GENETIC RESOURCES FOR TROPICAL AREAS: ACHIEVEMENTS AND PERSPECTIVES

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Abstract

This paper analyses the present status of tropical forage resources and their utilization in the development of novel cultivars based on the accumulated information from past decades of collecting, evaluation and whatever little breeding has been pursued. The situation of world collections of tropical forages is presented and discussed in the light of limited investment and dwindling resources. A cause for concern is the lesser priority assigned to conservation and manipulation of official tropical germplasm banks, such as CSIRO'S and CIAT's. In order to assure the availability of tropical genetic resources for the future it is imperative that international efforts be undertaken to renew investments into organizing world databases, providing human and financial resources to maintain existing collections and that national and international research organizations be stimulated to act cooperatively in favor of a common goal. Perhaps by assigning value to biodiversity, the stimuli for national organizations to collect, conserve and exchange will come forth. In order to fully exploit genetic resources and guarantee continued diversity for selection, breeding activities need to be pursued. It is odd, however, that tropical forages have deserved such little input from breeding: most cultivars in use, are little more than selections from the wild, whereas the animals grazing those pastures have been bred for generations and many times using sophisticated methodologies. A survey of major Brazilian university curricula in agronomy and animal sciences provided a clue: only two of those have a forage breeding course at the graduate level and hardly any of those has a forage breeder in the staff. However, all of them have at least one animal breeding course in the required curriculum and animal breeders in their staff. If no forage breeders are being trained, genetic resources of forage plants will continue to be underutilized in the future. A vast body of information was generated in the past decade on characteristics and agronomic value of tropical forages. A scheme generally followed to develop new cultivars was presented in this paper and discussed using examples of a grass (*Panicum maximum*) and a legume (*Stylosanthes*). Forages as pastures for animal production in the tropics are ever so much more important than in the temperate zones, where some form of forage conservation or grain needs to be utilized to maintain animals over the winter. Meat is produced mostly from pasture-fed cattle in the tropics, which has an ecological appeal, contributes to competitiveness and gains public endorsement worldwide. Therefore the perspectives for developing new improved cultivars to yield better quality and produce meat more cost and energy efficiently are large. To achieve such goals, team work is essential such that breeders, agronomists, phytopathologists, etc. establish priorities closely linked with the demands of the producer, as to assure quick and easy adoption once the variety is released, without forgetting the requirements of the consumers. A form of involving the private sector in the development of the technology should be seriously considered in these times of diminished resources and plant protection laws.

Keywords: adaptation, breeding, cultivars, germplasm, selection, tropical grasses, tropical legumes.

Introduction

Tropical pastures represent the one single most valuable resource in animal production worldwide. Besides providing means of transforming roughage grown more commonly on soils of low fertility levels into high quality protein for human consumption, it conveys an ecological and sustainable approach for doing so. Native and cultivated pastures cover wide extensions of land in the tropics and these natural environments encompass a wide array of genera and species of forage plants. Brazil alone is presumed to possess 20 % of the whole planet's diversity (Vilela-Morales and Valois, 2000). Cultivated pastures in the tropics, however, are dangerously composed by few varieties and in the case of grasses, of apomictic ecotypes, which, for all practical purposes, 'clones' through seeds, these few genotypes creating monocrops. This lack of biodiversity exposes the ecosystems by exerting tremendous pressure on pests and/or diseases which may wipe out a susceptible variety, as was the case of *Brachiaria decumbens* in the Amazon region (Seiffert, 1984).

Biodiversity has been gaining much deserved attention in the last decade. Heated debates and plenty of controversy surround the ascribing economical worth to natural resources as countries prepare their legislation over exchange and use of local natural resources; between the Biological Diversity Agreement and the World Action Plan, countries delineate their legal transference agreements in order to continue to exchange and establish the conditions and obligations upon receiving germplasm: in Brazil, the Ministry of the Environment is creating a Water control Agency and stimulating the 'Brazilian Environment Commodities Exchange – BECE. This is a clear sign of changes in mentality and priorities.

