Genetic analyses of agronomic traits in $F_{4:3[8]}$ and $F_{5:3[8]}$ progenies derived from eight-parent soybean crosses

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ABSTRACT

The utilization of exotic germplasm comprises a strategy for improving the genetic diversity within soybean cultivars, whose present narrowness is a main limitation in soybean breeding programs that utilize two-way crosses between homozygous pure lines. Progenies from forty-five soybean crosses obtained through the combination of eight parents (octuple crosses) in a chain mating system were evaluated in the $F_{4:3[8]}$ generation for grain yield and other agronomic important traits. The octuple crosses included both adapted and exotic parents mated in a chain system during three generations to assemble a group of materials with the proportion of 75% : 25% of genes stemming from adapted and exotic parents, respectively. In addition to this, adapted parents were selected to form a second group with 100% adapted germplasm. The $F_{4:3[8]}$ progenies were evaluated in an augmented block design in the 1994/95 growing season. The $F_{5:3[8]}$ progenies were evaluated in six experiments during the 1995/96 growing season. Three augmented block designs (without replications) and three complete randomized- block designs with two or three replications were used. The analyses of the results indicate that octuple crosses produced superior progenies for all the traits studied, especially grain yield which presented the excellent mean yield of 5.530 kg/ha. Remnant genetic variability amongst selected progenies in some crosses allowed the prediction of additional gains for grain yield through selection in more advanced cycles.

KEY WORDS: Glycine max, multiple crosses, grain yield.

INTRODUCTION

Soybean (Glycine max (L.) Merrill] is an oilseed plant cultivated for more than 5,000 years, and has become the staple food of the Chinese people, a habit influenced by its availability after domestication in Northeast China (Hymowitz, 1970). There is general consensus among the majority of specialists that the most likely primary center of genetic diversity of the species is the Central-Southern region of China with a secondary center in Manchuria.

The expansion of soybean cultivation in Brazil began in the 1970s, when the country became the second largest world producer of this legume crop, right after the United States, reaching a production of 30 million tons of grains in an area of approximately 13 million hectares in the 1997/98 growing season (Embrapa, 1998).

The utilization of exotic germplasm was suggested by Vello (1985) as a strategy to widen the genetic base of the Brazilian soybean cultivars. The genetic background of the Brazilian cultivars is very narrow, since their genealogy traces back to only 26 ancestors, 11 of them contributing with 89% of the total gene pool (Hiromoto and Vello, 1986). Furthermore, six of these ancestors are also the most frequent genotypes found in the genealogies of the Northern American cultivars. Vello (1985) suggested that a proportion of 25% of selected exotic germplasm should be gradually introduced into the cultivated germplasm, through triple crosses or using populations with a wide genetic base.

Because of the many disadvantages of classic breeding methods, several modifications have been introduced to make them simpler, quicker and more efficient and above all increasing their genetic gains. The so-called new methods such as the SSD, in the most cases don no allow a more vigorous action of natural selection. The use of large F_1 populations and mainly F_2 populations is therefore generally recommended.

The application of recurrent selection to soybean breeding programs, suggested by Hanson et al. (1967), would be a way of minimizing the limitations which characterize soybean breeding programs, such as the narrow genetic base of the populations synthesized by crosses among two pure homozygous lines, with the fixation of the desirable traits by successive self pollination. Such procedures are frequently adopted in soybean breeding, which make cultivars extremely vulnerable to pests and diseases and resulting in heavy losses. Hence much emphasis has been placed in the use of recurrent selection procedures with wide genetic base populations (Brim and Stuber, 1973). However, inherent difficulties in artificial crossing and the small number of seeds obtained in each cross has limited the application of recurrent selection in soybean, even when experienced personnel is available.

Among the mechanisms which allow an increase in natural cross-pollination rates in autogamous species, genetic male sterility has been utilized and it is observed in many diploid species (Duvic, 1966). Brim and Young (1971) reported that male sterility in soybean is inherited as a single pair of recessive genes (ms1 ms1). They discovered that non-viability of pollen in male sterile plants was complete and that more than 99% of the seeds produced in such plants was a result of natural crosses. Except for pollen non-viability, the apparent phenotype of the male sterile plant is altered only as far as pod shape at maturity is concerned. Male sterile plants usually produce a small number of large seeds.

Ininda et al. (1996) after three cycles of recurrent selection, suggested that selection in populations developed from elite cultivars, continues to be the most efficient method for obtaining high yielding cultivars. The introduction of exotic germplasm in adapted populations would help the improvement of quantitative traits (Vello, 1992). A large interference of strictly quantitative character such as yield grain on the trait "yield of oil" has been detected (Laínez-Mejia, 1996; Farias Neto, 1995), emphasizing the need to consider as well traits providing greater adaptation and yield potential so that crosses among divergent genotypes could be recommended in breeding programs. The objective of this study was to select superior genotypes in terms of agronomic traits such as plant height at maturity, cycle, agronomic value and, especially, grain yield, in segregating populations derived from octuple soybean crosses.

