State of the Art - Developing Grain Cultivars for Acid Savannas of Brazil

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INTRODUCTION

Brazil is a large country of approximately 8,500,000 square kilometers, with abundant water resources, both tropical and subtropical climates and a vast vegetative cover. A site of megabiodiversity, Brazil has a diverse and rich vegetation pattern divided into six ecological regions: the Amazon Forest in the North, the Savannas of Central Brazil, the semi-arid Caatinga in the Northeast, the Atlantic Forest along the coast, the Southern Grasslands and Forests, and the Pantanal, an extensive marsh land located in the western part of the country in the state of Mato Grosso (Figure 1).

The Brazilian Savanna, also known as the cerrado, covers an area of 205 million hectares, with 175 million hectares located in the central plateau, covering the states of Mato Grosso, Mato Grosso do Sul, Tocantins and Goiás and part of the states of Minas Gerais, São Paulo, Bahia and Piauí, between latitudes 6°S and 20°S and longitudes 42°W and 60°W. The cerrado area constitutes about 25% of the Brazilian territory (Figure 1). The region is a complex mosaic of grasslands, savanna, riparian palm communities and gallery forests (known as "veredas") (Figure 2). Cerrado, meaning "closed" or "dense" in Portuguese, has a well diversified prevailing tropical climate with well defined wet and dry seasons. The average annual temperature is 21°C and the rainfall varies from 900 to 1800 mm. The region has a five to seven month rainy season occurring between October and April, abundant sunlight and sufficient moisture and temperature levels for crop exploitation. The area possesses complex hydrological systems with a large number of streams and rivers and abundant underground water sources. (Santana and Bahia Filho 1998).

The vegetation of the cerrado is characteristically composed of medium height trees with thick bark and twisted branches, coriaceous leaves and usually deep roots. Depending on the density, the vegetation is classified as "campo cerrado", clear fields lacking woody vegetation, where native grasses and small bushes prevail; typical cerrado with native grasses, bushes and twisted trees of 2 to 4 meters high (Figure 2), and "cerradão", which are dense arboreal formations that resemble a forest. (Santana et al 1998). Several scientists emphasize that the cerrado's biodiversity is equal or even superior to that found in the Amazon basin.

Figure 1. The main ecological regions of Brazil: AM - the Amazon Forest, CE — the Cerrado (savannas) of Central Brazil, SA - the semi-arid Caatinga of the Northeast, AF - the Atlantic Forest, a thin strip along the coast, the SG - Southern Grasslands and Forests and PT - Pantanal of Mato Grosso, an extensive marsh land. The Cerrado area (CE) alone corresponds to 205 million ha, approximately the combined areas of Spain, France, Italy and Britain. Map Source: Embrapa Cerrados.

Approximately 113 million hectares of cerrado are suitable for mechanized farming and the remaining 91 million hectares are adequate for pasture and forestry. Today, grain crops are cultivated on 15 million hectares and improved pastures occupy about 55 million hectares. Approximately 75% of the farms are less than 200 hectares in size, and 66% of the land area corresponds to farms greater than 1000 ha. (Nasser et al, 1990). Seventy percent of the area has a plain to slightly rolling topography and 89% has good drainage, allowing extensive mechanization.

Oxisols are the most frequent soil type in the cerrado ecosystem. These Oxisols have excellent physical properties but are strongly weathered with low cation exchange capacity, frequently exhibiting major mineral element deficiencies and toxicities; deficiencies of P, Ca, Mg, and Zn are common, toxic exchangeable Al is usually high, and the fixation of P by soil particles is extensive. Also, dry periods during the rainy summer growing season are of common occurrence throughout the cerrado area.

The development of crop production in the cerrado stressed the need for better adapted cultivars with Al tolerance and high nutrient use efficiency, for sustainable economic cropping. Lime applications to these acid soils have been used to decrease the toxic effects of Al to the roots, but practical mechanical methods for deep lime incorporation have not been developed. Therefore, the combination of liming practices for neutralization of soil acidity at the surface, together with selection for plants more tolerant to Al toxicity has been a more economical approach.

Figure 2. Agricultural Development in the Cerrado Area. The native vegetation of cerrado is a complex mosaic of gallery forests and grasslands (a), savanna-like vegetation and riparian palm communities (b). Aluminum tolerant rice crops (c) and pastures initially pioneered the area. Today, the cerrado is one of the prime areas for corn and soybean production in the world (d and e).

AGRICULTURAL DEVELOPMENT IN THE CERRADO AREA

EARLY RESEARCH STRATEGIES

The pioneering work supporting agricultural expansion into the Brazilian cerrado started with the work of Valdemar Cardoso de Meneses and Wilson Alves de Ara□jo in 1940 at the Sete Lagoas Experimental Station located on the eastern edge of the cerrado region in the state of Minas Gerais. They were responsible for the first experimental trials to correct soil acidity, to utilize green manure crops for fertilization and evaluate the combined use of calcium and phosphorus in fertility recovery. The first lime mill in the state of Minas Gerais was built within the Experimental Station during this time period. Even in this early work, scientists incorporated the concept of a sustainable production system, encouraging soil erosion control combined with crop rotation, pH correction with lime and fertility building with applications of chemical fertilizers and incorporation of organic matter (Menezes and Ara□jo, 1964). The early work developed at IBEC with detailed studies on building cerrado fertility, with special emphasis to phosphorus, the most limiting nutrient in the cerrado oxisols (Mclung et al 1953) was also important.