In sharp contrast, dwindling resources, both in funding and personnel, is a cause for concern and complicate the dilemma of the recognized value and importance of handling (collecting, characterizing and utilizing) natural resources vs. the cost of manipulating (maintenance and distribution) of large collections of germplasm. As one example, CIAT's (International Center for Tropical Agriculture) Tropical Forage Program and Genetic Resources Unit were references in the world for tropical forages but budget restrictions and cut back of staff has significantly reduced their possibilities and consequently their scope of action, specially in Latin America. A similar situation in Australia has also caused CSIRO to revise priorities and propose a workshop to discuss with potential clients, their demands for future research (Hacker, 1997). The aforementioned dilemma is specially worrisome in the tropics where many ecosystems are rapidly being degraded, not all major genera and species to be tackled have yet been clearly identified and intense collection efforts are not envisioned for the near future. The involvement of international coordination, by the International Plant Genetic Resources Institute (IPGRI) for example or the CGIAR through its International Centers, could greatly contribute to reverse this situation, both by directly promoting collecting efforts and maintenance of genetic resources and by consolidating the available information on existing germplasm into readily accessible data bases.

Another discrepancy in the tropical world lies in the fact that cultivated pastures are based on varieties that are little more than side of the road selections whereas the animals grazing them have been bred and selected for highest performance. Breeding tropical forage programs are as scarce as there are tropical forage breeders. Harlan (1983) posed well the contrasts between crops and forage breeders, these last ones many times having to deal with more than one grass and legume genera at the same time, with little pre-breeding information available such as mode of reproduction, chromosome behavior, adaptive traits inheritance and hybridization methodology. Furthermore, a forage cultivar needs to be tested for animal performance, for ability to coexist with other forages - such as in grass-legume mixtures, - or to adapt to lower input production systems, requiring a large team of researchers to work objectively. Consulting curricula of the most renowned universities in Brazil (http://www.ufv.br; http://www.ufla.br; http://www.esalq.usp.br; http://www.ufrrj.br; http://www.unesp.br; http://www.ufrgs.br) only the two last ones have a forage breeding course, and only at the graduate level in agronomy/animal science, and the focus of the last one is on subtropical and temperate forages since they are in the southernmost state of Brazil. Most of these universities do not even have a Forage breeder as professor in their midst, therefore no forage breeding program is practically being undertaken there. In contrast, most of these school have a formal animal breeding section and professors carrying out research. If forage breeders are not being trained or stimulated in the universities, genetic resources of forage plants will continue to be severely underutilized to generate new cultivars. Despite the bleak scenery, advances in animal performance either on traditional or on new cultivars is patent in the tropical world and is not only closely associated with the adoption of better technology but also to improved management of pasture resources.

World collections: presently and perspectives

A remarkable effort by international and national organizations with the support from IPGRI has resulted in the assemblage of representative collections of tropical germplasm in the past two decades. Schulze-Kraft *et al.* (1993) presented the distribution of genera and species of legumes and grasses in the three most important tropical forage collections: Australia (CSIRO), Colombia (CIAT) and Ethiopia (ILRI, ex-ILCA), a summarized representation of which can be seen in Figure 1. Hanson and Maass (1999) reported an estimate of about 30000 distinct accessions of forage species contained in these genebanks (Figure 2) but remarked that many areas of tropical diversity have not yet been properly sampled.

It is, at least interesting to observe the overall predominance of forage legume genera and species in germplasm collections, when grasses are, in fact, much more ubiquitous in nature and thus, play a major role in sustaining livestock production systems worldwide. The value of legumes is indisputable, be it as a supply of nitrogen enriched organic matter to the soil-plant system, as a source of protein in the grazing animal's diet, and a key factor in sustainable pastureland. On the other hand, grasses have shown more plasticity in adaptation and lesser constraints to production than legumes thus justifying the search for more legume genera and species to complement and improve grass pastures or to be used as protein banks.

A cause for concern is that most of the resources in these banks are not being renewed at the desired rate due to funding and personnel restrictions. The problem is even greater for the grasses which tend to lose cultural value in the seeds more rapidly than legumes. Toledo *et al.*, (1989) had already pointed to the limitations in assemblage and conservation of tropical genetic resources, referring to lack of information on seed-borne diseases, or optimum storage conditions, associated to lack of financial continuity to maintain seed multiplication efforts in order to keep an effective flow of germplasm in evaluation programs. Hanson and Maass (1999) emphasized the need for further studies on seed storage in order to guarantee long-term conservation of the valuable resources accumulated.

