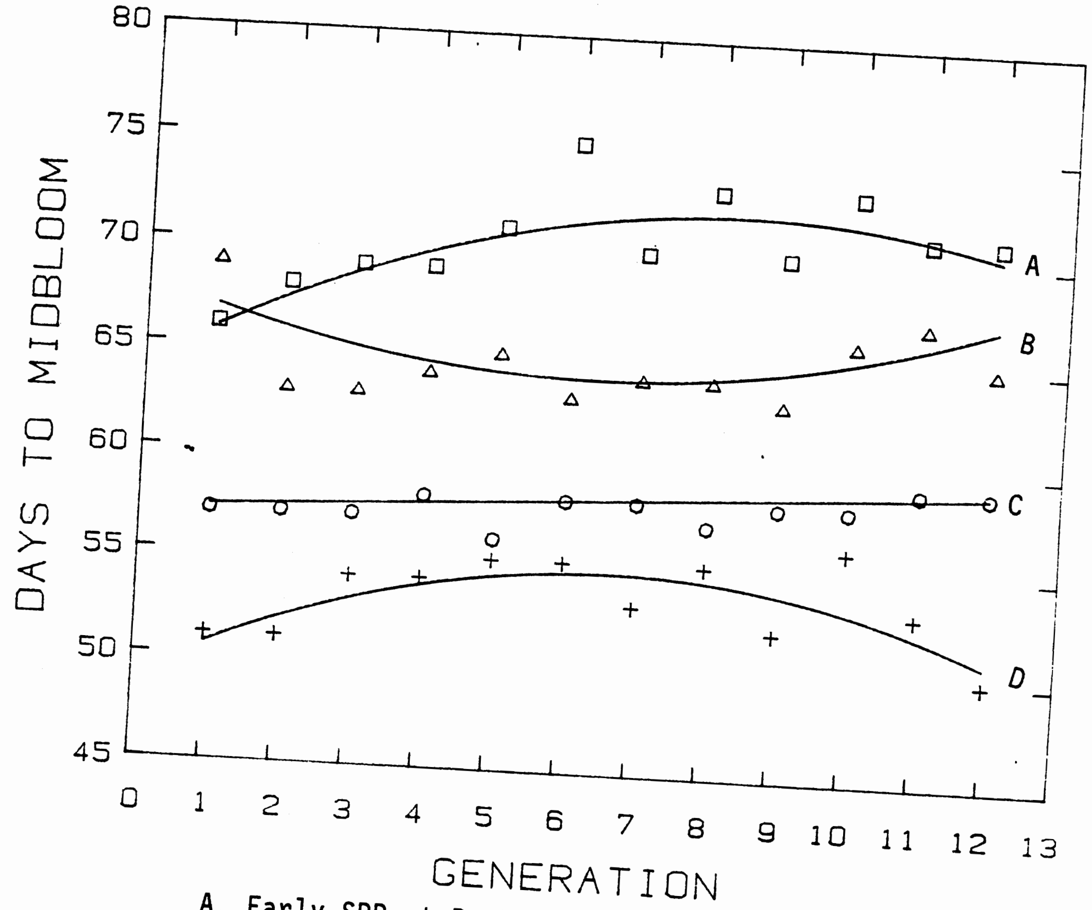
The SPP and CPP differed significantly in days to midbloom in all environments (Table XXIX). In both maturity populations, the CPP bloomed at least 4 days earlier than the SPP (Table XXX). This type of difference has been observed in breeding nurseries between A- and B-lines of a paired progeny.

TABLE XXVI

ANALYSES OF GENERATION EFFECTS USING ORTHOGONAL POLYNOMIALS FOR DAYS TO MIDBLOOM AT GOODWELL AND PERKINS, OKLAHOMA IN 1984 AND 1985

