BREEDING SOYBEANS TO THE LOW LATITUDES OF BRAZILIAN CERRADOS (SAVANNAHS)[1]

CARLOS ROBERTO SPEHAR[2]

ABSTRACT - The breeding of soybeans is among the great contributions of research to expand agriculture in the low latitudes of the Brazilian Cerrados (Savannahs). The main factor that prevented their incorporation into farming was the predominantly Al-rich low fertile soils. Soil improvement techniques were developed, but there was a virtual lack of adapted varieties. The progress in soybean breeding has led this low latitude region to contribute with more than 40% of the national production, pioneering modern large scale soybean cultivation. 'FT-Cristalina', 'Doko', 'EMGOPA-301', 'Numbaira', 'BR-9 (Savana)', 'BR-15 (Mato Grosso)' and 'BR-40 (Itiquira)' are examples of varieties selected to suit the farming systems. The programme has been carried on to select genotypes for high yield and good seed quality; first pod and plant heights suitable to combine harvest; different maturity groupings to allow sowing and harvest planning to minimize field grain and seed loss; tolerance to aluminium and efficient nutrient utilization; resistance to potential epidemic diseases; resistance to insects; and adaptability to farming systems. The breeding methods and their improvement to enhance efficiency in the acquisition of cultivars are presented.

Index terms: Glycine max, variety, selection, productivity, adaptation, stability, efficiency,

MELHORAMENTO DA SOJA PARA AS BAIXAS LATITUDES DOS CERRADOS

RESUMO - O melhoramento genético da soja representa uma das grandes contribuições da pesquisa para a expansão da agricultura nas baixas latitudes dos Cerrados. O maior fator limitante que impedia sua incorporação ao cultivo era a predominância de solos ácidos, ricos em alumínio e de baixa fertilidade. Desenvolveram-se técnicas para a elevação da sua fertilidade, mas não havia variedades adaptadas. O progresso no melhoramento permitiu que esta região passasse a contribuir com mais de 40% da produção nacional, com cultivo moderno e em larga escala, pioneiro nessas regiões do mundo. 'FT-Cristalina', 'Doko', 'EMGOPA-301', 'Numbaira', 'BR-9 (Savana)', 'BR-15 (Mato Grosso)' e 'BR-40 (Itiquira)' são exemplos de variedades para os sistemas de produção regionais. O programa tem continuado para selecionar genótipos com elevada produtividade e qualidade de sementes; altura de planta e de inserção de primeira vagem satisfatórias à colheita mecanizada; maturação diferenciada para permitir o planejamento de semeadura e de colheita e diminuição das perdas de grãos e de sementes; tolerância ao alumínio e eficiência na utilização de nutrientes; resistência às doenças com potencial epidêmico, resistência a insetos e adaptabilidade aos diferentes sistemas de produção. Os metodos de melhoramento são apresentados com a possibilidade de aperfeiçoá-los para aumentar a eficiência na obtenção de novas cultivares.

Index terms: Glycine max, variedade, seleção, produtividade, adaptação, estabilidade, eficiência.

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[1]Accepted for publication on February 18, 1994.

[2]Eng. - Agr., Ph.D., EMBRAPA-Centro de Pesquisa Agropecuária dos Cerrados (CPAC), Caixa Postal 08223, CEP 73301-970 Planaltina, DF, Brazil.

INTRODUCTION

The breeding of soybeans [*Glycine max* (L.) Merrill] has been of paramount importance in the sustainable occupation of the Brazilian Cerrados (a Savannah-like environment). They cover a vast area of two million sq. km. which corresponds to one-fourth of the country's territory. The basic factor to expand its cultivation to the low-latitude savannah of Brazil was the enhancement of existing breeding programme by the creation of the Brazilian Organization for Agricultural Development (EMBRAPA) in the early 1970's. The main factors that prevented its cultivation were the low soil fertility and day-length response (Spehar et al., 1993).