MATERIAL AND METHODS

The genotypes used in this study are progenies developed by the Soybean Oil and Yield Breeding Program of the Department of Genetics, Escola Superior de Agricultura 'Luiz de Queiroz', São Paulo University (ESALQ/USP). All the initial phases of the recurrent selection program were carried out by members of the Sector of Genetics Applied to Self Pollinating species, Department of Genetics, ESALQ/USP, within the growing seasons of 1988/89 and 1992/93, including the three recombination cycles and the advancing of the $F_{4:3[8]}$ $F_{1[8]}$ and $F_{2[8]}$] generations. The procedure for obtaining biparental, four-way (quadruple) and octuple crosses was reported by Vello (1992). A total of 45 octuple crosses was made. In the fall-winter of 1994, the $F_{3:2[8]}$ generation was obtained, but no assessment was made at field level, as the main objective was seed multiplication. During the growing seasons of 1994/95 and 1995/96 the $F_{4:3[8]}$ and $F_{5:3[8]}$ generations were respectively obtained and evaluated. The $F_{4:3[8]}$ and $F_{5:3[8]}$ were obtained from a 45-cross chain involving 40 parents, which were previously divided into two groups of 20 genotypes each, for the assembling of two-cross chains. The designation of the octuple crosses differed from that used for the simple crosses. The symbols $F_{3:2[8]}$, $F_{4:3[8]}$ and $F_{5:4[8]}$ were adopted, where the first number means generation of the progeny selection, the second number stands for generation selected plant and the [8] accompanying the identification of each generation explains its origin from an eight-parent cross. These symbols are similar to those that adopted by Lopes (1997). The first group of crosses, the mixed chain, included ten exotic genotypes and ten adapted genotypes, and was therefore made up of hybrid combinations presenting 50% of exotic genes. The second group of genotypes, the adapted-chain crosses, involved 20 adapted genotypes.

All the initial phases of the recurrent selection program and the experiments of the $F_{4:3[8]}$ generation, whose progenies represent the materials in the present study, were conducted in an purple red soil (Terra Roxa Estruturada) in the experimental area of the ESALQ/USP Campus, in Piracicaba-SP, at 22°42′30′ latitude south, 47°39′00′ longitude west and altitude of 540m above sea level.

The experiments with the $F_{5:4[8]}$ progenies were carried out on the Anhembi Experimental Station, which also belongs to the Department of Genetics of ESALQ/USP. The experimental area is located 60 km from the ESALQ Campus and is characterized by sandy, acid soils with toxic levels of aluminum and low phosphorus content, which represents the soils found in the Brazilian Savannah. Soil acidity and toxicity were neutralized through liming before planting the experiments.

From the $F_{3:2[8]}$ generation, 1,872 $F_{4:3[8]}$ progenies were obtained by collecting at least 50 $F_{3:2[8]}$ plants within each cross and selecting more plants from superior progenies, up to a maximum of ten plants from each progeny evaluated in 1994/95. Treatments consisted of the 1,872 $F_{4:3[8]}$ progenies and four checks (cultivars IAC-12, UFV-4, Bossier and IAC-Santa Maria–702) arranged in an augmented block design (Federer′s blocks; Federer, 1956). The progenies were distributed in 82 sets without replication, while the four check treatments were included in all sets representing common treatments. Each plot consisted of 5.0 m rows spaced 0.5 m apart.

The experimental data was used in progeny selection, by means of a different selection intensity for each cross, based on the following traits: yield, agronomic value, lodging and cycle, taken in this same order of importance. The $F_{5:4[8]}$ progenies obtained from selections in the $F_{4:3[8]}$ generation and the four controls (IAC-12, UFV-4, Bossier and IAC-Santa Maria-702) were sown on 12/6/95 at the Anhembi Experimental Station, SP. The plots consisted of two 5.0m long rows spaced 0.5m apart within plots and 1.0m between plots. A total of 836 $F_{5:4[8]}$ progenies selected from the previous generation was evaluated together with the four controls (IAC-12, UFV-4, Bossier and IAC-Santa Maria=702) in randomized blocks with two or three replications. Each replication was analyzed individually, as Federer augmented block design (Federer, 1956). The individual data were later analyzed jointly using the average mean square values.

The procedures adopted to set up and carry out the experiment were the same as the ones described for the previous generation. The following traits were used to evaluate the $F_{4:3[8]}$ and $F_{5:4[8}$] progenies as well as the controls:

NDM: number of days to maturity, defined as the period between the sowing date and the date when approximately 95% of the pods were mature;

PHM: Plant height (cm) at maturity, measured from the plant base to the tip of the main stem;

LO: lodging, evaluated at maturity [R8 stage; Fehr et al., 1971], by a scale of visual scores varying from 1 to 5, in which score 1 corresponded to the plots with erect plants and 5 to the plots with completely lodged plants (this is only an auxiliary trait in selection);

AV: agronomic value, evaluated at maturity (idem the previous) by a scale of visual scores varying from 1 to 5, where 1 corresponded to plots with plants without any agronomic value and 5 to plots with plants of excellent agronomic value; the agronomic value reflected the general aspect of the plants for a series of adaptive traits such as: pod number, vigor in terms of height and number of stem ramifications, plant health, viability of mechanical harvesting, resistance to premature pod shattering and little leaf retention at maturity;

GY: grain yield, evaluated at maturity in kg/ha after a drying period of approximately 30 days storage of grains in the shade and at room temperature;

The data for the observations of the experimental plots in the generation $F_{4:3[8]}$ were submitted to separate analysis of variance for each trait. The values for LO and VA were previously transformed in $(x + 0.5)^{1/2}$. The mathematical model adopted was the following:

$$Yijk = u + bi + cj + gk(j) + eijk$$

Where: Yijk is the observation in the ijkth plot (i = 1, 2, ..., B blocks or sets; j = 1, 2, ..., C crosses; and k = 1, 2, ..., G genotypes in the Jth cross;

u: overall mean of the observations;

bi: the random effect of the ith block

cj: is the fixed effect of the jth cross;

gk(j): is the random effect of the kth genotype within the jth cross; and eijk is the random experimental error in the referred plot, assuming errors to be independent and normally distributed, with zero mean and s^2 variance.