		Mean square			
		Goodwell		Perkins	
Source	df	1984	1985	1984	1985
			Early SPP		
Replication	2	2.6	0.8	6.9	4.4
Generation	11				
linear	1	0.2	0.4	61.6	2.8
quadratic	1	21.6*	75.2**	52.0*	87.4**
cubic	1	43.8**	31.4**	1.4*	1.1
residual	8	3.1	2.3	8.3	4.5
Error	22	4.5	3.3	9.4	1.9
			Early CPP		
Replication	2	20.4	6.6	27.1*	0.4
Generation	11				
linear	1	99.4**	6.8	0.9	1.5
quadratic	1	156.5**	19.6	56.4*	44.2**
cubic	1	48.9**	7.6	12.8	17.0**
residual	8	7.3	2.5	6.6	7.3
Error	22	6.1	4.8	6.4	1.7
			Late SPP		
Replication	2	16.4	3.1	45.2**	30.3**
Generation	11				
linear	1	12.4	3.3	0.2	0.6
quadratic	1	1.9	0.1	0.3	0.7
cubic	1	0.1	0.3	5.5	4.0
residual	8	4.5	8.7	14.7	4.7
Error	22	5.4	9.6	6.7	1.8
			Late CPP		
Replication	2	6.1	11.4	35.2**	6.9*
Generation	11				
linear	1	0.9	9.4	0.2	10.3*
quadratic	1	0.4	0.4	0.1	1.3
cubic	1	35.5	13.2	0.2	0.4
residual	8	8.5	7.3	9.0	1.0
Error	22	8.8	10.8	6.7	1.8

*,** Significant at the 0.05 and 0.01 probability level, respectively. NS is nonsignificant.



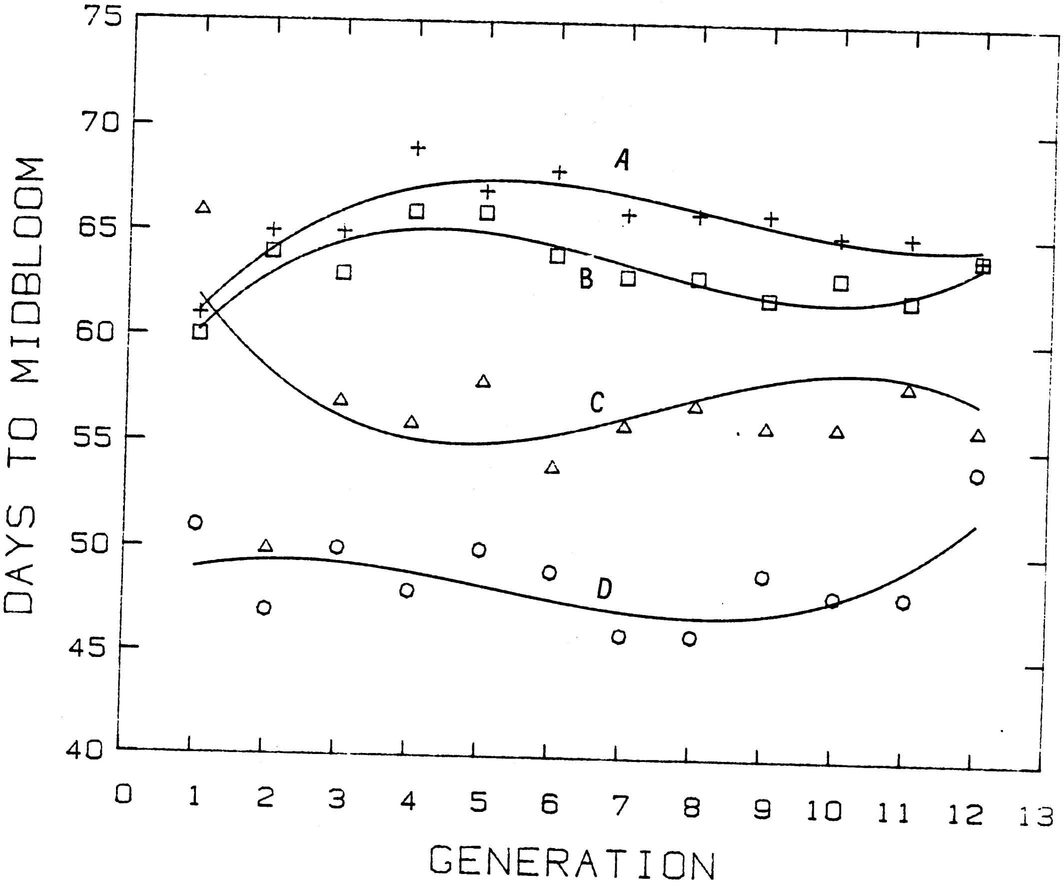
A. Early SPP at Perkins in 1984,
$y=64+1.91x-0.12x^2$, $R^2=64\%$

B. Early CPP at Perkins in 1984,
$y=68-1.29x+0.10x^2$, $R^2=35\%$

C. Late CPP at Perkins in 1985,
$y=57+0.17x$, $R^2=50\%$

D. Early SPP at Perkins in 1985,
$y=49+1.3x-0.12x^2$, $R^2=54\%$

Figure 11. Average Days to Midbloom Trends of selected SPP and CPP Over 12 Generations.