In 1961, t razilian president, Dr. Juscelino Kubistschek, created the "Instituto Agronômico do Oeste, IAO, in Sete Lagoas. This was the basis for the development, in 1962, of the "Instituto de Pesquisas e Experimentação do Centro-Oeste" (IPEACO), an official cerrado research institute. Thorough this institute, research directed to agricultural development in the cerrado region was significantly increased. In the early 1970's, when the Brazilian Government initiated a massive program for agricultural development in the western part of the country, IPEACO was incorporated into the newly created Brazilian Agricultural Research Corporation, Embrapa, and divided in two research centers, the National Cerrado Research Center, located in Planaltina, DF, and the National Maize and Sorghum Research Center, located in Sete Lagoas, MG.

With the formation of Embrapa, which evolved into a network of 39 research institutes within the first ten years, Brazilian agribusiness in the cerrado had an expressive impulse. Embrapa's mission to provide feasible solutions for the sustainable development of agriculture in Brazil provided means of generating, adapting and transferring knowledge and technology for the cerrado, thus reducing production costs and environmental degradation and diminishing external dependence on technologies, basic products and genetic materials.

BREAKTHROUGHS IN THE CERRADO OCCUPATION FROM THE 1970'S TO THE 1990'S

The Brazilian Agricultural Research Network (SNPC), which included Embrapa, state research institutions, universities, the private sector and international collaborators, provided several research breakthroughs in agricultural development in the cerrado in the 1970's and through the 1990's. The technology generated by SNPC was coupled with government policies to promote road building, agriculture credit and the use of nearby lime and phosphate rock deposits (Lopes 1983, 1996; Goedert 1986, 1987; Ableson and Rowe 1987, Sanchez, 1997). The establishment of the regional Polocentro program was critical to agricultural development in the region. This program was started in the 1970's and included financial support for infrastructure (storage, rural electrification, roads, etc.), credit for soil amelioration (liming and phosphate fertilizer) and machinery. The program had subsidies interest rates and very convenient repayment terms, which stimulated investment and new settlements throughout the cerrado and was established by Allyson Paulineli, Minister of Agriculture at this time.

The cultivated area in the Cerrado more than doubled from 1970 to 1990. Average grain yields increased by 60 percent and total grain production increased from 6 to 20 million tons per year (Table 1). Soybean production in the Cerrado became competitive with other traditional producing areas in the world, especially the United States. In addition, improved pastures went from negligible amounts to 30 million hectares and plantation forests increased from nothing to three million hectares (Sanchez, 1997).

Table 1. Impact of Oxisol management technologies in Cerrado of Brazil (1970-90).

	1970	1980	1990
Area planted to grain crops* (million ha)	5.0	7.0	11.0
Average grain yields* (tons/ha)	1.2	1.3	1.9
Grain production* (million tons)	6.0	9.0	20.0
Improved pastures (million ha)	nil	16.0	30.0
Plantation forests (million ha)	nil	1.0	3.0

* Soybean, upland rice, beans, wheat and maize
Source: Sanchez, 1997

Alves (1992), in a World Bank Report, presented a detailed evaluation of agricultural research in Brazil after the implementation of the Brazilian Agricultural Research Network (SNPC), from1972-1991. Great advances were achieved in the knowledge on how to manage marginal lands in a sustainable manner, dealing with the severe socio-economic constraints as well as with limitations such as aluminum toxicity, low nutrient contents and availability, low water holding capacity, high phosphorus fixation, etc. Also, great advances in optimization of biological efficiency with emphasis on optimization of nutrient cycling, minimization of external input application and maximization of the efficiency of their use were achieved. The inter-institutional networking involving Embrapa, state research institutions, universities, the private sector and international collaborators was of prime importance. By the 1990's, the resulting technologies allowed the cerrado region to reach production levels of 25% of the total grain, 20% of the total coffee, 40% of the total beef and 12% of the total milk production in Brazil.

Despite the great success story of commercial agriculture in the cerrado during the past three decades, there still remains much to be done to provide technological solutions that are appropriate for such an environment, keeping socio-economic development, sustainable production and ecological preservation in view. A constant monitoring of the balance between soil conservation, contamination and eutrophication of waters, biodiversity conservation and high input agriculture systems must be maintained to help implement and preserve sustainable agricultural production in the cerrado.

EVOLUTION OF AGRICULTURAL SYSTEMS IN THE CERRADO

In pre-colonial times, a number of Amerindian tribes dependent on hunting and gathering of wild plants sparsely inhabited the cerrado area. During the colonial period, and continuing from Independence up until about 35 years ago, the cerrado was considered to be essentially worthless for agriculture exploitation, except for the strips of alluvial soils along the margins of streams and rivers, which were less acidic and more fertile. The native grasses of poor digestibility and low nutritional quality were utilized for extensive cattle production. At the end of the 1960s, agricultural exploitation in the region was based on only two options: upland rice, which later paved the way for the establishment of cultivated pasture of brachiaria pasture grass and extensive cattle grazing. This upland rice-pasture system was dependent on low inputs (lime and fertilizers) with resulting low yields. Cattle raising technology dated from colonial times and some improvements were made with the introduction of the tropically adapted zebu cattle from India. (Alves 1992 and Santana et al 1998).