These collections are and will continue to be a valuable resource to future pasture improvement in the tropics. They are, by no means complete or fully exploited yet despite intensive exchange and evaluation in network trials such as the ones in the extinct International Tropical Pasture Evaluation Network (RIEPT) (Keller-Grein *et al*, 1993; Pizarro, 1992) or the one in southeast Asia (Ibrahim *et al*, 1999). The importance of a breeding oriented evaluation, which would include not just morphological and agronomic traits of the accessions involved but also their range of adaptation and response to selection was stressed by Charmet *et al.*, (1999), as a pre-requisite for the extensive utilization of germplasm collection. They emphasized the importance of establishing core collections to maximize in depth evaluation at a reasonable cost and although this methodology is being pursued with temperate forages within the framework of the European Cooperative Programme on Genetic Resources, a much needed effort in tropical forages does not exist and could conceivably be implemented by IPGRI and related International Centers with the active participation and support of national institutions.

In order to assure the availability of tropical genetic resources for the future it is imperative that international efforts be undertaken to renew investments into organizing world databases, providing human and financial resources to at least maintain existing collections and that national and international research organizations be stimulated to act cooperatively in favor of a common goal.

Value of locally adapted materials

Forages are mostly used as feed for livestock but they also play an important role in sustainable agricultural systems, by improving soil composition through nitrogen and carbon fixation, soil texture and water holding capacity, soil stabilization and pest/disease control in crop-pasture rotation systems. Livestock production is usually carried out on soils of moderate to low fertility and over a wide diversity of climates, therefore extensive testing of an array of genetic resources needs to be pursued in order to determine which adapted forages will sustain these operations.

Major forage legume species include genera such as *Stylosanthes*, *Arachis*, *Centrosema*, *Macroptilium*, *Desmodium*, *Leucaena*, *Zornia*, *Calopogonium*, many originally from the American continent but widespread in use in the tropics. Accessions from these genera have been exchanged and tested in multilocational trials in Latin America (Keller-Grein *et al.*, 1993; Pizarro, 1992) as far from their centers of diversity as Australia (Cameron *et al.*, 1993). These last authors have elaborated on the criteria for release of legume cultivars in Australia based on selection for adaptation, persistence and productivity. Several improved varieties have been released and their adoption in thousands of hectares was delimited by rainfall and latitude. These sustain a remarkable level of animal production with proper fertilizer use and grazing management: Cameron *et al.*, (1993) report a 20 fold increase in carrying capacity and animal output pet unit area in legume-based pasture systems in Australia. The value of adapted tropical legumes to their system is unparalleled, be it in the form of improved animal nutrition and/or as returning nitrogen to the soil-plant complex.

Success of legume adoption in the Americas has been less impressive, probably due to constraints such as indigenous diseases and also to traditionally abusive management practices which impair more the legume(s) than the aggressively growing C4 grasses associated with them. *Stylosanthes* and *Arachis* are the most promising genera for pasture use in the continent and large efforts are justifiably being devoted to those two genera in Brazil, Colombia and Australia, as germplasm collections are now available and locally adapted materials have been identified, as will be detailed below. A recent release of a multiline of *Stylosanthes* (*S. capitata* + *S. macrocephala*) in Brazil is being prepared as a result of remarkable animal performance and nitrogen fixing ability (up to 180 kg of N/hectare) in grazing trials with *Brachiaria decumbens*, on sandy soils (Embrapa Beef Cattle, 2000). Breeding of these forage legumes deserves attention as well as improving the establishment and management techniques to best utilize their potential in pastures.