A. Early SPP at Goodwell in 1985, $y=57+5x-0.7x^2+0.03x^3$, $R^2=83\%$

B. Early SPP at Goodwell in 1984, $y=56+5x-0.8x^2+0.04x^3$, $R^2=77\%$

C. Early CPP at Goodwell in 1984, $y=67-6x+0.94x^2-0.04^3$, $R^2 28\%$

D. Early CPP at Perkins in 1984, $y=48+1.4x-0.39x^2+0.03x^3$, $R^2=48\%$

Figure 12. Average Days to Midbloom Trends of selected SPP and CPP Over 12 Generations.

TABLE XXVII

ANALYSES OF VARIANCE OF DAYS TO MIDBLOOM AS INFLUNCED BY MATURITY AT GOODWELL AND PERKINS, OKLAHOMA IN 1984 AND 1985

		Mean squares			
		Goodwell		Perkins	
Source	df	1984	1985	1984	1985
		Self-pollinated population			
Replication	2	4.1	3.4	13.2	10.9
Maturity (M)	1	2334.7**	1830.1**	3186.7**	1073.4*
Error a	2	14.8	0.5	38.9	23.7
Generation (G)	11	8.5	7.7	17.7*	8.8*
M x G	11	4.3	10.3	10.0	6.6
Error b	44	4.3	6.5	8.0	3.6
		Cross-pollinated population			
Replication	2	24.1	1.3	4.3	4.3
Maturity (M)	1	2604.0**	2438.3**	3240.1*	1225.1**
Error a	2	2.3	16.7	58.0	3.0
Generation (G)	11	27.6**	8.3	7.3	7.6**
M x G	11	14.9**	4.0	10.4	5.2*
Error b	44	7.5	7.8	6.6	1.7

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*, ** Significant at 0.05 and 0.01 probability levels, respectively.

TABLE XXVIII

MEANS FOR DAYS TO MIDBLOOM OF THE EARLY AND LATE POPULATIONS GROWN AT GOODWELL AND PERKINS, OKLAHOMA IN 1984 AND 1985

	Midbloom			
	Goodwell		Perkins	
Maturity	1984	1985	1984	1985
	- - - - - days - - - - - -			
	Self-pollinated population			
Early	63	66	70	53
Late	75	76	84	61
LSD (0.05)	4	1	6	5
	Cross-pollinated population			
Early	58	61	65	49
Late	70	72	78	57
LSD (0.05)	2	4	8	2

TABLE XXIX

ANALYSES OF VARIANCE OF DAYS TO MIDBLOOM AS INFLUNCED BY TYPE OF POLLINATION AT GOODWELL AND PERKINS, OKLAHOMA IN 1984 AND 1985

		Mean squares			
		Goodwell		Perkins	
Source	df	1984	1985	1984	1985
		Early maturity			
Replication	2	14.9	6.0	18.4	3.8
Pollination (P)	1	517.3**	501.2**	618.3**	308.3**
Generation (G)	11	11.6	2.3	10.0	5.5
P x G	11	29.6	14.0**	17.7	17.0
Error	46	5.4	4.0	8.3	1.8
		Late maturity			
Replication	2	14.7	1.3	79.3**	27.7**
Pollination (P)	1	401.4**	249.4**	595.1**	234.7**
Generation (G)	11	4.8	7.7	12.2	2.4
P x G	11	9.4	6.3	5.6	3.2
Error	46	7.1	10.3	6.4	3.9

** Significant at 0.01 probability levels.

TABLE XXX

MEANS FOR DAYS TO MIDBLOOM OF THE SELF-POLLINATED POPULATIONS (SPP) AND CROSS-POLLINATED POPULATIONS (CPP) GROWN AT GOODWELL AND PERKINS, OKLAHOMA IN 1984 AND 1985

	Midbloom			
	Goodwell		Perkins	
Type of Pollination	1984	1985	1984	1985
	------ days ------			
	Early maturity			
SPP	63	66	70	53
CPP	58	61	65	49
LSD (0.05)	1	1	1	1
	Late maturity			
SPP	75	76	84	61
CPP	70	72	78	57
LSD (0.05)	1	1	1	1

CHAPTER V

SUMMARY AND CONCLUSION

A two year study was conducted at Goodwell and Perkins, Oklahoma during the crop seasons of 1984 and 1985. The objective of this study was to evaluate the effect of natural selection on the performance of 12 generations of four grain sorghum random-mating populations, namely: early self-pollinated population (SPP), early cross-pollinated population (CPP), late SPP, and late CPP.