The source of variation ‘crosses + controls′ was partitioned by orthogonal contrasts, in: cross effect (which generated the progenies), control effect and cross vs. control interaction. Similarly, the mean variation due to genotypes within crosses (G/C) was partitioned in genotypes within each cross that produced progenies for the generation in question (G/Cl, G/C2, ..., G/C45). Actually, although the program started with 45 crosses, progenies from cross number 37 did not produce any seeds and did not originate $F_{4:3[8]}$ and $F_{5:4[8]}$ generations.

Estimates for the components of variance for genotypes within crosses and for the cross means and genotypes within crosses means, all adjusted for blocks, and also for the respective associated standard errors, were obtained from the analyses. All analyses were carried out using the GLM procedure of the SAS (SAS, 1987). The univariate analysis of variance, for each one of the six experiments conducted in the $F_{5:3[8]}$ generation, followed the same model and structure of the previous experiment, except that the genotype effects within the crosses were considered as fixed, given the rigorous selection pressure applied in the $F_{4:3[8]}$ generation.

RESULTS AND DISCUSSION

Tables 1 and 2 show the 45 octuple crosses identified by numbers (C1 to C45) while Table 3 shows their respective genealogies. Controls were coded as follows: 46: UFV-4; 47: Bossier; 48: IAC-Santa Maria-702; and 49: IAC-12. All trait means were significantly different amongst the early, intermediate and late sub-populations of the replicated experiment. The non-significance of the NDM and VA traits within the late and the intermediate sub-populations, respectively, indicated that such progenies were correctly classified according to their maturity cycle. Similar result was obtained by Laínez-Mejia (1996) using biparental crosses.

Plant height at maturity

The four controls reached an overall PHM mean of 92.17 cm in 94/95 and a lower mean of 84.3 cm in 95/96 The general PHM mean of the $F_{5:3[8]}$ progenies was 82.7 cm. The $F_{5:3[8]}$ progenies of the replicated early

Table 1. PHM: Plant height at maturity (cm) and NDM: Number days to maturity (days). Means estimated and adjusted by progenies in subpopulations $F_{5:3[8]}$ early maturing, intermediate and late cycles with repetitions by chain crosses. ESALQ, Piracicaba-SP.

Crosses	Early maturing		Intermediate		Late	
	PHM	NDM	PHM	NDM	PHM	NDM
1	68.75	160.00	82.50	164.67	80.83	165.83
2	108.75	160.00	105.00	147.17	94.58	147.08
3	110.75	157.30	117.50	144.67	112.08	152.08
4	111.25	152.50	82.50	144.67	- - -	164.58
5	- - -	- - -	- - -	- - -	99.58	168.33
6	- - -	- - -	- - -	- - -	92.08	154.67
8	88.75	145.00	79.38	149.04	83.33	148.80
9	- - -	- - -	105.00	164.67	103.47	165.87
10	- - -	- - -	- - -	- - -	85.83	164.58
11	53.75	147.50	- - -	- - -	- - -	- - -
12	- - -	- - -	- - -	- - -	98.33	174.58
13	105.94	150.00	112.50	154.67	118.33	164.58
14	93.75	147.50	106.17	148.80	103.33	159.58
15	- - -	- - -	105.50	165.87	100.83	165.83
16	46.25	142.00	133.00	150.87	117.08	170.58
18	118.75	165.00	- - -	- - -	108.33	159.58
19	105.00	161.25	- - -	- - -	100.21	162.08
20	70.42	149.67	88.00	151.77	- - -	- - -
21	- - -	- - -	- - -	- - -	113.33	171.58
22	108.75	165.00	115.50	164.87	112.08	160.83
23	98.13	147.50	128.00	150.87	- - -	- - -
24	89.79	148.33	120.50	158.37	102.08	163.33
25	58.13	142.00	75.50	151.87	84.58	161.08
26	68.13	160.00	93.00	165.87	- - -	- - -
27	59.38	145.00	- - -	- - -	- - -	- - -
28	38.13	148.00	- - -	- - -	97.08	162.08
29	50.63	146.50	- - -	- - -	- - -	- - -
31	123.13	165.00	95.25	168.02	117.08	163.33
32	88.13	165.00	118.00	165.87	111.25	171.83
33	63.13	150.00	- - -	- - -	107.08	170.33
34	- - -	- - -	- - -	- - -	122.08	173.33
36	- - -	- - -	94.50	149.47	112.08	173.33
40	84.79	146.00	114.50	145.97	- - -	- - -
41	97.29	148.33	92.00	146.97		- - -
43	- - -	152.00	- - -	154.47	- - -	173.33
44	91.88	151.38	110.50	153.97	122.08	173.33
46	100.00	175.00	105.00	175.17	105.00	175.00
47	73.33	145.00	81.67	145.00	83.33	146.67
48	101.67	165.00	98.33	165.00	96.67	165.00
49	75.00	142.00	90.00	144.00	98.33	166.67
Mean	84.98	153.07	102.27	155.28	102.89	164.37

sub-population experiment (Table 1) that showed greater PHM were: C31 with 123.1 cm; C18 with 118.7 cm; C4 with 111.2 cm and C3 with 110.7 cm.

This is a very promising result considering that they have a shorter cycle and are able to avoid the drought spell at the grain filling stage even when planting has occurred in the first ten days of December. This type of late planting is a fact of fairly common occurrence nowadays in soybean cropping because of the constant variation in rainfall patterns at the Southeast/ Central Western region. All crosses of sub-populations with intermediate cycle in the replicated experiment (Table 2) showed PHM means greater than 60 cm, especially crosses C23 with 128.0cm; C24 with 120.5 cm; C32 with 118.0 cm; and C22 with 115.5 cm.