Cultivated soybeans originated from China, probably Manchuria, from where it has dispersed to other parts of Asia since thousands of years. The region of origin is located in the temperate zone, with continental climate characterized by cold winters and hot summers with relatively frequent dry spells (Bonetti, 1981; Mota, 1981). It is a short day plant, i.e., the onset of flowering is determined by the shortening of days in the Summer, maturing in the Autumn. Comparatively, the amount and distribution of rainfall in the Cerrados were not limiting to soybean growth and the low soil fertility could be overcome by appropriate use of amendments. Thus, it was necessary to search for late flowering genes in tropical germplasm, among other characters, that allowed sufficient plant growth before flowering. The regional breeding programme to adapt the crop to low latitude environments has been carried out since the 1970's and comprises the methods of hybridisation, natural crosses and mutations to obtain new genotypes.

Hybridisation

The hybridisations were made among varieties adapted to the high latitudes and those from the tropics, which are the sources of genes for lateness. The initial basis for crosses that segregated late types were the genotypes 'PI 240-664' from the Philippines, extensively utilized, 'Santa Maria' and 'IAC 73-2736', a mutant found in 'Hardee'. From the 1980's, the mutants 'Paranagoiana' and 'PR 77-10001', also from Brazil were incorporated to the programme. All of these showed the late flowering character in low latitudes (Kiihl & Garcia, 1989). However, they presented some limiting factors such as low yield, lodging and pod shattering, which needed to be screened out from hybrid populations.

By this crossing scheme, Jupiter, a late flowering variety in Southern Florida, originated from the American programme (Hinson, 1972). The Brazilian programme to select late types originated the IAC lines, obtained at the Campinas Agricultural Institute. This consisted of the first selection cycle to obtain late soybeans that grew sufficiently for combine harvest in the tropics.

These genotypes were not yet desirable due to their low yielding ability and were disease susceptible. Thus, there was a need to repeat the cycle of crossing and selection, using the already improved material from the first cycle. Late flowering lines were then crossed to high yielding varieties from the temperate zone of the world to obtain high yielding soybeans. The further breeding work at the national level was carried out mainly by the National Soybean Research Centre, whereas selection and testing in the low latitude Cerrados was carried out by the Cerrados National Research Centre (CPAC), both of EMBRAPA.

The success in selecting high yielding and stable cultivars of this breeding programme was based on the growing interchange among research Centres, State research enterprises and other members of the research cooperative system, under the leadership of EMBRAPA. In the establishment of uniform trials, differences on day-length, soil and climate were considered, given the vastness of the region. Thus, with a network of experiments in a range of environments, the release of new cultivars was followed by practical recommendations to the farmers of growing conditions under which they were selected.

A very important factor that enhanced the speed at which new cultivars were acquired has been the possibility of advancing more than one generation per year in the Brazilian Cerrados. This region does not present any problem with frost bite that could damage the plants and restrict the work. With at least two cycles, one in the Summer and the other in the Winter, the time with which new lines were ready for uniform trials was shortened and the farmers benefited by the new releases reaching them more quickly.

As a result of this integrated programme, cultivar Doko was released in 1980 (Almeida et al., 1982). It was obtained from a population originated from crosses among American varieties and Brazilian late flowering lines. This cultivar presented suitable plant height in both winter and summer sowings and this was an advantage for seed production. Two years after its release it was already available to the farmers. The starting point to expand commercial cultivation of soybeans throughout the year in the low latitude savannahs was the generation advance from the breeding programme. This allowed to conclude that selected lines grown in the dry season (Winter) grew enough for combine harvest under short days. Besides cultivar Doko others were released using the same breeding strategy 'Numbaira', 'BR-9 (Savana)', 'BR-15 (Mato Grosso)' 'EMGOPA 301', 'EMGOPA 302',' EMGOPA 304' 'MSBR-17 (São Gabriel)', 'FT-11', 'FT-Estrela,' 'FT-Seriema' and 'BR-40 (Itiquira)' (Kiihl et al., 1982; Souza et al., 1984; Costa et al., 1989; FT-Pesquisa e Sementes, 1990; Zuffo et al., 1990; Souza et al., 1993). The breeding methods employed in their acquisition were mass selection, pedigree and modified pedigree.