At the onset of the cerrado conquest, rice was a strategic crop, used in shifting cultivation systems and as the first option in newly opened areas for pasture formation (Figure 2). Rice was used as the first crop mainly due its tolerance to aluminum toxicity and its low requirements of P. The yields were low and the short dry spells or "veranicos" were reasons of high risk for the crop. In modern cultivation, upland rice has been used in rotation with other crops and associated with pasture establishment. Reduced fertilization of the soil, bad crop husbandry, incidences of the brusone disease and the high frequency of dry spells in the growing season have been the main factors for low yield, as compared to other parts of Brazil. The recent development of an agriculture zoning model, that identifies low risk areas and the best timing for crop production has helped change this picture. New high yielding disease resistant varieties and new technologies have been developed to enable the farmers to obtain higher and more stable levels of productivity (Kluthcouski et al., 1991). In 1995, 1,8 million hectares were planted with rice but by the 1998/99 growing season the upland rice crop acreage had a tremendous increase, with two new varieties developed by the Embrapa Rice and Beans Research Center. These varieties yield 5 t/ha and have long, needle like grains, similar to irrigated rice, which has high economic value in Brazil.

Soybean development and expansion has been based on studies of biological nitrogen fixation (BNF) and the selection of adapted and competitive strains of *Rhizobium*, developed by Dr. Joana Dobereiner's group at the Embrapa Agrobiology and Embrapa Cerrado Center. This laboratory has had strong interactions with universities in graduate training and has helped develop a national competence in BNF. This has been instrumental, together with the development of varieties adapted to low latitudes, in the establishment of a very competitive soybean crop in the cerrado. The increase in the efficiency of BNF in tropical environments has led to the elimination of the requirement of nitrogen fertilizer for soybean production in the cerrado.

The new soybean varieties developed by collaborative networks of public institutes (Embrapa, state research institutes) and private businesses has created a diversity of new options that has allowed for the rapid expansion of soybeans throughout the cerrado. Additionally, success with soybeans has generated positive effects on corn production in the area, due to the well known positive effects of soybean rotations on corn yields. In 1995, 4.5 million hectares of the cerrado were cultivated with soybeans, with an average yield of 2.2 t/ha. Yields have been improving rapidly during the past years with the release of improved high yielding varieties. Embrapa has been a major player in the development of cultivars more productive and resistant to the main diseases, for the various producing areas within the cerrado region. Also, the National Soybean Research Center has been responsible for the introduction of the juvenile period in new varieties. This has allowed an increase in the planting period, guaranteeing plants of adequate height, allowing for the rapid migration of the crop northward.

Common beans were cultivated in the cerrado region on a small scale, to sustain the scattered local population until 20 years ago. It was a low input crop, which in most cases was grown by subsistence farmers. This low input cropping systems explains the low yields, in contrast with the modern high input bean cultivation systems used with central pivot irrigation. Yield records of 4,000 kg/ha have been obtained with new high yielding and diseases resistant varieties, disease and pest management, appropriate fertilization, and crop husbandry. This has contributed to an increase in bean production in the cerrado region accounting for about 25% of the national production (Spehar, 1996.)

Another production system successfully being used in the cerrado is an annual crop-pasture rotation. (Santana et al 1998). This is a very efficient nutrient recycling system that also positively contributes to enhancing soil structure. The grass-legume pasture association in rotation with annual crops offers the following advantages: soil fertility improvement by incorporating N, P, S and other nutrients through annual crop fertilizer inputs and incorporation of crop residues; increased biological activity in the subsoil due to the deep root growth of perennial acid tolerant plants and efficient nutrient recycling by plants and animals; improvement of soil physical conditions by better organic matter management and, consequently, reduced erosion; improvement of the soil microbiological activity; reduction of weed, pest and disease problems; and elimination of some noxious weeds on pasture fields by plowing them for annual crops (Spehar & Souza, 1995). This production system has resulted in a more than a two fold increase in the animal supporting capacity of pastures (Ayarza et al., 1993).

The no-tillage production system is has been used very successfully in the cerrado region and is becoming increasingly popular. In the 1996/97 season, the no-till system was used on more than 2 million hectares (Figure 3) of the cerrado. No-tillage has been the best option to avoid soil structure destruction by repetitive disk harrowing, commonly practiced in the cerrado region. Repeated tillage for seedbed preparation for each crop creates two distinct soil layers: one loose superficial layer and a compact sublayer, which severely limits root development. No tillage has been also the best option for soil erosion control. Another additional advantage of the no-tillage system is rapid and efficient operations, suitable for double cropping and crop rotation, time and money savings, and longer duration of machinery (Spehar & Souza,1995). No-tillage is of particular interest in intensive cultivation systems with irrigation in the dry season. This is the recent trend in cerrado farming, which enables up to three crops to be produced within the same year, e.g., maize, soybeans or field beans and wheat; or soybeans, maize and peas, etc. Different crop sequences will apply when the commodities have attractive prices and when farmers produce them with different purposes. Maize can be used as a grain or a silage crop.