Table 2. AV: Agronomic value (note) and GY: Grain Yield (kg/ha). Means estimated and adjusted in $F_{5:3[8]}$ progenies by chain crosses of early maturing, intermediate and late cycles, with repetitions . ESALQ, Piracicaba-SP.

Crosses	Early maturing		Intermediate		Late	
	AV	GY	AV	GY	AV	GY
1	1.84	2484.74	3.03	2328.90	3.18	2599.27
2	1.84	3210.92	3.50	3613.02	1.65	2630.52
3	2.59	3072.06	3.03	3202.05	2.66	2752.92
4	2.32	4063.45	2.52	2773.79	- - -	- - -
5	- - -	- - -	- - -	- - -	2.92	3808.92
6	- - -	- - -	- - -	- - -	3.70	2910.49
8	2.32	3660.46	3.11	- - -	2.81	2953.04
9	- - -	- - -	2.02	3643.28	3.66	3460.20
10	- - -	- - -	- - -	1784.27	2.56	2372.52
11	2.28	2262.63	- - -	- - -	- - -	- - -
12	- - -	- - -	- - -	- - -	3.78	2883.22
13	2.92	3597.50	3.70	3377.61	3.30	3477.72
14	2.81	3923.80	3.22	3241.03	2.81	1603.77
15	- - -	- - -	3.11	2592.20	3.30	3401.92
16	1.84	1809.10	3.62	3641.57	3.54	3842.79
18	3.30	2439.52	- - -	- - -	2.32	1680.87
19	2.66	3752.23	- - -	- - -	2.95	3621.34
20	1.84	2553.90	2.70	3201.87	- - -	- - -
21	- - -	- - -	- - -	- - -	3.30	3819.52
22	1.84	2867.78	3.34	2801.01	2.92	4349.52
23	2.81	4042.61	3.62	3600.34	- - -	- - -
24	3.07	3375.84	3.34	3597.68	2.95	4251.12
25	3.07	3428.15	2.84	3394.19	2.06	2576.02
26	2.56	2294.99	2.59	3573.74	- - -	- - -
27	2.32	1850.10	- - -	- - -	- - -	- - -
28	3.07	3382.93	- - -	- - -	3.54	3113.34
29	2.52	2636.80	- - -	- - -	- - -	- - -
31	2.06	3941.53	2.88	3906.37	4.42	2865.32
32	2.06	3103.63	3.11	3770.58	3.42	2661.80
33	3.52	3143.53	- - -	- - -	2.95	3410.62
34	- - -	- - -	- - -	- - -	4.42	4098.17
36	- - -	- - -	3.78	4207.35	3.70	3439.87
40	2.63	3039.57	3.78	3765.79	- - -	- - -
41	2.95	3296.04	3.30	2439.78	- - -	- - -
43	2.22	2879.48	3.30	3397.38	2.95	2821.37
44	2.45	3300.03	3.14	2927.36	4.42	5530.62
46	3.99	1657.18	3.95	2291.15	3.89	2431.23
47	2.63	1935.00	2.99	1807.77	2.63	1758.30
48	2.63	2397.55	2.63	1766.24	2.99	1564.93
49	2.99	2797.43	2.99	2793.00	3.14	2067.70
Mean	2.39	2074.21	2.99	3090.35	3.14	3056.74

The late crosses in the replicated experiment (Table 1) showed good plant development, and no cross presented APM mean shorter than 60 cm. Crosses C34 and C44 with 122.08cm; C13 with 118.3 cm; and C31 with 117.08 cm showed superior plant development. Among those crosses with superior PHM values in the $F_{5:3[8]}$ generation (Table 1), the C18 cross was the only one which stood out, presenting means of 102 and 118 cm, respectively. The crosses C12, C13, C22, C23, C24 and C31 were the tallest ones in at least two sub-populations, and C23 was the tallest of all, with plant height mean of 128 cm. This cross is derived from the hybrid between IAC-6 and UFV-4, which was one of the outstanding combinations pointed out by Farias Neto (1995) and Laínez Mejia (1996). The PHM mean values obtained allowed the inference that several crosses generated sufficiently tall progenies for cultivation in low fertility soils such as the partially corrected cerrados (Savannah), allowing cost effective cultivation with the adoption of mechanical harvesting with small losses, and possibly late sowing since they also have the long juvenile period trait.

Number of days to maturity

The means of the four controls in 94/95 and in 95/96 were 133 and 152 days, respectively (Table 1). The $F_{5:4[8]}$ progenies presented an overall NDM mean of 151 days, with 12, 13 and 26 progenies in the replicated experiment belonging to the early, intermediate and late maturity cycles, respectively (Table 1). The sub-populations in the replicated experiments included the following early crosses in each maturity cycle: a) C16 and C25 crosses (142 days) in the early; b) the C3 and C4 crosses (144.6 days) in the intermediate; and the C2 (147 days) cross in the late (Table 1). A small NDM in each maturity group may be considered an important factor under cultivation conditions of double cropping with maize as a secondary crop or in the renovation of one-and-a-half-year sugar cane plantations. The crosses C18, C22 and C31 showed the highest NDM mean (165 days) within the early sub-population, while the crosses C31 (168 days) in the intermediate, and C12 (174 days) in the late sub-populations also presented high NDM values. These genotypes are practically non-viable for commercial planting in the central-southern region, as there is an enormous risk of crop failure because of rain shortage in the critical crop periods, and also, because of the great chance of pest and disease incidence in the field. Crosses C45 and C6 presented respectively the shortest and longest cycles in the $F_{4:3[8]}$ generation, and were also included among the outstanding crosses within their respective maturity group in the $F_{5:4[8]}$ generation, with differences of 6 and 9 days between generations (Table 1).