The more recent phase of hybridisation came about as a consequence of soybean crop expansion. This happened at a great speed and pests and diseases which were not very serious became a treat to challenge breeders. At this point the private sector started contributing with new high yielding varieties. Another problem which has required attention is related to low seed quality in most producing areas in the Cerrados, notably the low lands, where high moisture and temperature favour deterioration of seeds. Of high priority in the full adaptation of soybeans is also the need to select genotypes which are aluminium tolerant and efficient in nutrient utilization, insect resistant and adaptable to the different production systems of the Cerrados.

The third selection cycle to fully adapt the soybeans to cultivation in the Brazilian via hybridisation shows the same characteristics of the breeding programmes for the traditional temperate and major producing zone of the world. It is directed to solving specific problems that resulted from the expansion of its cultivation. In the cases of monogenic inheritance such as frog eye leaf spot (*Cercospora sojina*), the back cross method has been used. When the character is polygenic and the source is in the wild form, a recurrent scheme is employed to transfer the desirable genes and at the same time get rid of the undesirable, similarly to what has been made at first to adapt the soybeans to low latitudes. Modifications have been introduced to avoid transferring undesirable genes, i.e., the use of multiple crosses that are backcrossed a few times to the agronomically adapted parents. Diallel crosses have also been used to identify the parental combinations that yield superior lines. However, when wild types or varieties adapted to very different environments are used the chances of obtaining superior families are likewise reduced (Spehar, 1989).

The aim of hybridisation at this phase is to obtain cultivars with high yielding ability, disease and pest resistance aluminium tolerance and nutrient utilization efficiency, good seed quality, different vegetative and reproductive cycles to adjust and promote the crop for definite participation in the regional production systems, emphasizing the sustainability of exploitation.

Natural crosses

The rate of natural crosses is very low and rarely goes beyond 1%, depending on environmental factors, insects, coincidence of flowering and distance among plants of different varieties (Andrade et al., 1973). However, due to the extensive cultivation in the Cerrados, hybrid plants from natural crosses have been recovered with relatively high frequency, mainly the ones which are easily detected by the phenotype such as maturity. The most important example of cultivar obtained by this method of breeding is FT-Cristalina. It originated probably from the cross between 'UFV-1' and 'Davis'. It is a transgressive segregant since both parents have a shorter cycle than this cultivar. Another example is of 'EMGOPA 306' which possibly originated from the a natural cross between 'FT-Cristalina' and 'EMGOPA 301'. Once the natural hybrid is recovered, the handling of segregating population follows the same steps mentioned for hybridisation.

Mutations

The frequency of natural mutation in higher plants is very low and estimated at a rate of one individual in one million (Rothwell, 1983). Considering that not all mutants will express themselves in the phenotype, the occurrence of mutants becomes a very rare event. However, due to the vastness of soybean fields, it has been possible to recover mutants, notably the ones for late maturity. The oldest example of cultivar selected by this method is 'UFV-1', a 'Viçoja' mutant for lateness. Later there came other mutants such as 'Paranagoiana', likewise a 'Paraná' mutant with late cycle. The recovery of mutants of soybean field in the Cerrados has been possible because both vegetative and reproductive cycles are controlled by few genes which will show in the phenotype. The plants carrying genes for lateness will be easily distinguished in the field at harvest time. Mutants such as these are advantageous to originate new varieties because the basic agronomic features are maintained or there is no disruption of favourable gene combinations accumulated in the traditionally cultivated varieties.

PROGRESS IN EXPERIMENTATION

The success of a breeding programme depends directly on the efficiency of experimentation. Just to exercise, when the programme aims to select for high yielding, different plant cycles, good seed quality and tolerance to aluminium, with ten different crosses being made for each case to increase the probability of selecting a desirable genotype, it is not unusual to end up in large numbers of hybrids, among which the desirable types will be selected.