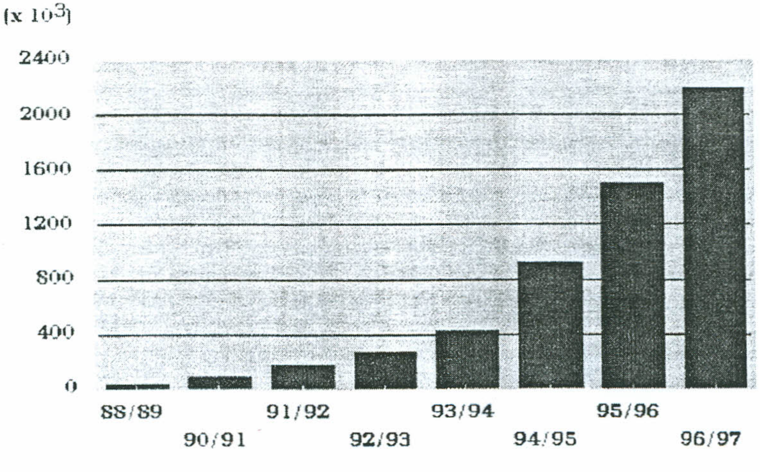

Figure 3. Evolution of no-tillage systems in the cerrado area (y axis = '000 ha). Source: Fundação ABC, PR.

In a substantial area of the region, crops irrigated by center pivots are becoming increasingly common. This makes the growing of a winter crop possible and guarantees summer production in the case of "veranicos." Permanent cultures involving forests, rubber trees, coffee and tropical and subtropical fruits are also proving to be economically viable alternatives. Extensive cattle raising with minimum use of technology is still predominant in the region, but there is a clear tendency for the incorporation of technologies already developed by research. Agroindustrial projects, especially for the production of alcohol, are being developed in the region. Also, swine and poultry production with the related processing industries are rapidly migrating from southern Brazil to the cerrado, where low cost maize and soybean production is being concentrated. (Santana et al 1998).

DEVELOPING CORN CULTIVARS TO THE CERRADO REGION

A MODEL OF CROP ADAPTATION TO MULTIPLE STRESSES

Maize has only recently become a major crop in the cerrado region, growing from a share of 17% of the Brazilian production in the 1970's, mostly concentrated in naturally fertile areas, it has evolved to about one third of the current national production. When planted in rotation with soybeans in the cerrado, maize yields are as high as in the most productive areas of Brazil. In areas where the rainfall distribution is prolonged, maize is also successfully cultivated in double cropping systems after the soybeans. Although fully mechanized in several areas, like in soybean cropping systems, subsistence cultivation of maize is a common practice that still contributes to low average yields. The increasing area planted to maize in the cerrado is typically by farmers who also plant soybeans using high technological inputs. In the Center West area yield of corn grow at the same pace and at high rates in the last tem years (3,34% and 3,68% respectively). It is the region where corn production has had the largest increase in Brazil (7,14% in the last 10 years) and where the adoption of modern technology is the most prominent engine of growth. The growth rate of yield increases when moving to an upper yield class (Alves et al 1999).

A combination of soil management practices and the use of crop cultivars developed for these low pH conditions have been a solution encountered for sustainable maize production in the cerrado. The research program to develop maize cultivars adapted to the acid soils of the Brazilian cerrado began in 1975 at the National Maize and Sorghum Research Center of Embrapa. An interdisciplinary research team including scientists in the area of breeding, soil fertility, plant nutrition, plant pathology, and production economics was formed to tackle this development problem. The emphasis of the program was to develop new cultivars to fit the existing conditions of stress, rather attempting to dominating the environment through extensive use of chemical fertilizers, soil amendments, and pesticides (Magnavaca & Bahia Filho, 1993, 1995; Bahia Filho et al., 1997), an expensive and at times environmentally risky approach. Plants that are tolerant to toxic levels of Al and more efficient in nutrient utilization can develop root systems into this chemical barrier, or subsoil, and explore a greater volume of soil, increasing the supply of soil nutrients and water.

SCREENING AND SELECTION METHODOLOGY DEVELOPMENT

The first step in evaluating germplasm for adaptability to soil acidity and mineral stress was to establish an effective parameter or set of parameters for selection. Initially, the principal strategy of the program concentrated on screening for tolerance to Al toxicity in the soil. Standardizing the Al saturation, relative to the effective cation exchange capacity of the soil was necessary to obtain repeatability in measuring plant responses (Magnavaca and Bahia Filho, 1993). Field trials confirmed genetic variability for tolerance to Al toxicity and established the possibility of obtaining genetic material tolerant to Al toxicity with high yielding potential (Bahia Filho et al., 1978). The level of 45% Al saturation was elected for identifying germplasm sources and selecting segregating genetic material for Al tolerance and production potential. Selection and evaluation ermplasm at an Al saturation of 55% and higher tended to discriminate against materials with good production potential. The level of P available in the soil can also cause misinterpretation of the results, as a high level of phosphate can mask the effect of toxic Al (Magnavaca & Bahia Filho, 1993, 1995; Bahia Filho et al., 1997).