Among the crosses with lowest NDM means, stand C14, C2, C11 and C38 (Table 1) and among those of longer cycle, C4, C5 in $F_{4:3[8]}$ and C12 in F5:3[8]. Crosses C2, C11, C14 and C38 present as parents, among others, the genotypes : GO 81-8,491 x Sel. BR 80-15,725-B, FT-2 x Sel. N82-2,764, which were all pointed out as exceptional ones by Faria Neto (1995), and Sel. Paraná x Kirby, FT 79-3,408 x Sel. Ax53-55, Sel. SOC 81-127 x Wright (Faria Neto, 1995; Laínez-Mejia, 1996) FT-8 x OC 79-7 (Laínez-Mejia, 1996).

Agronomic value

The controls presented overall means of 3.42 and of 2.99 in 94/95 in 95/96, respectively, which indicated satisfactory agronomic performance. In the $F_{5:4[8]}$ progenies the highest scores were obtained by the crosses C36 (3.70), C13 (3.30), C28 (3.54) and C33 (2.96) (Table 2). Such information would be an aid for the breeder who could select higher yielding materials with excellent general plant characteristics. Crosses C13 and C36 showed the highest scores among the progenies in the replicated experiments, indicating a good general performance of the plants, both in the vegetative and reproductive aspects. Several progenies had high AV mean values, which were higher in F4:3[8] than in the F5:4[8] generation. The latter showed wider AV range, which would facilitate the selection of superior progenies.

Grain yield (GY)

Among the four controls evaluated in 94/95, only UFV-4 (GY= 1,334 kg/ha) showed higher yield than the overall mean of 1,203 kg/ha (Table 1). In 95/96 the controls had a mean of 2,290 kg/ha, with only the Bossier cultivar (with GY = 1,910 kg/ha) standing below average (Table 2). The effect of the environmental factor in the growing season was evident, with the mean of controls in 95/96 surpassing the previous season by 1,274 kg/ha or 136.7%. The crosses showed an overall mean of 1,046 kg/ha in the $F_{4:3[8]}$ generation and the best performing crosses were C19 with 1,277 kg/ha, C8 with 1,227 kg/ha, C42 with 1,248 kg/ha and C20 with 1,200 kg/ha. Twenty-one crosses exceeded the overall mean. The overall $F_{5:3[8]}$ generation mean was 2,775 kg/ha and 19, 18 and 19 crosses were detected respectively in the early, intermediate and late groups, with performances superior to that (Table 2). In the sub-populations of the replicated experiment, crosses C4 with 4,063 kg/ha, C23 with 4,042 kg/ha and C31 with 3,941 kg/ha showed superior GY performance within the early group; C36 cross with 4,207 kg/ha, C31 with 3,906 kg/ha and C40 with 3,765 kg/ha were superior among the crosses within the intermediate group; C44 cross with 5,530 kg/ha, C22 with 4,349 kg/ha and C24 with 4,251 kg/ha were the ones considered superior among the late maturity group progenies (Table 2). The presence of genotypes with GY values greater than 4,000 kg/ha expressed the enormous potential of the octuple crosses for the trait yield. It also shows the importance of using large number of parents in hybridization due to the greater chances of genetic recombination, creating genetic variability also for other agronomically important traits. Table 2 shows that the best crosses had, in their composition, the hybrid combinations which were also quoted by other authors as favorable for high GY: GO 81-8.491 x Sel. BR80-15,725-B, BR-11 x FT-8, FT 81-2,129 x Cobb, Paranagoiana x Sel. Jackson-4,028, GO 81-11,094 x BR-11, OC 79-7 x BR-9 (Farias Neto; 1995); Emgopa 301 x IAC-9 (Gomes, 1995; Laínez Mejia, 1996); FT 79-3.408 x Sel.Ax53-55, BR-9 x EMGOPA 301 (Laínez_Mejia, 1996). The C24 and C44 crosses were the best performing ones in both sub-populations (Table 2). C44 was the highest

Table 3. Fourty-five octuple crosses composition. ESALQ, Piracicaba, SP, 1995.