To solve the problems of handling great numbers of segregating populations in the present stage of soybean breeding to the cerrados, changes in the traditional methods have been proposed, based on experience and accumulated information in the literature. The adaptation which has become popular is the use of modified pedigree method also known by **single seed descent**. It consists of giving to all individuals the opportunity of contributing progeny to next generation by the means of collecting one pod per plant at harvest to make a bulk. The inferior types will be discarded. This method was originally suggested by Brim (1973) for soybean breeding on the basis that in self-pollinating species the gene effect for yield and other quantitative traits is predominantly additive. The lines are drawn from the population only in the F_4 or F_5 generations, when most gene combinations will be at the homozygous stage and variability within plants in the F_2 will be among lines in advanced generation. As there is no selection involved, more than one generation per year can be used and rapidly that stage will be reached. By using this method time and costs will be saved for the same probability of acquiring superior genotypes as in the traditional pedigree method. The regional breeding programmes have employed the single seed method to select high yielding genotypes.

The next step in the experimentation consists of yield tests. The breeding lines will be grown on single row four metres long plots. The blocks will contain standard cultivars at regular intervals, with which the lines will be compared. The grouping is made taking into account the differences in plant cycle, the closest possible to the standard cultivars. At this stage additional evaluation on lodging, pest and disease reactions, pod shattering will be made. Only the ones which are superior for these characters and that are better performers than the standards will further proceed in the tests, on four row plots. The augmented design experiment has been employed for statistical comparison of entries, as a modification to this procedure (Spehar, 1989). This method adapted from Federer (1961), consists of repeating the standard varieties in blocks as many as needed to accommodate the breeding lines to be selected. These are placed on the gaps originated by enlarging the blocks and are repeated only once across the experiment. This method enhances efficiency in selection because it allows to eliminate block effect as measured by the standard varieties. The local variation in terrain will not be confounded to the genetic potential of the breeding lines and thus increases the chances of selecting desirable genotypes. Other methods of reducing these confounding effects on preliminary evaluations of breeding lines have been described (Vivaldi, 1990) and might be as efficient as the augmented design experiment.

The preliminary and intermediary tests with the previously selected lines have used the randomized complete block design with three replicates. The latter have been repeated in more that one location, depending on the seeds availability. The lines are grouped into early medium and late cycles, for which the corresponding standard cultivars are used. It is interesting to add that the Cerrado Region, due to its vastness, is divided into two for this integrated breeding programme: one for locations superior and the other inferior to 15° South. This is due to the great differences in plant cycles of the material selected in the South of the Region when transferred to areas near the Equator line.

The second step is characterized by joint planning of experiments involving all the public and private breeding institutions in the Cerrado Region. This intermediate testing consists of trials with all superior lines from each organization and the numbers of entries shared are proportional to the respective testing ability. These have been repeated in at least three locations and each organization will be in charge of supplying seeds of their respective lines to the joint trials. The evaluations have been carried out by the participants and pulled statistical analyses of data is performed. The superior lines at this stage are included in the uniform trials which are repeated in and increased number of locations, within each of the two zones, according to the latitude above described. Two years after being tested in the uniform trials, the superior lines are officially released and recommended as new cultivars in the Soybean Research Planning Annual Meeting, co-ordinated by the National Soybean Research Centre. It is worth adding that once the line integrates the uniform trial the production of genetic seeds is automatically started, irrespective of its release, by the corresponding breeding institution. Progenies of randomly chosen single plants are first grown in single lines. The off-types are roughed out and homogeneous lines are harvested separately for plot growth in the next generation and only the homogeneous for the genetic descriptors are bulked to make the genetic seeds. With the possibility of growing more than two generations per year, the further steps of foundation and certified seeds are quickly reached. This has been successfully made to anticipate its availability to the farmers by the time of its release.

PROSPECT FOR IMPROVING THE BREEDING PROGRAMME

It was already shown the logical sequence that precedes the acquisition of a new cultivar to the low latitudes of the Cerrados. Obviously, when a character to be selected is multigenic, e.g., grain yield, it is necessary to evaluate its stability which, in the present programme, has been assessed through variety trials over locations and years, also a common routine in the traditional zone of cultivation. Stability of a character can be defined by expression repeatedly over a range of environments. Techniques to evaluate stability for agronomic characters have been improved in more traditional zones of cultivation. In this section it will discussed on how to adapt and improve the efficiency of selections in the generations falling between hybridisation and the release of a new cultivar. This will ensue opportunity to further reduce the costs to obtain superior and stable cultivars, in relation to the methods presently being employed.