A nutrient solution technique tool was developed to evaluate the isolated effect of Al on the plant, in contrast with field evaluations, where a complex of factors related to nutrient and water availability as well as climate effects, interfere with plant response to Al stress, making selection more complicated. The nutrient solution technique used in this program was that developed by Furlani and Clark (1981) and Magnavaca (1982). Plants are grown in the greenhouse with natural light and with temperature varying from 25°C to 35°C. The initial length of the seminal root is measured when seedlings are transferred to treatment solutions. Upon completion of the experiment, the final seminal root lengths are measured. Relative seminal root growth (RSRG) is used to evaluate plants for Al tolerance. RSRG values are determined by dividing the final seminal root length by the initial length. This trait was selected because it gives low correlation with initial length of the seminal root and a lower coefficient of variation, especially useful when inbred lines are evaluated The greater the RSRG value, the greater the Al tolerance (Magnavaca, 1982).

IDENTIFICATION OF TOLERANT INBRED LINES

The search for Al tolerance in maize was initiated at Embrapa in 1975, with the evaluation of 363 inbred lines from the maize germplasm collection (Bahia Filho et al., 1978). These lines were not originally selected for acid soils, but random fixation of genes for tolerance may have occurred during their development. Phenotypic evaluation based on a 1 to 5 scale was used to access survival of inbred lines in an acid soil with 55% al saturation. Although 70 % of the lines died within 60 days, it was possible to select 30 lines that yielded at least 2 t/ha of grain. This selected group of lines was evaluated in an acid soil at three levels of Al saturation (Naspolini Filho et al., 1981) and in nutrient solution with different levels of Al (Magnavaca et al., 1987a). The results demonstrated different plant responses in field and nutrient solution evaluation, which can be described as: a) low yielding lines not affected by the level of Al in the soil or nutrient solution; b) lines which had high yield per se at an intermediate level of Al saturation and c) lines which were not affected under low levels of Al saturation. These three types of responses were quite common and gave the opportunity to select genotypes useful for different breeding objectives. The correlation between results from nutrient solution evaluations and field experiments in acid soil is not expected to be high. The nutrient solution technique is specific for Al toxicity effects on root development. Field tests measure the effects of a nutritional complex that includes Al as one of the factors involved in crop yield. However, the field and nutrient solution evaluations usually agree in terms of results when the genotype being tested is highly tolerant to toxic Al (Magnavaca & Bahia Filho, 1993, 1995; Bahia Filho et al., 1997).
One objective at the beginning of the program was to develop high yielding hybrids and varieties with Al tolerance. There was concern about the possibility of Al tolerance being associated with low yield potential. Several experiments addressing this question led to the conclusion that it is necessary to evaluate Al tolerant hybrids not only in acid soil conditions, but also in fertile soil conditions (Magnavaca & Bahia Filho, 1993, 1995; Bahia Filho et al., 1997). In Embrapa's maize improvement program, selection has been based on results from trials conducted in both acid and fertile soils, and results from nutrient solution with varying levels of Al Figure 4). A large number of field test locations are used to detect better yield stability. (Magnavaca et al 1998).

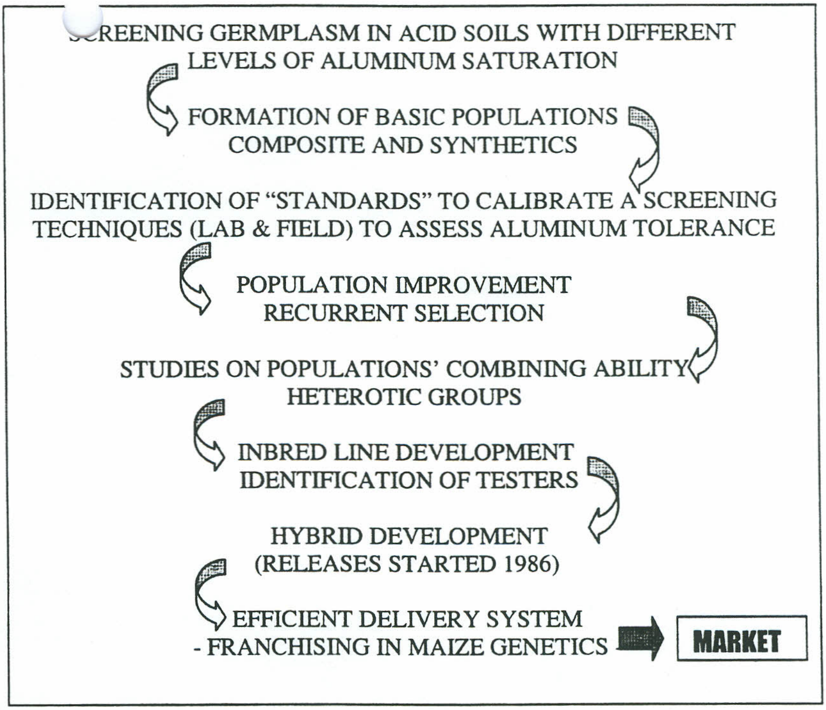

Figure 4. Key points in Embrapa's maize improvement program for adaptation to multiple stress factors in the acid soils of the cerrado.