Major tropical forage grasses belong to fewer genera when compared to the legumes (*Panicum*, *Pennisetum*, *Brachiaria*, *Andropogon*, and *Paspalum*) and come mostly from the savannas of Africa. Introduced accessions of several of these have shown remarkable adaptation to other tropical ecosystems and cover yet more environments than the legumes, over millions of hectares, which attests to their larger genotypic plasticity. If genetic variation is considered in this equation, the result is even more surprising, since most of the cultivars in use are apomicts or vegetatively propagated, thus of reduced variability. Grasses have secured profitable animal production for decades, withstanding mismanagement and biotic constraints but the scenery today is one of fast degrading grass pastures and lack of options to replace old cultivars. Improved cultivars will have to come from selections in germplasm collections and from breeding for specific traits among the better studied species and genera. Due to the high demand for new grass varieties, the expected adoption is comparatively much faster and widespread than with legumes, and the tendency is to utilize those even outside their range of adaptation as has been the case for *Brachiaria brizantha* cv. Marandu in Brazil: released by the Brazilian Corporation for Agricultural Research (EMBRAPA), for soils of medium fertility and good drainage in 1984, it has spread to low fertility and wet soils of the southern Amazon region because of its resistance to a major pest – spittlebugs (Homoptera: Cercopidea). Thousands of hectares are now dying and the resistance to the pest has been broken as a result of the monoculture of this cultivar.

Tropical germplasm: evaluation, selection and breeding

The evaluation of germplasm is a common activity in tropical research institutes and universities. It generally involves evaluation plots of a few representatives of a variety of genera and species, owing to the diversity of ecosystems sampled, or to the small collection of a single genus/species available. That was even more true 20 years ago, prior to the very active international network – RIEPT - established by CIAT in the 80´s. Manuals of evaluation were produced then (Toledo, 1982), and extensive germplasm exchange and training of members took place. National programs profited immensely from this activity and the major outputs from this effort were the definition of the adapted genera and species for the different regions, the school of competence originated and most important of all: the consciousness about the importance of working with broader forage germplasm collections that was created in the participating countries.

In Brazil, it was not different: at the onset of Embrapa – 1973-75 - most of its research centers (at least 8) where animal production was studied had introduction gardens consisting of one to a few accessions of a myriad of forage genera. Even 10 years after that, not many releases of new forages resulted from these plot evaluations, where emphasis was placed on scoring for adaptation, visual estimates of leafiness and vigor, morphological characterization, insect/disease presence, flowering patterns and a few cuts at a fixed interval. But the most adapted forages were identified and the need to work on large germplasm pools became evident (Savidan *et al.*, 1985). Collecting in the wild and exchange was stimulated and important working collections date from this period: *Brachiaria* (Keller-Grein, 1996), *Panicum maximum* (late 60´s in Africa but transferred to Brazil in 1982, Savidan *et al.*,1989), *Centrosema*, *Paspalum* (Valls, 1987), *Stylosanthes* (Schulze-Kraft *et al.*, 1984) and *Arachis* (Valls and Pizarro, 1994). Some examples to illustrate the sequence of events in the evaluation, selection and breeding of tropical forages will be presented below.

a) Grasses

The release of a new variety is a process and not an event and it may take between six to ten years. Figure 3 illustrates a typical sequence followed in the breeding and evaluation of forage grasses. One starts ideally with a representative collection of accessions or hybrids (Germplasm stage) of one or more species and as it is planted for the first time, generally in unreplicated plots. Several traits are observed or measured, such as vigor, presence or absence of pests and diseases, ability to flower and produce seed, leafiness, regrowth after cuts, resistance to cold or drought. Information gathered in these plots may form a data base with indications towards potential of adaptation to the ecosystem.

A *Panicum maximum* collection representative of the variation observed in the wild in East Africa was evaluated in Campo Grande, Mato Grosso do Sul, from 1983 onwards (Savidan *et al.*, 1989). Information on mode of reproduction and chromosome numbers had already been gathered prior to the introduction in Brazil (Combes and Pernes, 1970; Savidan, 1983). Other basic information such as vegetative and reproductive morphology, pest and disease occurrence as well as agronomic traits such as dry matter and seed production, leaf:stem ratio, response to fertilizer, etc., were recorded in Stage 1 (Fig. 3) and assembled in a data bank on the species (Jank *et al.*, 1997).

The next step is to evaluate groups of promising accessions in diverse ecosystems as a means of establishing genotype x environment interaction and defining which materials deserve recommendation for a wider range of ecosystems – Stage 2 (Fig.3). Continuing with the example of *P. maximum*, 25 selected ecotypes from Stage 1 were evaluated in 7 regional trials for two consecutive years, in ecosystems ranging from savannas to tropical rain forests to the subtropics and the most productive, regionally as well as nationally, were thus identified (Jank *et al.*, 1993). Eight of them were then evaluated in 1000 m^2 plots, under grazing, to study animal effects on these pre-selected genotypes (Stage 3a). The animal in these trials function as the herbage removal element, thus are not evaluated at all. Carrying capacity and grazing intervals, however, can be estimated in these kind of trials, as well as resistance to trampling and regrowth after grazing. Consumption may also be evaluated with the use of fistulated animals. Usually in these trials, every time the animals enter and leave the plots, herbage is sampled to determine available dry matter and a subsample is saved for chemical analysis of nutritive value.