It is important to emphasize that before the genes from wild types be transferred to cultivated forms, the crosses using a recurrent scheme be carried out in a research institute where a team of breeders work together. In Brazil the National Soybean Research Centre this is practiced, where active germplasm banks are kept. In a likewise procedure described for the adaptation of soybeans to the low latitudes, these new recurred lines with good agronomic character but in need of further improvement, will be the source for additional cycles of crossings and selection. They shall be available to public and private institutions interested in breeding soybeans, by the means of appropriate agreement.

It has been a common practice in the last ten years to manipulate the hybrids by advancing generations via **single seed descent** method before new lines are drawn for testing. The predictability of success of a cross to generate high yielding lines has not yet being considered, except for the chance provided by the superiority of parental varieties employed in crosses. Productivity is a functions of several genes and, thus, of complex inheritance. This is to say that not always adapted and superior genotypes being used as parents will generate superior offspring, even though the gene effects are predominantly additive in self-pollinating plants. Even though this mostly explains the high general combining ability for a trait such as yield, the possible explanation for obtaining specific desirable combinations is that the favourable genes, accumulated along several selection cycles practiced by man during crop domestication and in modern times, may be linked together. With the possibility of crossing over to occur, the favourable combinations will be broken and the offspring will not carry the best combination in one individual. It is then necessary to evaluate the potential of hybrids to generate superior individuals. Proposals have been formulated to enhance efficiency of breeding programmes by early generation testing among them are the ones described by Cooper (1990) and by Toledo (1989). The early evaluation allows to predict the probability of generating superior cultivars before great numbers of lines are drawn and tested and contributes to reduce costs.

In the present work modifications of these methods are suggested as follows:

. After hybridisation, the F_1's will be advanced into F_2's by growing the hybrid plants under artificially prolonged days to control flowering. This allows a great productions of seeds for laboratory screening. A clonal propagation of hybrids may be used to obtain large numbers of seeds. The methodology for cloning F_1 soybean hybrids has already been described by Spehar and Galwey (1990), although considering the probable heterozygous residue, if parents have been selected at the F_4 or F_5 generation, it is suggested that at least two hybrids with random plants be made. These will originate the mother plants from which clones are derived. At this point the F_2 individuals will be screened in laboratory for aluminium tolerance, nutrient efficiency, disease reaction, seed quality and other characters that can be evaluated at the seedling stage by non--destructive methods. The superior for these characters will be transplanted to generate the seeds of F_3 generation. These will be sown in the field, on hill plots, for yield evaluation. At physiological maturity one pod per plant will be harvested and grouped for maturity to make the F_4 generation. The potential of crosses to generate high yielding lines will be evaluated and the inferior will be discarded. The restriction to this yield evaluation on hill plots is when the parental varieties are of a wide range of maturity groups, thus causing experimental error by random plants of different maturity groups in the hills.

. In the F_4 generation, from the selected crosses, individual plants may be selected from the maturity groups for the preliminary tests, or advanced into the F_5 by single seed descent and then tested. The lines, will be tested on randomized complete blocks in hill plots. The use of hill plots to replace the traditionally used row plots is another modification suggested to introduce in the preliminary testing to allow appropriate assessment of genotype x environment interaction with reduced costs. Results obtained elsewhere point out to advantageous use of hills over rows being equally efficient in selecting superior genotypes (Garland & Fehr, 1981; Spehar, 1989). Its use will help overcoming the scarcity of seeds at an early assessment of yield stability by repeating the experiment in more than one location as early as in the F_4 or F_5. Hill plots are easy and quick to sow and because they use less labour and reduced area will allow increasing the number of experiments with new breeding lines. These trials can be repeated over location and time and may include one generation advance in the winter for increasing the seed supply for the tests.