The remnant seed of the 12 generations of the four populations was planted in a split-plot design with three replications. Data were obtained for grain yield, test weight, 100-kernel weight, protein percentage of the grain, plant height, and days to midbloom.

The data from the four environments (Goodwell 1984 and 1985, Perkins 1984 and 1985) were analyzed separately. Trend analyses were utilized to examine the change in each trait over the 12 generations. Analyses of variance were used to compare the early with the late populations, and the SPP with CPP.

For grain yield the early SPP was the only population which showed a similar trend in more than one environment, and the only significant linear relationship between yield and generation was for the early CPP (at Perkins in 1985) and the late SPP (at Goodwell in 1984). The yield increase per generation for these two populations was 71 and 93 kg/ha, respectively. In general, the late maturing populations yielded more than the early populations. The differences between the SPP and CPP were significant at only one of the four environments for both early and late populations. In general, significant yield loss or gain did not occur in the CPP, indicating that continuous random-mating did not have a negative effect on grain yield.

The late CPP showed slight increases for test weight in three of the four environments, but continuous propagation had little effect on this trait. There were no significant differences between the early and late populations for the SPP in any environment nor for the CPP in three environments. The CPP produced grain of greater weight per volume than the SPP. This could be due to the fact that the seeds of the CPP were smaller, which increased the number of kernels per volume.

The weight of 100 kernels decreased for the early SPP in two environments, and in one environment for the early CPP and late SPP, suggesting that the kernel weight of these populations was affected only slightly during the continuous random-mating. The 100-kernel weight of the late populations was significantly higher than that of the early ones at Goodwell for both the SPP and CPP. In most cases the kernels of the SPP were slightly heavier than the CPP, indicating that the CPP suffered a slight reduction in seed size.

The grain protein of the early CPP showed a similar trend in two of the three environments. The protein percentage of this population decreased by about 0.1% per generation, indicating that random mating had a negative effect on this trait in the absence of selection for the trait. The protein percentage of the early populations was significantly higher than that of the late in 1984 at both locations, but at Perkins in 1985 the percentage of the late was higher. Also this trait seems to be higher in 1984, but lower in 1985.

The trend in plant height showed a significant change during the 12 generations for the late CPP in all environments, and for the late SPP in only two environments. The height increased by about 1 cm per generation for the late CPP in two environments, and decreased by about 1 cm for the late SPP in one environment. The plants of the late populations were taller than those of the early. The plants of the early SPP were taller than those of the early CPP, but in the late maturing populations the plants of the CPP were taller. This emphasizes the potential for change in height in a population breeding program which involved late maturing grain sorghum lines.

The days to midbloom during the 12 generations showed a significant trend to increase for the early SPP in all environments, for the early CPP in three environments, and for the late CPP in one environment. The second-degree function showed that the trend of the early SPP at Perkins in both years was similar. The third-degree function revealed that the trend of this population at Goodwell in both years was similar. The similarity of the trends of the early SPP at each location indicated that the change in maturity of this population is somewhat consistent over generations. In general, the change of this variable has a more predictable trend in the early SPP than in the other populations. The early populations bloomed significantly earlier than the late ones in all environments. In both maturity populations, the CPP bloomed at least 4 days earlier than the SPP

In general significant loss or gain was not detected during the 12 generations of random mating for grain yield, test weight, or protein percentage, suggesting that population breeding did not cause significant change in these traits under 12 generations of natural selection. A slight decrease in 100-kernel weight was found in the later generations. Plant height and days to midbloom showed a slight trend of increasing. Selection can readily influence these two traits in either early or late maturing populations. Observation in the field as well as the data obtained indicated that the occurrence of outcrossing in the SPP maintained a high level of variability in the random mating populations.