INHERITANCE FOR ALUMINUM TOLERANCE

Studies of Magnavaca et al., (1987b) demonstrated that Al tolerance is a quantitatively inherited character, indicating that progress from recurrent selection and selection of intermediate types is possible from crosses between tolerant and susceptible genotypes. The type of variance involved for Al tolerance can also be inferred from the magnitude of general and specific combining effects obtained from crosses between lines or between populations. The magnitude of these effects from studies by Magnavaca et al.(1987b), Naspolini Filho et al., (1981), Lopes et al., (1987), and Eleutério et al., (1988) indicated that general combining ability variance accounts for the major part of the total genetic variance, but the variance for specific combining ability is significant in all the data, again demonstrating the importance of additive effects, and on a smaller scale dominance effects.

DEVELOPMENT OF HIGH YIELDING H RIDS ADAPTED TO MULTIPLE STRESSES

Cultivated plants grown in the cerrado are also generally subjected to stresses other than aluminum, especially those caused by limitations in phosphorus and nitrogen availability and water deficit. Therefore, the expectation is that the mechanisms regulating plant adaptation to this condition are very complex (Bahia Filho et al., 1997). Hybrid evaluation in cerrado oxisols carried out by Bahia Filho et al. (1979) showed differential response to phosphorus, indicating the possibility of selecting cultivars with tolerance to Al toxicity and greater efficiency in phosphorus acquisition. These authors suggest that this result may be related to the high density of fine roots in the root system, which is typical of the lines that constitute these hybrids. The efficiency of double-cross maize hybrids selected for tolerance to acid soils, in absorption and utilization of P was also evaluated by Alves et al., (1991). Sixteen hybrids were evaluated in a cerrado soil at Sete Lagoas, Minas Gerais, with an initial P level of 1 $\mu.g^{-1}$. The soil acidity was corrected with dolomitic lime and other nutrients were supplied as indicated by soil analysis plus 43.7 $kg.ha^{-1}$ of P. The results of these evaluations indicated that hybrids selected for acid soils were efficient in P utilization. Hybrids with a good level of tolerance to Al and lower production levels were much less efficient in P utilization. BR 201, a hybrid, which has been a commercial success in the cerrado for over 10 years, was included in the trial.

Alves et al. (1995) showed that BR 201 presents lower decrease in the rate of root growth with reduction of phosphorus when plants are grown in nutrient solution, compared to other hybrids. The lower decrease of root growth was associated with an elevation of the levels of soluble sugars in the roots. This increase in sugars is higher in BR 201 when compared with hybrids less efficient in phosphorus absorption. Higher rates of root elongation and higher root volumes allow better contact with the soil and facilitate phosphorus absorption. This is especially true when the supply of phosphorus is discontinuous in function of moisture reduction due to short periods of drought, common in the cerrado during the growing season. Phosphorus deficiency has been hypothesized to lead to an accumulation of higher levels of soluble sugars in the roots, which may be involved in the mechanism of osmotic regulation and possibly tolerance to short periods of drought. The work of Novais et al. (1990) has shown that phosphorus diffusion in oxisols is practically interrupted even under reasonable levels of moisture. Therefore, phosphorus mobility in the soil and its absorption by the roots are very discontinuous and intimately linked to alternating periods of high and low water availability. Kinetic studies in plants grown, in nutrient solution with continuous reduction of phosphorus levels, showed that BR 201 has higher values for the maximum rate of phosphorus absorption (Vmax), higher rates of liquid influx (LI) and higher contents of phosphorus in the xylem exudate, when compared to other hybrids, (Alves et al., 1997). These results indicate possible mechanisms involved in higher efficiency in phosphorus absorption and utilization. The availability of genetic resources well characterized field performance is facilitating the development of detailed studies of mechanisms controlling the adaptation of maize to the cerrado conditions (Bahia Filho et al., 1997).

Magalhães (1996) conducted experiments involving nitrate and ammonium absorption kinetics using the male parent of BR 201 grown under phosphorus starvation. The results showed that under phosphate starvation, these plants have a greater reduction in nitrate absorption compared to ammonium absorption. These observations indicate that ammonium may be a nitrogen form more easily absorbed under phosphorus stress conditions. Under this assumption, it may be possible that tolerant plants have the capability of absorbing ammonium rather than nitrate during periods of phosphorus starvation. França and Coelho (1995) have shown that ammonium is the main form of nitrogen in acid soils of cerrado, indicating that adapted plants may have evolved to better use this supply.

The results obtained to date indicate that adaptation to the acid soils of the cerrado is intimately linked to a better development of the root system. Roots of tolerant cultivars are able to grown in the layer of acid soil immediately below the 15 to 20 cm top layer, usually corrected by liming. In addition to developing a better root system, tolerant materials also have the ability to rapidly absorb phosphorus when moisture level is high. Higher translocation of sugars to the root system in efficient materials may explain their more aggressive growth. Also, maintenance of ammonium absorption, which prevails under low pH, appears to supply nitrogen, even if for short periods or under low phosphorus availability (Bahia Filho et al., 1997).

It is possible to conclude that adaptation to aluminum stress, low phosphorus availability and short periods of drought may be controlled by mechanisms that are common as a whole or at least in some parts (pathways). Linked mechanisms, in tolerant cultivars, would allow better response under limitations common in the cerrado and result in greater yield stability and better average agronomic performance over many growing seasons.