The uniform variety trials are maintained on row plots over locations for two years or two sowing dates in the same year. The alternative to repeat the experiment in sowing dates in the same year, has been suggested by Arantes et al. (1982), who obtained high heritability values, comparable to repeating the experiment over year. However, it is advisable that, before replacing year by sowing date, sowing date experiments be conducted and analyzed to chose the most contrasting dates that most simulate year effect. From the intermediate testing the superior genotypes may be included in the crossing scheme to initiate a new cycle of selection.

The above described scheme is presented in Fig.1 The techniques referred here to enhance efficiency have already been employed isolately in breeding programmes by breeders in many institutions. The conjugation of their use has been presented to simplify some of the most laborious steps in the acquisition of soybean cultivars. The amount of investment required has greatly prevented the expansion of existing breeding programmes and the initiation of new ones to adapt the crop into other specific environments. These modifications have primarily been suggested to be used in the soybean breeding for the Cerrados, even though the conjugated method shall be equally effective in breeding of other self--pollinating species to different environments, e.g., common beans and other legumes, small grains, horticulture and forage crops among others. In each case the method shall be worked out, adjusting to the specific problems and needs.

IMPACTS OF NEW CULTIVARS AND RESEARCH FUNDING

The maintenance and additional investment on research are necessary to carry on the programme to further adapt the soybeans to economical cultivation in the Cerrados, even though the recent trend point out to reduced funding in the public institutions. The results of the co-operative programme are more than sufficient to justify the need to revert this trend. In a comparison of germplasm introduced prior to the great expansion and the ones selected for the low latitudes, it becomes obvious the superiority of the latter concerning grain yield, plant height and maturity groupings (Spehar et al., 1993). Moreover, it is interesting to point out that the adaptation of the crop to modern production in the tropics is an achievement unique in the world and this was done basically with technology developed by the public sector. The crop evolution in Goiás State, fully located in the Cerrados, illustrates this progress. The acreage, production and productivity are presented in Fig. 2. It can be observed that the expansion in the last twenty years coincides with the acquisition of new adapted cultivars which respond for a great proportion of high average yields, comparable and ever superior to obtained in the traditional