Contrary to the results of Burton (1976) with pearl millet, these RMPs, or "gene pools" of sorghum were advanced 12 or more times with few detected changes. Thus, these germplasm pools have been advanced without apparent loss of, or changes in frequency of, these genes conditioning the characters studied. It appears that breeders can maintain sorghum RMPs through many advances (cycles) without marked change utilizing a form of natural selection.

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APPENDIXES

TABLE XXXI

MEANS FOR GRAIN YIELD OF THE EARLY POPULATIONS GROWN AT GOODWELL AND PERKINS, OKLAHOMA IN 1984 AND 1985

	Grain Yield					
	Perkins			Goodwell		
Generations	1984	1985	means	1984	1985	means
	- - - - - - - -- kg/ha - - - - - - -					
	Self-pollinated population					
1	4282	2933	3608	3070	4175	3622
2	4499	3133	3816	4038	3811	3825
3	4066	3464	3765	4728	4526	4439
4	4228	4326	4277	4858	4019	4439
5	4499	2456	3477	5489	4234	4861
6	4770	2857	3814	4623	4402	4513
7	4879	3079	3979	3954	3948	3951
8	4445	3616	4030	3642	4091	3866
9	4662	2417	3540	3622	4013	3817
10	4011	3268	3640	4084	4611	4348
11	4825	2835	3830	4182	3525	3853
12	4390	3957	4174	3831	3453	3642
	Cross-pollinated population					
1	4120	2504	3312	2731	3232	2982
2	4120	2900	3510	4019	3733	3876
3	4499	2922	3711	3375	4247	3811
4	3740	2965	3353	2972	3284	3128
5	4228	2970	3599	3044	3161	3102
6	4391	3285	3838	3655	4474	4065
7	4011	2868	3440	2874	3941	3408
8	4445	3659	4052	3245	4104	3674
9	3957	3274	3616	3297	3102	3200
10	4228	3041	3635	4097	4227	4162
11	4391	3762	4076	3330	3401	3366
12	4662	3290	3976	3447	4552	4000

TABLE XXXII

MEANS FOR GRAIN YIELD OF THE LATE POPULATIONS GROWN AT GOODWELL AND PERKINS, OKLAHOMA IN 1984 AND 1985

	Grain Yield					
	Perkins			Goodwell		
Generations	1984	1985	means	1984	1985	means
	- - - - - - - - - kg/ha - - - - - - - - -					
	Self-pollinated population					
1	4282	3876	4079	4845	3174	4009
2	3360	4266	3814	5177	3336	4257
3	3361	3448	3404	3980	3356	3668
4	4228	3849	4038	5599	3479	4539
5	3849	3551	3700	5645	4019	4832
6	3740	3892	3816	6386	3805	5095
7	4499	3876	4188	6094	4084	5089
8	4662	3681	4171	5782	3642	4712
9	4337	4922	4629	5586	3987	4787
10	4553	3491	4022	4604	3414	4009
11	3361	3881	3621	6146	3356	4751
12	3957	5258	4608	6074	4039	5056
	Cross-pollinated population					
1	4066	2591	3328	5678	3239	4458
2	4445	4272	4358	5359	3180	4270
3	4066	4494	4280	5385	3921	4653
4	4011	3204	3608	4780	3583	4182
5	3902	4033	3968	4956	3466	4211
6	4120	4244	4182	5879	5092	5486
7	4120	3984	3833	6308	4819	5564
8	4337	4011	4174	5280	5099	5190
9	4120	3984	4052	5294	4539	4917
10	4337	3892	4114	4383	3876	4130
11	3632	5155	4394	3779	4559	4169
12	4120	4456	4288	4995	4819	4907