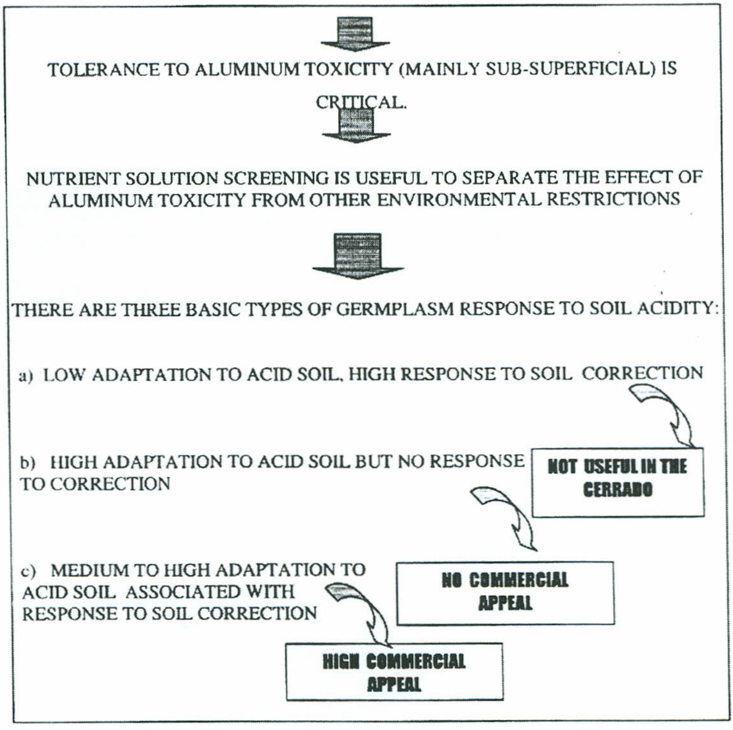

Figure 5. Key points for development of commercially desirable maize hybrids with adaptation to multiple stress factors in the acid cerrado soils.

FRANCHISING IN MAIZE GENETICS: A MODEL OF TECHNOLOGY TRANSFER TO THE CERRADO

Embrapa developed a team approach to help resolve the problems of agriculture expansion in the cerrados of Brazil. Breeders, soil scientists, pathologists, entomologists, economists, agrometerologists, etc. working together, developed promising germplasm and production systems to expand crop production into this immense region. However, at the time the first commercially promising corn hybrids were developed, there was mechanism in place to deliver the technology (hybrid seeds) from a public research institute to the farmer. Embrapa developed a unique system of franchising, with small and medium size seed companies in Brazil to resolve this problem. In this franchising scheme, Embrapa authorizes the use of its trademark, provides the foundation seed, transfers seed production technology, provides training and technical assistance, and oversees a rigorous system of quality control. Financial resources return to Embrapa through the sales of foundation seed and the assessment of a five percent royalty on gross sale of commercial seed, paid by the collaborating seed companies. In the 1998/1999 season this system had approximately 12% of the market share for commercial maize hybrid seed in Brazil, which is equivalent to approximately 1 million bags of seeds commercialized with the brand BRS. The system has been highly successful in the cerrado region, where the eight cultivars so far released have high adaptation.

PUBLIC RESEARCH PROGRAMS COMMITTED TO SOLVE DIFFICULT, LOCAL PROBLEMS ARE STRATEGIC IN DEVELOPING COUNTRIES

Companies committed to "life sciences", or biotechnology-based agrochemical businesses integrated to traditional fields, like plant and animal breeding, have developed aggressive programs of consolidation and vertical integration and are now moving rapidly to transform and control much of the global food system. This may be viewed as a biotechnology revolution or green technology, promising enormous benefits for the consumers and the environment. This may, however, lead to a situation where the major decisions in the whole agricultural system of developing nations are made by an ever-declining number of companies, a growing number of which are involved in several strata of the food system. This is reason of great concern, since chemicals, fertilizers, seed and genetics may become concentrated and controlled at a small number of decision making points, where the primary concern is maximization of profits.

A typical example of such a movement, is the corn seed industry in Brazil that has undergone a wave of corporate concentration since 1997 (Table 2). These corporations come from temperate regions and have limited experience in dealing with complex tropical problems that need long term, multidisciplinary research investment. The cerrado, for instance, is a very fragmented environment with a great diversity of biotic and abiotic stresses, combined with complex socio-economic situations (Paterniani, 1993). As seen in this paper, it took many decades of multidisciplinary work led by public research institutes to tackle the most limiting problems of the cerrado. The wave of corporate concentration in genetics may lead to a reduction of needed investment in strategic plant and animal breeding programs with the promise that the private sector has the capabilities to tackle all difficult problems of tropical agriculture. Obviously, a balance between public and private effort must be reached, especially in those strategic fields that need long term investment without a sure promise of immediate high profits.