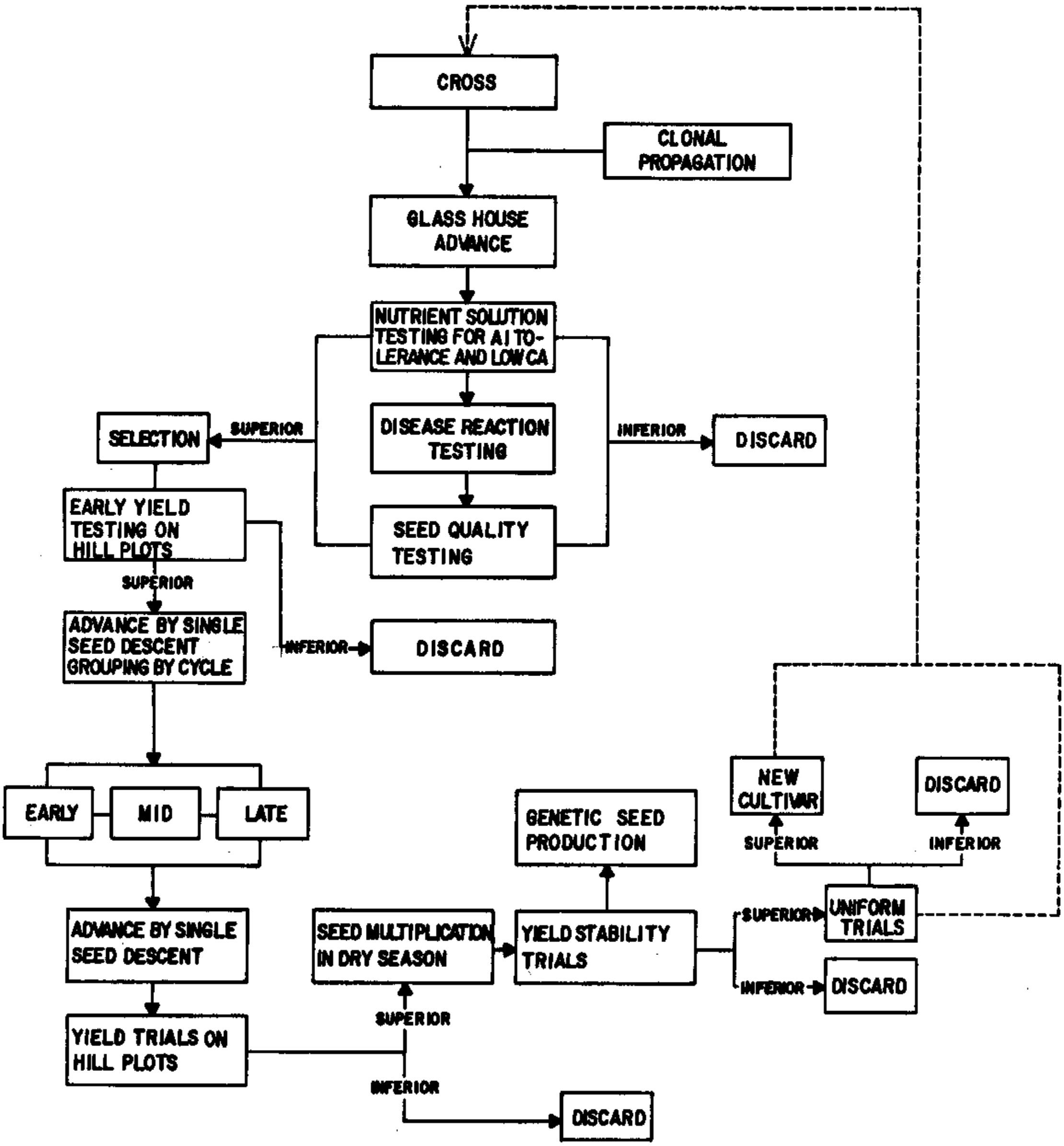

FIG. 1. Proposed breeding scheme to enhance efficiency in the acquisition of new soybean cultivars.

high latitude of soybean cultivation. Earlier work pointed out to the comparative advantage of variety substitution (Crocomo & Spehar, 1981). When potential yield gains are considered in comparison of less adapted introduced cultivars to the locally selected ones the regional economy experiences an increase in profit to the order of hundreds of millions of dollars (Spehar et al., 1993). This figure takes into account only the higher yielding ability of adapted cultivars. When other suitable agronomic