TABLE XXXIII

MEANS FOR TEST WEIGHT OF THE EARLY POPULATIONS GROWN AT GOODWELL AND PERKINS, OKLAHOMA IN 1984 AND 1985

	Test Weight					
	Perkins			Goodwell		
Generations	1984	1985	means	1984	1985	means
	- - - - - - - - - kg/mc - - - - - - - - -					
	Self-pollinated population					
1	768	725	746	712	720	716
2	768	699	734	712	712	712
3	772	686	729	682	704	693
4	759	691	725	686	699	693
5	755	678	716	686	721	704
6	776	674	725	716	708	712
7	742	674	708	695	704	699
8	764	678	721	682	686	684
9	746	661	704	678	699	689
10	759	678	719	721	691	706
11	759	678	719	695	682	689
12	768	699	734	699	691	695
	Cross-pollinated population					
1	776	708	742	694	716	706
2	763	725	744	699	716	707
3	776	708	742	716	734	725
4	781	716	749	699	725	712
5	776	716	746	699	716	708
6	785	716	751	682	725	704
7	781	708	744	716	716	716
8	768	712	740	712	729	720
9	776	699	738	720	721	720
10	772	708	740	695	729	712
11	785	695	740	708	704	706
12	806	695	751	729	721	725

TABLE XXXIV

MEANS FOR TEST WEIGHT OF THE LATE POPULATIONS GROWN AT GOODWELL AND PERKINS, OKLAHOMA IN 1984 AND 1985

	Test Weight					
	Perkins			Goodwell		
Generations	1984	1985	means	1984	1985	means
	- - - - - - - - - kg/mc - - - - - - - - -					
	Self-pollinated population					
1	759	695	727	699	704	701
2	772	682	727	716	665	691
3	759	721	740	712	695	704
4	751	678	714	712	699	706
5	789	682	735	729	708	719
6	759	682	721	716	712	714
7	738	691	714	725	691	708
8	776	691	734	725	708	716
9	768	699	734	721	704	712
10	768	674	721	742	691	716
11	785	746	766	729	691	710
12	776	725	751	729	695	712
	Cross-pollinated population					
1	769	695	731	729	712	721
2	759	691	725	734	716	725
3	772	691	731	738	725	731
4	737	686	712	721	704	712
5	776	734	755	742	725	733
6	776	699	737	734	729	731
7	781	712	746	725	725	725
8	776	738	757	738	738	737
9	789	695	742	746	708	727
10	781	716	748	734	734	734
11	789	755	772	751	734	742
12	798	746	772	725	734	729

TABLE XXXV

MEANS FOR 100-KERNEL WEIGHT OF THE EARLY POPULATIONS GROWN AT GOODWELL AND PERKINS, OKLAHOMA IN 1984 AND 1985

	100-Kernel Weight			
	Perkins			Goodwell
Generations	1984	1985	means	1984
	------ g -----			
	Self-pollinated population			
1	2.33	2.60	2.47	2.73
2	2.57	2.93	2.75	2.53
3	2.53	2.83	2.68	2.40
4	2.57	2.70	2.63	2.60
5	2.47	2.87	2.67	2.50
6	2.43	2.73	2.58	2.43
7	2.43	2.80	2.62	2.33
8	2.46	2.80	2.63	2.20
9	2.50	2.57	2.53	2.27
10	2.17	2.87	2.51	2.23
11	2.40	2.73	2.57	2.27
12	2.20	2.73	2.47	2.07
	Cross-pollinated population			
1	2.74	2.67	2.70	2.57
2	2.37	2.73	2.55	2.33
3	2.40	2.77	2.58	2.17
4	2.23	2.80	2.52	2.17
5	2.17	2.60	2.38	2.17
6	2.53	2.67	2.60	2.30
7	2.40	2.83	2.62	2.17
8	2.33	2.67	2.50	2.00
9	2.37	2.73	2.55	2.17
10	2.13	2.80	2.47	2.20
11	2.23	2.73	2.48	2.20
12	2.23	2.77	2.50	2.27

TABLE XXXVI

MEANS FOR 100-KERNEL WEIGHT OF THE LATE POPULATIONS GROWN AT GOODWELL AND PERKINS, OKLAHOMA IN 1984 AND 1985

	100-Kernel Weight			
	Perkins			Goodwell
Generations	1984	1985	means	1984
	- - - - - g - - - - - -			
	Self-pollinated population			
1	2.27	2.83	2.55	2.70
2	2.33	2.77	2.55	2.67
3	2.33	2.73	2.53	2.53
4	2.60	2.83	2.72	2.47
5	2.33	2.90	2.62	2.53
6	2.40	2.80	2.60	2.73
7	2.70	2.73	2.72	2.60
8	2.40	2.73	2.57	2.43
9	2.33	2.87	2.60	2.57
10	2.43	2.97	2.70	2.40
11	2.53	2.83	2.68	2.40
12	2.43	2.73	2.58	2.53
	Cross-pollinated population			
1	2.27	2.80	2.53	2.63
2	2.43	2.67	2.55	2.70
3	2.60	2.67	2.63	2.67
4	2.40	2.80	2.60	2.50
5	2.57	2.90	2.73	2.70
6	2.37	2.70	2.53	2.53
7	2.27	2.80	2.53	2.80
8	2.27	2.60	2.43	2.73
9	2.27	2.63	2.45	2.50
10	2.40	2.67	2.53	2.60
11	2.17	2.73	2.45	2.50
12	2.56	2.63	2.60	2.63