Table 2. The Corn Seed Industry in Brazil by Market Share*

COMPANY	MARKET SHARE	
	ton	%
Agroceres/Monsanto	50.317	32
Cargill/Monsanto	39.310	25
Braskalb/Monsanto	9.434	6 — 63**
Pioneer/DuPont	20.441	13
Novartis	7.862	5
Dina/Dow	6.290	4 — 22**
Unimilho/Embrapa	18.869	12
Other	4.717	3 — 15***
Total	157.240	100

* Based on seed availability for the 98/99 growing season, including open pollinated varieties (7.322 t).
** Biotechnology companies have developed aggressive programs of consolidation and vertical integration in Brazil. In recent years participation of transnational seed companies in the market has increased substantially, reaching 85% in the 98/99 growing season.
***Most of the national seed companies remaining in the market belong to the franchising system developed by Embrapa.
Source: Compiled by Embrapa from data of APPS (São Paulo State Association of Seed Producers) and Report on the Maize Production Chain in Brazil - "Pensa" Group – USP, São Paulo (1998).

TRANSFERRING THE CERRADO EXPERIENCE TO OTHER PROBLEM SOILS OF THE WORLD

Until the 1970's the cerrado region was considered marginal for crop production in Brazil. However, the technologies developed by a network of research institutions have changed this picture. Bits and pieces of research information and new crop cultivars have been assembled into technologies and applied by pioneering farmers. Due to this effort, a burst in agricultural development has taken place in the area during the last three decades.

The Nobel Peace Prizewinner, Dr. Norman Borlaug, has pointed out that Brazil's current development of the cerrado is converting tens of millions of hectares of naturally degraded land into productive farmland. This is now significantly contributing to food production while at the same time indirectly reducing the demand to explore and consequently destroy the Amazon rain forest. The vast cerrado ecosystem, over untold millions of years, was leached of nutrients and made unproductive by Mother Nature. Over the last three decades, it is being converted into a huge new, highly productive, "bread basket" through the collective efforts of scientific development, effective government and private sector programs, plus aggressive, creative farmers and ranchers. The "Cerrado Revolution" can be referred to as the Second Green Revolution, concluded Dr. Borlaug (Borlaug and Dowswell, 1997) in a recent visit to the cerrado.

In all probability, much of the technology being developed for the cerrados will be of considerable value in the future for effectively exploring areas with similar soil problems and production constraints.

This may include areas such as the vast plains (llanos) of the Orinoco River watershed in Colombia and Venezuela and large tracts in Central and Southern Africa (Santana et al., 1998). Also, according with an extensive analysis of Sanchez (1997), the Brazilian experience in managing acid tropical soils is relevant to several parts of Africa. The main difference lies in the socio-economic conditions, with Africa dominated by smallholder farmers, largely female, in contrast to the dominant commercial farming sector in the cerrado. Taking this into consideration, the author stresses that the Brazilian experience is applicable to parts of Africa in different degrees. It is directly applicable to the dystrophic Miombo Woodlands, a very similar acid savanna, with the same latitude, elevation and with similar soils (Lopes and Cox 1977; Sanchez et al. 1991). The Miombo encompasses about 100 million hectares of thinly populated land in eastern Angola, southern Zaire, northern Zambia, Malawi and Mozambique and Southern Tanzania (Huntley 1982, Scholes and Walker, 1993).

Sanchez (1997) also indicates that the Brazilian experience is applicable, with modifications, to much of the smallholder areas of the subhumid Eastern and Central African Highlands of Kenya, Uganda, Tanzania, Rwanda, Burundi, eastern Zaire, and also parts of Ethiopia and the high plateau of Madagascar. The Brazilian experience is similarly applicable to the subhumid plateau of Southern Africa, that ranges from Tanzania to South Africa (ICRAF 1996) particularly to the high phosphorus fixing soils derived from basaltic parent materials, which are now extremely depleted of phosphorus and nitrogen. The Brazilian concept of "corrective" and maintenance fertility applications (Lopes 1983, 1996) is very much applicable to these areas and also to nutrient-depleted regions of the subhumid savannas of West Africa. Obviously, strategic biophysical and socioeconomic research would be needed to evaluate the applicability of the Brazilian concepts to Africa.
Sanchez 1997 pointed that there is an important difference between Brazilian and African situations related to the initial level of fertility. In the Cerrado the starting point is extreme low fertility and high aluminum toxicity. In Africa subhumid the fertility in higher and values of aluminum saturation are lower although still on the aluminum-toxic side.

Problems of aluminum toxicity occur in many oxisols and ultisols of Rwanda and Burundi, some acid savannas of the Congo and areas in Kwazulu-Natal South Africa. Extreme phosphorus deficiency is found in the Central Plateau of Madagascar.

As in Africa, other countries in the tropical belt of the world have a scenario similar to Brazil, in that a large portion of land suitable for agriculture production is considered marginal for crop production due to soil acidity and/or poor soil fertility. Brazilian scientists have clearly demonstrated that by using a combination of genetic resources tolerant to aluminum toxicity in acid soils and more efficient in nutrient uptake coupled with improved crop management; sustainable food production can be increased on the good agriculture lands and marginal agriculture lands can be transformed into productive sustainable agriculture systems.

A new global model or approach to bring together research scientists to work in a collaborative research and development mode for mutual benefit can greatly contribute to the effectiveness of agricultural development, food security, and nutritional improvement of the human diet. Research for maintaining current sustainable production levels as well as attaining new increments in sustainable productivity become progressively more difficult and more expensive. The pooling of human, technical and financial resources in collaborative efforts will increase the level of information, reduce the costs and speed up the process of generating and disseminating new technology.

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