C1	[(Andrews Púrpura x FT 81-2.706) x (Bienvile x UfV – Araguaia)] x [(P.I. 371.610 x Sel. Paraná) x (Sel. Bossier x UFV-2)]
C2	[(P.I. 371.610 x Sel. Paraná) x (Sel. Bossier x UFV-2)] x [(Kirby x FT-2) x (GO 81-8.491 x Sel. BR 8015.725-B)]
C3	[(Kirby x FT-2) x (GO 81-8.491 x Sel. BR 8015.725-B)] x [(Sel. N 82-2.764 x Sel. SOC 81-127) x (Sel. Planalto x GO 81-11.094)]
C4	[(Sel. N 82-2.764 x Sel. SOC 81-127) x (Sel. Planalto x GO 81-11.094)] x [(Wright x SOC 81-76 x (BR-11 x FT-8)]
C5	[(Wright x SOC 81-76) x (BR-11 x FT-8)] x [(Foster x FT 79-3.408) x (OC 79-7 x BR-9)]
C6	[(Foster x FT 79-3.408) x (OC 79-7 x BR-9)] x [(Sel. Ax53-55 x Paranagoiana) x (EMGOPA-301 x IAC-9)]
C7	[(Sel.Jackson 4.028 c FT 81-2.129) x (GO 79-1.030 x Sel. Cristalina)] x [(Cobb x BR –8) x (IAC-6 x UFV-4)]
C8	[(Cobb x BR-8) x (IAC-6 x UFV-4)] x [(P.I.200.521 x SOC 81-216) x (BR 80-76.309 x UFV-1)]
C9	[(P.I. 200.521 x Soc 81 -216) x (BR 80-76.309 x UFV-1)] x [(FT 81-2.706 x P.I. 371.610) x (UFV -Araguaia x Sel. Bossier)]
C10	[(FT 81-2.706 x P.I. 371.610) x (UFV -Araguaia x Sel. Bossier)] x [(Sel. Paraná x Kirby) x (UFV-2 x GO 81-8.491)]
C11	[(Sel.Paraná x Kirby) x (UFV-2 x GO 81-8.491)] x [(FT-2 x Sel. N 82-2,764) x (Sel.BR 80-15.725-B x Sel.Planalto)]
C12	[(FT-2 xSel. N 82-2.764) x (Sel. BR 80-15.725-B x Sel. Planalto)] x [(Sel. SOC 81-127 x Wright)x (GO 81-11.094 x BR-11)]
C13	[(Sel.SOC 81-127 x Wright) x (GO 81-11.094 x BR-11)] x [(SOC 81-76 x Foster) x (FT-8 c OC 79-7)]
C14	[(SOC 81-76 x Foster) x (FT-8 x OC 79-7)] x [(FT 79-3.408 x Sel. Ax53-55) x BR-9 x EMGOPA-3010]
C15	[(FT 79-3.408 x Sel, Ax53-55) x (BR-9 x EMGOPA-3010] x [(Paranagoiana x Sel. Jackson 4.028) x IAC-9 x GO 79-1.030)]
C16	[(Paranagoiana x Sel. Jackson 4.028) x (IAC-9 x GO 79-1.030)] x [(FT 81-2.129 x Cobb) x (Sel. Cristalina x IAC-6)]
C17	[(FT 81-2.129 x Coob) x (Sel. Cristalina x IAC-6)] x [(BR-8 x P.I. 200.521) x (UFV -4 x BR 80-76.309)]
C18	[(BR-8 x P.I. 200.521) x (UFV -4 x BR 80-76.309)] x [(SOC 81-216 x Andrews Púrpura) x (UFV-1 x Bienville)]
C19	[(SOC 81-216 x Adrews Púrpura) x (UFV-1 x Bienville)] x [(Andrews Púrpura x FT 81-2.706) x (Bienville x UFV-Araguaia)]
C20	[(Sel. N 82-2.764 x Sel. SOC 81-127) x (GO 81-8.491 x Sel. BR 80-15.725-B)] x [(Wright x SOC) x (Sel. Planalto x GO 81-11.094)]
C21	[)Wright x SOC) x (Sel. Planalto x GO 81-11.094)] x [(Foster x FT 79-3.408) x (BR-11 x FT-8)]
C22	[(Foster x FT 79-3.408) x (BR-11 x FT-8)] x [(Sel. Ax53-55 x Paranagoiana) x (OC 79-7 x BR-9)]
C23	[(Coob x BR-8) x (GO 79-1.030 x Sel. Cristalina)] x [(P.I. 200.521 x SOC 81-216) x (IAC-6 x UFV-4)]
C24	[(P.I. 200.521 x SOC 81 -216) x (IAC-6 x UFV-4)] x [(ET 81-2.706 x P.I. 371.610) x (BR 80 -76.309 x UFV-1)]
C25	[(FT 81-2.706 x P.I. 371.610) x (BR 80 -76.309 x UFV-1)] x [(Sel. Paraná x Kirby) x (UFV-Araguaia x Sel. Bossier)]
C26	[(Sel.Paraná x Kirby) x (UFV-Araguaia x Sel. Bossier)] x FT-2 x Sel. N 82-2.764) x (UFV-2 x GO 81-8-491)]
C27	[(FT-2 x Sel. N 82-2.764) x (UFV-2 x GO 81-8.491)] x [(Sel. SOC 81-127 x Wright) x (Sel. BR 80-15.725-B x Sel.Planalto)]
C28	[(Sel.SOC 81-127 x Wright) x (Sel. BR 80-15.725-B x Sel Planalto)] x [(SOC 81-76 x Foster) x (GO 81-11.094 x BR-11)]
C29	[(SOC 81-76 x Foster) x (GO 81-11.094 x BR-11)] x [(FT 79-3.408 x Sel. Ax53-55) (FT-8 x OC 79-7)]
C30	[(FT 79-3.408 x Sel. Ax53-55) x (FT-8 x OC 79-7)] x [(Paranagoiana x Sel Jackson-4.028) x (BR-9 x EMGOPA-301)]
C31	[(Paranagoiana x Sel Jakson-4.028) x (BR-9 x EMGOPA-301)] x [(FT 81-2.129 x Coob) x (IAC-9 x GO 79-1.030)]
C32	[(FT 81-2.129 x Coob) x (IAC-9 x GO 79-1.030)] x [(BR-8 x P.I. 200.521) x (Sel. Cristalina x IAC-6)]
C33	[(BR-8 x P.I. 200.521) x (Sel. Cristalina x IAC-6)] x [(SOC 81-216 x Andrews Púrpura) x (UFV-4 x BR 80-76.309)]
C34	[(SOC 81-216 x Andrews Púrpura) x (UFV-4 x BR 80-76.309)] x [(Andrews Púrpura x FT 81-2.706) x (UFV-1 x Bienvile)]
C35	[(Andrews Púrpura x FT 81-2.706) x (UFV-1 x Bienvile)] x [(P.I. 371.610 x Sel. Paraná) x (Bienvile x UFV-Araguaia)]
C36	[(P.I. 371.610 x Sel. Paraná) x (Bienvile x UFV-Araguaia)] x [(P.I. 200.521 x SOC 81-216) x (IAC-6 x UFV-4)]
C37	[(Sel. Paraná x Kirby) x (UFV-Araguaia x Sel. Bossier)] x [(Sel. SOC 81-127 x Wright) x (Sel. BR 80-15.725-B x Sel. Planalto)]
C38	[(FT 79-3.408 x Sel. Ax53-55) x (BR-9 x EMGOPA-301)] x [(Sel. SOC 81-127 x Wright) x (GO 81-11.094 x BR-11)]
C39	[(P.I. 200.521 x Soc 81 -216) x (BR 80-76.309 x UFV-1)] x [(FT 79-3.408 x Sel. Ax53-55) x (BR-9 x EMGOPA-301)]
C40	[(Sel. Ax53-55 x Paranagoiana) x (EMGOPA-301 x IAC-9)]x[(Sel.Jackson-4.028 x FT 81-2.129) x (GO 79-1.030 x Sel. Cristalina)]
C41	[(Sel. N 82-2.764 x Sel. SOC 81-127) x (GO 81-8.491 x Sel. BR 80-15.725-B)] x [(P.I. 200.521 x SOC 81-216) x (IAC-6 x UFV—4)]
C42	[(FT-2 x Sel. N 82-2.764) x (Sel.BR 80-15.725 x Sel. Planalto)] x [(SOC 81-76 x Foster) x (FT-8 OC 79-7)]
C43	[(Sel SOC 81-127 x Wright) x (GO 81-11.094 x BR-11) x [(Coob x BR-8) x (GO. 79-1.030 x Sel. Critalina)]
C44	[(Sel. SOC 81-127 x Wright) x (GO 81-11.094 x B R-11)] x [(Sel. Ax53-55 X Paranagoiana) x (OC 79-7 x BR-9)]
C45	[(P.I. 200.521 x SOC 81 -216) x (BR 80-76.309 x UFV-1)] x[(Sel. SOC 81-127 x Wright) x (GO 81-11.094 x BR-11)]