TABLE XXXVII

MEANS FOR PROTEIN PERCENTAGE OF THE EARLY POPULATIONS GROWN AT GOODWELL AND PERKINS, OKLAHOMA IN 1984 AND 1985

	Protein Percentage			
	Perkins			Goodwell
Generations	1984	1985	means	1984
	----- % ------			
	Self-pollinated population			
1	12.03	12.70	12.36	11.30
2	11.43	13.00	12.21	10.87
3	10.97	12.97	11.97	10.80
4	11.50	13.50	12.50	10.53
5	11.10	13.40	12.25	10.43
6	9.83	13.13	11.48	10.30
7	10.57	13.13	11.85	10.63
8	11.77	12.90	12.33	11.03
9	11.40	13.97	12.68	11.03
10	11.57	13.30	12.43	10.86
11	11.27	13.00	12.13	11.13
12	10.87	12.73	11.80	10.87
	Cross-pollinated population			
1	11.87	12.90	12.38	11.90
2	12.37	12.83	12.60	11.37
3	12.37	12.76	12.57	11.57
4	11.93	13.06	12.50	11.93
5	11.23	13.33	12.28	11.77
6	11.77	12.60	12.18	11.33
7	11.30	12.63	11.97	11.50
8	11.67	12.90	12.28	11.70
9	11.70	13.03	12.37	11.40
10	10.77	12.13	11.45	10.90
11	10.70	12.77	11.73	10.80
12	11.10	13.47	12.28	10.77

TABLE XXXVIII

MEANS FOR PROTEIN PERCENTAGE OF THE LATE POPULATIONS GROWN AT GOODWELL AND PERKINS, OKLAHOMA IN 1984 AND 1985

	Protein Percentage			
	Perkins			Goodwell
Generations	1984	1985	means	1984
	- - - - -	%	- - - - - -	
	Self-pollinated population			
1	10.57	15.23	12.90	10.67
2	11.80	14.57	13.18	11.07
3	10.73	15.90	13.12	11.07
4	10.70	13.97	12.33	10.43
5	10.87	14.83	12.85	10.57
6	10.40	15.23	12.82	10.17
7	11.80	14.87	13.33	10.23
8	11.76	15.37	13.57	10.10
9	11.50	15.13	13.12	10.43
10	11.40	14.17	12.78	10.17
11	10.87	14.47	12.67	10.10
12	10.10	14.90	12.50	10.10
	Self-pollinated population			
1	11.10	14.23	12.66	10.63
2	11.67	14.30	12.98	10.83
3	11.93	14.03	12.98	10.97
4	10.27	13.73	12.00	10.97
5	11.50	13.53	12.52	10.97
6	10.87	13.93	12.40	10.53
7	10.60	13.87	12.23	10.90
8	11.60	14.47	13.03	10.96
9	11.93	14.13	13.03	11.33
10	12.30	14.93	13.62	11.03
11	10.77	15.40	13.08	11.26
12	9.97	14.63	12.30	11.03

TABLE XXXIX

MEANS FOR PLANT HEIGHT OF THE EARLY POPULATIONS GROWN AT GOODWELL AND PERKINS, OKLAHOMA IN 1984 AND 1985

	Plant Height					
	Perkins			Goodwell		
Generations	1984	1985	means	1984	1985	means
	cm					
	Self-pollinated population					
1	106	99	102	123	124	124
2	99	107	103	122	116	120
3	105	108	106	114	122	118
4	108	109	109	124	124	124
5	108	100	104	117	116	117
6	110	102	106	120	127	123
7	107	105	106	132	128	130
8	100	105	103	116	122	119
9	110	107	108	131	117	124
10	101	99	100	116	119	117
11	105	104	104	125	121	123
12	105	104	106	125	126	125
	Cross-pollinated population					
1	103	95	99	121	113	117
2	98	103	100	119	118	119
3	100	104	102	123	123	123
4	94	102	98	112	109	111
5	101	106	103	117	115	116
6	97	104	101	124	122	123
7	101	104	103	116	112	114
8	99	104	102	121	114	118
9	99	113	106	128	116	122
10	101	100	101	122	108	115
11	106	108	107	131	115	123
12	108	100	104	134	118	124