Again, with, after two years, three ecotypes were advanced to grazing trials (Stage 3b) were animal performance (e.g. gain per head and per hectare) was evaluated for two full growing cycles (Euclides *et al.*, 1993 and 1999). Two of those ecotypes have already been released as cultivars – cv. Tanzania-1 and cv. Mombaça - and represent over 80% of the *P. maximum* seed commercialized in Brazil, thus an impressive example of technology adoption by farmers. The third ecotype, cv. Massai, despite sustaining less animal gain than the previous two, is to be released in 2001 as a spittlebug resistant alternative to *Brachiaria brizantha* cv. Marandu pastures in the outskirts of the Amazon, where these insects are beginning to pose a problem (Euclides *et al.*, 2000).

All of these stages need to be accompanied by seed multiplication activities, since each step involves larger areas of each pre-selected genotype. Together with producing seed for the next stage, these activities help consolidate information on seed producing ability of the selected genotypes in addition to leaving a seed production plot for pre-basic seed, in case of a release.

Other supporting experimentation may be conducted in parallel to the stages listed in Figure 3 such as response to fertilizer, specific management for seed production, pasture establishment, nutritive potential under differential uses, etc.

The scheme discussed above represents the path undertaken to generate the majority of the grass cultivars in use in the tropics, where primarily, the natural variation has been screened to identify potential new cultivars.

Following the same orientation, a valuable collection of *Brachiaria* - the most widespread pasture genus being planted in the tropics, estimated to cover more than 60 million hectares in Brazil alone – has deserved considerable attention in the tropics, especially in Brazil and in Colombia. National and international symposia and workshops have produced valuable literature discussing international experience with this genus (Miles *et al.*, 1996; Peixoto *et al.*, 1994; Paulino *et al.*, 1986 and 1991).

The evaluation of natural variability of *Brachiaria* has identified some promising genotypes in Stage 1 (Valle *et al.*, 1993 and 1999), 2 - regional trials (Valle et al, 2001), and 3 (Euclides *et al.*, 2001). Examples of numbers of genotypes involved in these trials were: 200 accessions of 8 different species in Stage 1, down to 21 of three species in stage 2, and eight *B. brizantha* in plots under grazing. Four of these have recently been advanced to grazing trials, in four ecosystems with hopes of releasing at least one in 2002.

Several ecotypes of good agronomic potential in the Brazilian collections of both *P. maximum* and *Brachiaria*, still await evaluation under grazing and probably deserve to be released in the near future, allowing a greater option of apomictic cultivars commercialized and thus lessening the risk of monoculture.

In contrast with the temperate grasses scenario, where germplasm has been extensively examined and sophisticated methodology as marker assisted selection using QTL´s is routinely applied to improve efficiency, very few breeding projects are actively being pursued with tropical grasses. Some of the explanations relate to the lack of specialized personnel (forage breeders) as discussed above, difficulties in breeding apomictic species, but also, in many cases, because the natural variability has not yet been fully exploited. *Panicum maximum* is one of these examples: besides evaluation of the natural variation and selection of ecotypes, it is being bred in at least two contrasting environments: Brazil and Japan. Hybrids between sexual or facultative apomicts crossed with other apomicts have been generated and traits improved include better tolerance to acid soils (cv. Vencedor – Embrapa Cerrados, 1990), better dry matter distribution between dry and rainy seasons, high production associated to better cold tolerance (cv. Natsukase – Sato *et al*., 1993). Breeding in Campo Grande, Brazil, is attempting to incorporate stoloniferous growth into erect growing genotypes of good agronomic performance (L. Jank, personal communication; Hacker and Jank, 1998).