yielding cross due to the high genetic potential of the parents involved in its composition and of the probable high genetic combining ability among them, allowing the derived progeny to break the 5,500 kg/ha yield barrier. Presently, only the elite cultivars, belonging to a new generation of lines with very high yield, have similar agronomic performances. They are recommended for sowing in growing regions without any limiting environmental factor such as the Central West of Brazil, where favorable environmental conditions allow the expression of maximum genetic potential of this trait. The C44 cross is a combination among the biparental hybrids: Sel.Ax5355 x Pananagoiana, reported as superior in other studies (Farias Neto, 1995, Laínez-Mejia, 1996), GO 81-11,094 x BR-11 and OC-79-7 x BR-9 (Farias Neto, 1995). C24 has the IAC-6 and UFV-4 cultivars in its genealogy. IAC-6 was reported as outstanding in terms of grain yield (Gomes, 1995) and UFV-4 was the highest yielding control in the 94/95 and 95/96 seasons, which is a similar result to that obtained by Laínez-Mejia (1996). The hybrid combination IAC-6 x UFV-4 was also depicted as high yielding in reports of Farias Neto (1995) and Laínez-Mejia (1996). Similarly, the BR80-76.309 x UFV-1 hybrid also stood out as one of the highest yielding hybrid combinations in studies of Laínez Mejia (1996). From Table 2 it can be observed that the late sub-population showed the highest GY mean among the sub populations (3,078 kg/ha) and the greater number of crosses with GY values superior to the overall mean. The intermediate sub-population GY value was 2,673 kg/ha and the early one was 2,579 kg/ha. Such performance showed the high potential of the late progenies, confirming results obtained by other authors (Dutra et al., 1996; Farias Neto, 1995; Gomes, 1995; Laínez-Mejia, 1996). The efficiency of the selection in the $F_{4:3[8]}$ generation also became evident, with the screening of the progeny according to cycles, in early, intermediary and late sub-populations. Besides both C24 and C44 crosses, which were superior for their high GY values, nine other crosses showed GY means greater than 3,000 kg/ha, widely surpassing the means of the controls in the 1994/95 and 1995/96 agricultural seasons (1,203 and 2,290 kg/ha, respectively). Taking only the UFV-4 cultivar with the GY value of 3,763 kg/ha in 1995/96 as a reference, C4, C22, C23 , C24, C36 and C44 crosses were still superior, as they presented GY values above 4,000 kg/ha (Table 2). The high genetic potential of the progenies of the quoted crosses is evident, showing promising perspectives of these genetic materials in obtaining superior cultivars. This confirms the wide genetic variability for the trait among the octuple crosses that combine adapted and exotic parents. The results in this study allowed us to reach the following considerations: 1. Octuple crosses combining adapted x adapted and adapted x exotic parents allowed superior progeny to be obtained for all the studied traits, especially GY. The C44 cross stood out with the excellent yield mean of 5,530kg/ha; 2. The superior hybrid biparental combinations for GY reported by other authors were also present in the best octuple crosses, like BR-11 x FT-8 in the C4 and C22 crosses and IAC-6 x UFV-4 in the C23 and C24 crosses and 3. The remnant genetic variability detected within the selected progenies of some crosses allows the inference that further gains are still possible through selection in later generations.