TABLE XXXX

MEANS FOR PLANT HEIGHT OF THE LATE POPULATIONS GROWN AT GOODWELL AND PERKINS, OKLAHOMA IN 1984 AND 1985

	Plant Height					
	Perkins			Goodwell		
Generations	1984	1985	means	1984	1985	means
	- - - - - - - - - cm - - - - - - - - -					
	Self-pollinated population					
1	111	131	120	126	121	124
2	118	125	122	137	111	124
3	119	127	123	155	132	143
4	110	117	114	127	125	126
5	110	121	115	128	118	123
6	110	119	115	127	120	124
7	111	119	115	126	115	120
8	113	116	115	121	122	121
9	120	116	118	125	120	123
10	110	120	115	126	124	125
11	108	119	113	128	113	121
12	111	119	115	128	124	126
	Cross-pollinated population					
1	126	118	122	130	123	126
2	115	124	120	133	131	132
3	129	117	123	134	124	129
4	117	127	122	143	131	137
5	119	136	128	153	146	150
6	123	117	120	147	124	135
7	116	139	128	126	139	133
8	114	121	117	137	123	130
9	126	123	124	141	129	135
10	115	135	125	142	141	142
11	127	139	133	148	149	148
12	134	123	128	158	139	148

TABLE XXXXI

MEANS FOR DAYS TO MIDBLOOM OF THE EARLY POPULATIONS GROWN AT GOODWELL AND PERKINS, OKLAHOMA IN 1984 AND 1985

	Days to Midbloom					
	Perkins			Goodwell		
Generations	1984	1985	means	1984	1985	means
	- - - - - - - -	- - -	days	- - -	- - - - - - - -	
			Self-pollinated population			
1	66	51	58	60	61	61
2	68	51	60	64	65	65
3	69	54	62	63	65	64
4	96	54	62	66	69	68
5	71	55	63	66	67	67
6	75	55	65	64	68	66
7	70	53	65	63	66	65
8	73	55	63	63	66	65
9	70	52	63	62	66	64
10	73	56	64	63	65	64
11	71	53	62	62	65	64
12	71	50	60	64	64	64
			Cross-pollinated population			
1	69	51	60	66	63	65
2	63	47	55	50	61	56
3	63	50	57	57	61	59
4	64	48	56	56	59	58
5	65	50	57	58	61	60
6	63	49	56	54	59	57
7	64	48	56	56	60	58
8	64	48	56	57	60	58
9	63	49	56	56	60	58
10	66	48	57	56	60	58
11	67	48	58	58	62	60
12	65	54	60	58	60	60

TABLE XXXXII

MEANS FOR DAYS TO MIDBLOOM OF THE LATE POPULATIONS GROWN AT GOODWELL AND PERKINS, OKLAHOMA IN 1984 AND 1985

	Days to Midbloom					
	Perkins			Goodwell		
Generations	1984	1985	means	1984	1985	means
	- - - - - - - - - days - - - - - - - - -					
	Self-pollinated population					
1	86	61	74	73	77	75
2	81	61	71	75	75	75
3	85	62	73	73	79	76
4	81	59	70	75	75	75
5	83	61	72	76	75	75
6	88	62	75	74	77	76
7	83	60	71	75	76	75
8	85	60	73	74	74	74
9	83	62	73	75	76	76
10	82	62	72	77	76	76
11	85	63	74	76	77	76
12	83	60	71	74	74	74
	Cross-pollinated population					
1	78	57	68	73	73	73
2	79	57	68	69	70	70
3	76	57	66	68	71	70
4	77	58	67	69	71	70
5	78	56	68	69	73	71
6	81	58	69	72	69	71
7	77	58	68	69	74	71
8	77	57	68	71	71	73
9	79	58	68	72	73	71
10	77	58	67	68	73	71
11	78	59	69	72	73	73
12	78	59	69	68	72	71

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