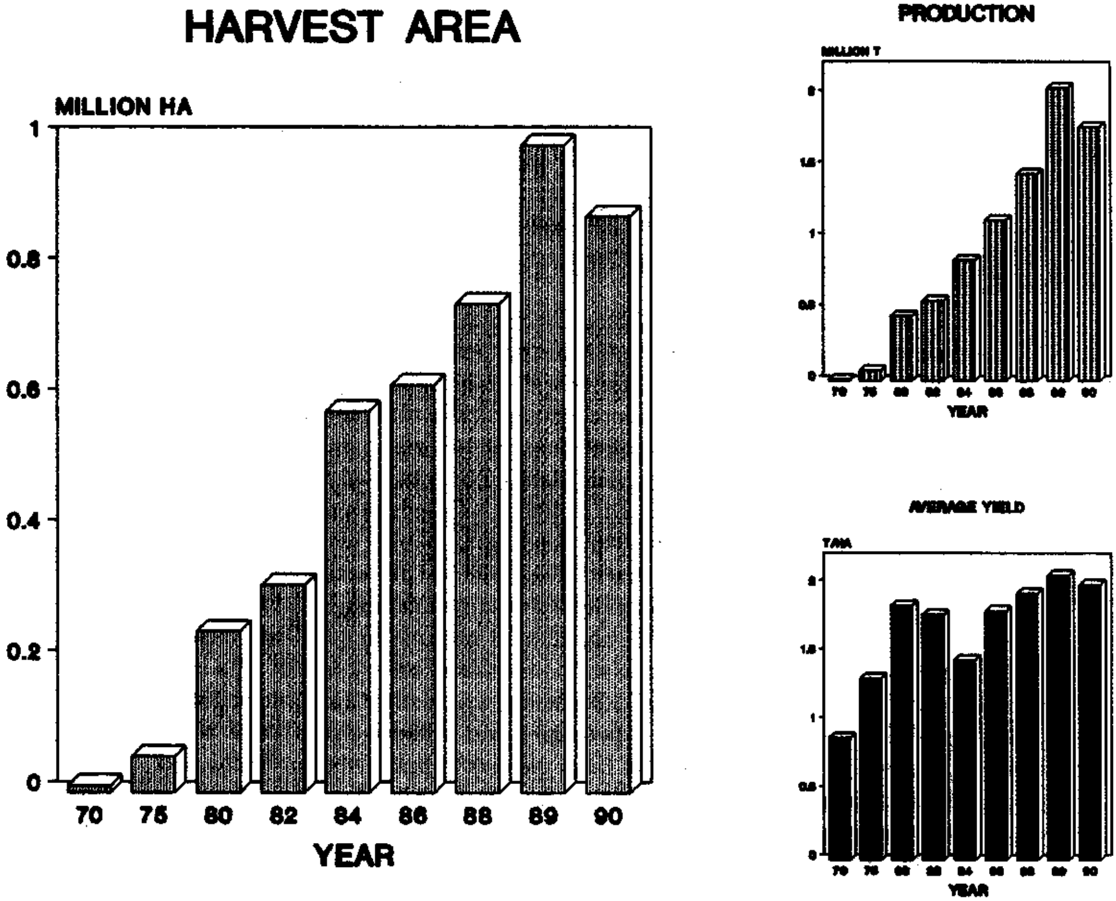

FIG. 2. Soybean crop evolution in Goiás State, in the Cerrado Region, from 1970.

characters also present in the cultivars are considered, e.g., adequate plant and first pod heights, diversity of maturity groupings to suit planning of sowing and harvest, disease and pest resistance, the advantages are of even greater magnitude, reaching the one-billion dollar mark at the present stage of soybean exploitation in the Brazilian Savannahs.

It is important that research planning to meet the future needs be made. Without further breeding contributions, such as the ones reported here, to turn the low latitude savannah environment into a major world soybean producer, there will be serious threat, posed by new problems, to the prospects of further developing and maintaining a sustainable system. Obviously, most problems related to environment aggression, with serious consequences to mankind, are direct or indirectly related to sustainability of agricultural systems, i.e., with additional costs on crop protection if cultivars are susceptible to new diseases and pests, farmers may sacrifice soil conservation to keep the expected profit level. This contingent rearrangement of production costs will bring about serious problems of soil loss and, consequently, reduced production in the long run, turning farming inviable. The private sector will have a role to play in the new order by investing in breeding to meet specific needs that the public enterprise can not cope with. It is expected that through biotechnological means desirable genes from other species will be transferred to the soybeans to enhance its use as food and in the industry. However, there is a need to define the basis for breeders rights which attracts investments and at the same time preserves the free access to germplasm for scientific purposes.

With increasing investment from the private sector it will be possible to establish agreement with the public institutions such that financial support will be given to the maintenance of a basic breeding programme of gene transfer from less adapted to more agronomically suitable germplasm. The private sector may be concentrated in the advanced cycles of varietal selection, contribute to assess yield stability by increased testing and seed production of jointly released cultivars. Co-operatives and farmers associations may participate with funding to public research and seed production of released cultivars. This will be of mutual benefit and contribute to generating better cultivars to suit the farming systems.

It is not always possible in agricultural research to conciliate income with priorities. Thus, the public sector must carry on research of long term revenue by investigating basic problems which offer little attractive to private enterprises. This is a necessary cost without which there is no progress. In a great majority of cases the cost of basic breeding is covered by the social progress promoted by the use of technology that increases farmers income and consequently tax collection, with extended benefits to all the industry associated to the production chain. In addition, the public sector shall carry on its regulatory action in the release of new cultivars such that they be superior and cost effective to promote the standards of farming and society as a whole through production efficiency.

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