RESUMO

ANÁLISE GENÉTICA DE CARACTERES AGRONÔMICOS NAS GERAÇÕES $F_{4:3[8]}$ E $F_{5:3[8]}$ DE CRUZAMENTOS ÓCTUPLOS DE SOJA

A utilização de germoplasma exótico é uma estratégia para aumentar a base genética dos cultivares de soja, a qual constitui a principal limitação nos programas de melhoramento de soja que utilizam cruzamentos entre duas linhagens puras homozigotas. Este estudo teve o objetivo de avaliar 45 cruzamentos óctuplos de soja, em cadeia, na geração $F_{5:3[8],}$ visando a seleção de progênies superiores quanto à produtividade de grãos e outros caracteres de importância agronômica. Os cruzamentos óctuplos foram sintetizados, cruzando-se parentais adaptados x exóticos, em um sistema de cadeia, durante três gerações, até a obtenção de cruzamentos óctuplos tendo 75% genes adaptados e 25% de genes exóticos, em um grupo; e hibridações de parentais adaptados x adaptados, em cadeia que originaram cruzamentos óctuplos tendo 100% de genes adaptados. No ano agrícola 1994/95 foram avaliadas as progênies $F_{4:3[8],}$ onde foi empregado o delineamento em blocos aumentados. No ano seguinte, as progênies $F_{5:3[8]}$ foram conduzidas em seis experimentos, sendo três delineados em blocos aumentados (sem repetições), e outros três experimentos em delineamento de blocos ao acaso com duas ou três repetições. As análises dos resultados revelaram que cruzamentos óctuplos, originaram progênies superiores para todos os caracteres estudados, notadamente em produtividade

de grãos, com uma produtividade média de 5.530 kg/ha. A existência de variabilidade genética remanescente entre progênies selecionadas de alguns cruzamentos permite antever a possibilidade de se obter ganhos adicionais em ciclos mais avançados de seleção para produtividade de grãos.

REFERENCES

Brim,C.A. and Young, M.F. 1971. Inheritance of a male sterile character in soybeans. Crop Science. 11(4):564-566.

Brim, C. A and Stuber, C. W. 1973. Application of genetic male sterility to recurrent selection systems in soybean. Crop Science. 13(5):528-530.

Dutra, J.H.; Sediyama, T. and Hamawaki, O. T. 1996. Estabilidade e adaptabilidade de 15 genótipos de soja em função de 19 épocas de plantio, no Triângulo Mineiro. R. Cent. Ci. Bioméd. Univ. Fed. Uberlândia. 12(1):3-12.

Duvick, D.N. 1966. Influence of morphology and sterility on breeding methodology. In: Frey, K. J. (Ed.). Plant Breeding. Ames, Iowa.

Embrapa. 1998. Recomendações técnicas para a cultura da soja na região Central do Brasil, 1998/99. Documentos,106. Embrapa-Soja, Londrina.

Farias Neto, J. T. de. 1995. Potencialidade de progênies $F_{4:3}$ e $F_{5:4}$ derivadas de cruzamentos em cadeia para produtividade de óleo em soja. M. S. Thesis. Escola Superior de Agricultura "Luiz de Queiróz", USP. Piracicaba.

Federer, W. T. 1956. Augmented (or hoonuiaku) designs. Hawaiian Planter's Record, 55:191-208.

Fehr, W. R.; Caviness, C. E. and Pennington, J. S. 1971. Stages of development descriptions for soybeans (Glycine max (L.) Merrill). Crop Science. 11(6):929-931.

Fehr, W.R. and Weber, C.R. 1968. Mass selection by seed size and specific gravity in soybean populations. Crop Science. 8(5):551-554.

Gomes, R. L. F. 1995. Análise genética de progênies F_6 e $F_{7:6}$ de soja obtidas de cruzamentos dialélicos. M. S. Thesis. Escola Superior de Agricultura "Luiz de Queiróz", USP, Piracicaba.

Hanson, W. D.; Probst, A H. and Caldwell, B. E. 1967. Evaluation of a population of soybean genotypes with implications for improving self-pollinated crops. Crop Science. 7(2):99-103.

Hiromoto, D. M. and Vello, N. A 1986. The genetic base of brazilian soybean (Glycine max (L.) Merrill) cultivars. Revista Brasileira de Genética. 9(2):295-306.

Hymowitz,T. 1970. On the domestication of soybean. Economic Botany. 24:408-421.

Ininda, J.; Fher, W.R.; Cianzio, S.R. and Schnebly, S.R. 1996. Genetic gain in soybean population with different percentagens of plant introductions parentage. Crop Science. 36(6):1470-1472.

Lainez-Mejia, J.R. 1996. Implicações da interação genótipo x ambientes na seleção de progênies de soja com ênfase nas produtividades de grãos e óleo. M.S. Thesis. Escola Superior de Agricultura "Luiz de Queiróz", USP, Piracicaba.

Lopes, A. C. A. 1997. Potencialidade de cruzamentos óctuplos de soja com ênfase na produtividade de grãos. M. S. Diss. Escola Superior de Agricultura "Luiz de Queiroz", USP, Piracicaba.

SAS Institute. 1987. SAS/STAT guide for personal computers. version 6 ed. SAS Institute, Cary, NY.

Vello, N.A. 1985. Efeitos da introdução de germoplasma exótico sobre a produtividade e relações com a base genética das cultivares de soja [Glycine max (L.) Merrill]. M. S. Thesis. Escola Superior de Agricultura "Luiz de Queiroz", USP, Piracicaba.

Vello, N.A 1992. Ampliação da base genética do germplasma e melhoramento de soja na ESALQ/USP. p.60-81. In: Câmara, G.M.S.; Marcos Filho, J. and Oliveira, E.A M., (Ed.). Simpósio sobre Cultura e Produtividade da Soja, Piracicaba, 1992.

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