Another example is elephantgrass (*Pennisetum purpureum*), a grass generally planted by cuttings and with a wide array of released natural varieties, in which the most important breeding objectives in Brazil, include the development of cultivars with tolerance to grazing, adapted to different ecosystems and to propagation through seed, in this case by crossing to pearl millet (Hanna, 1999; Pereira, 1999).

Breeding schemes have been proposed for apomictic species (Savidan *et al.*, 1989; Gobbe *et al.*, 1983; Miles and Valle, 1996) once a compatible source of sexuality is located in the genus or species. These are based on the principles of quantitative genetics and on the limited information available on genetic control of desirable traits. Use of recurrent selection has been proposed by Miles and Valle (1996) in an attempt to improve resistance to spittlebugs. Interspecific crosses are used in breeding programs with *Brachiaria*, since a compatible sexual form is still not available to cross with apomictic *B. decumbens* or *B. brizantha*, the two commercial cultivars in the market. Crosses between sexual and apomicts can only be accomplished one way (apomictic pollen over sexual flowers) and the hybrids recovered are 50% sexual and 50% apomictic, indicating a simple genetic control, with apomixis dominant over sexuality, as reported for *P. maximum* (Savidan, 1983) and *Brachiaria* (Valle and Savidan, 1996). Superior apomictic F1´s may be advanced to Stage 1 in the process of selecting new cultivars (Fig. 3), since their genotype is fixed by apomixis.

Another simpler means of improving heterozygous populations, homozygous for sexuality, would be to use mass selection of half-sib families, as is being done in CIAT and Brazil, with *B. ruziziensis* and obligate sexual hybrids (Miles and Valle, 1996). Later, the improved population needs to be crossed to superior apomicts to recover apomictic hybrids for cultivar development.

Special problems of breeding forage plants such as the complex criteria of merit and the high cost of evaluating animal performance can be compounded by inefficient means of screening for edafic adaptation, or persistence under grazing, or spittlebug resistance, or even the difficulties associated with determining mode of reproduction. Molecular markers are being sough in some cases though here also, little knowledge about the inheritance of the traits, variation in ploidy level and few teams investing in this type of research make progresses slow.

Other grasses of economic importance to the tropics are *Paspalum* and *Andropogon*, the first a predominant apomict, native to South America and the second a sexual genus of mostly African origin. *Andropogon gayanus* cv. Planaltina (CIAT 621 - known by different cultivar names in tropical America) gained acceptance by farmers due to its excellent edafic adaptation to savanna soils, resistance to spittlebug, rapid regrowth in the spring and good nutritive value. It proved susceptible to ants and slow to establish due to its very small and light seeds. In 1994 a new cultivar (cv. Baeti) was released in Brazil as a result of breeding for ease of establishment (Batista and Godoy,1994). Intrapopulation half-sib selection as well as mass selection within families were carried out for three cycles, preserving the original plant's good agronomic attributes and selecting for early, vigorous seedlings. The released cultivar represented an expressive 40% improvement in stand formation when compared to the original population and other positive correlated traits were plant height, plant development and competitiveness, height and speed of regrowth.

At least two active teams work with genetic resources, agronomic evaluation, cytogenetics and breeding of the genus *Paspalum*: one in Corrientes, Argentina and another in Brazil dispersed through Brasilia, São Carlos, Lages and Rio Grande do Sul. An extensive literature has been produced on adaptation and production, phylogeny, reproductive and chromosome behavior of *Paspalum* dealing with many species of three major groups: plicatula, notata and dilatata (Batista and Godoy, 1992 and 2000; Quarin and Norrmann, 1990, Quarin, 1992; Valls, 1987; Pizarro, 2000). In Brazil, a cultivar of *Paspalum atratum* has recently been released: cv. Pojuca (BRA009610) as a result of extensive evaluation in poorly drained areas of savannas ecosystems. Other countries have demonstrated interest in *Paspalum* as well, and cultivars released include cvs. Pensacola and Suerte in the United States, Hi-Gane in Australia, and several others reviewed by Pizarro (2000).

Valuable grasses widespread in the American continent but which have received very little attention include molassesgrass – *Melinis minutiflora* and jaragua grass – *Hyparrhenia rufa*. These were both introduced from Africa in colonial times, became naturalized wherever cattle herds were moved to, but apomixis and lack of natural variability available, has impaired selection and/or breeding in these genera. Major collection efforts in the centers of origin and dispersion followed by evaluation and selection in specific ecosystems could most certainly result in identification of significant new cultivars. There is certainly room for investment in collecting and evaluation with these two genera.

b) **Legumes**

Tropical legume evaluation has followed a variation on the scheme proposed on Figure 3. However most cultivars have not been subjected to grazing trials prior to release which could account for their short persistence once under commercial use. Another explanation could be a mistake in establishing goals from the legume evaluation: in association with grasses, tropical legumes will normally produce less, be less palatable and depend heavily on reseeding for survival, therefore requiring specific management to persist. To evaluate benefits from the association in a grass-legume pasture one must thus consider the soil-plant-animal interaction and not just in a time span of only a couple of years.

The repeated lack of success with legumes in the tropics created a negative image and consequently a barrier to adoption. Once superior materials become available, more effort will probably need to be dedicated to marketing the new product than in the production of the technical information to prove their advantages.

Tropical legumes are less competitive than grasses under environmental stresses (biotic or abiotic) so common in these ecosystems. High temperatures and irradiation favor the C4 photosynthetic pathway of most tropical grasses, which also compete better for soil nutrients especially in the acid and poor soils of the savannas.

Legumes are typically of the American tropics where the population of herbivores has always been notoriously lower than in the African savannas, where the grasses evolved. Therefore, under grazing pressure and low fertilizer inputs, legumes tend to succumb after the second or third year of utilization. Evaluation procedures should thus involve the animal presence for selection as early as possible, instead of the typical cutting regime imposed on most regional and plot trials.

Some legume genera were reviewed in symposia and workshops and again, valuable information was compiled (Cameron *et al.*, 1984; Kerridge and Hardy, 1994; Schulze-Kraft and Clements, 1990).

Arachis and *Stylosanthes* have received the widest attention in the tropical world and will be used here as examples for the sake of illustrating the activities involved in the evaluation, selection and breeding of legumes.

Arachis species have undoubtedly revitalized the interest in legumes in the tropics due to its value as forage, hay and cover crop. It has been called the “alfalfa of the savannas” due to its remarkable nutritive value and palatability. The major constraints to its wide adoption lies in the cost of planting as well as the time to establish and produce significant contribution to the pasture – 1 to 2 years.

Arachis research was reviewed in a workshop held in Colombia in 1993 (Kerridge and Hardy, 1994) and topics covered include mostly activities predicted in Germplasm and Stage 1 and 2 of Figure 3. There is no practical breeding programs underway yet but a respectful body of basic knowledge has been produced. Germplasm has been widely collected and catalogued but taxonomic revision is pending; tissue culture protocols and transformation in some species have been accomplished, isozyme and molecular markers detected broad genetic variation in the collections assembled; little is known however, about the breeding behavior of the species with forage potential, also about the cytology and affinity among species.

Several accessions, mostly of *A. pintoi*, have been evaluated in plots and regional trials around the world and promising genotypes were identified. A need to exploit other potentially interesting species as well as invest in research to lower costs of establishment was detected in the *Arachis* workshop. In the United States, the sustainability of *A. pintoi* – grass pastures under heavy grazing for more than 10 years with evident increase in productivity over grass-only pastures justifies concerted efforts to promote Arachis adoption by farmers throughout the tropics.

The genus *Stylosanthes* is well distributed in the tropics and subtropics of all continents but the species of forage value are American and include *S. guianensis, S. scabra, S. hamata, S. humilis, S. capitata,* and *S. macrocephala*. It was in Australia, however, that the forage value of Stylo was discovered in the beginning of the century and where the commercial exploration is most significant in the tropical world, with over half a million hectares planted to the genus. Not only is it significant as forage for ruminants due to its ability to produce abundant forage of good quality and effectively fix nitrogen even if vegetating in acid, poor soils, but in southern China there are reports of and active production of leaf meal as feed for fish and poultry.

The focus of attention in this genus is anthracnose, a disease caused by a fungus – *Colletotrichum gloeosporioides*. It wiped out *S. humilis* in Australia and prompted increased interest in the introduction of different species and breeding for disease resistance in Australia, Colombia and Brazil. Released cultivars amount to about a dozen in tropical America and Australia but the majority has not been widely cultivated or persisted long enough to cause an important impact so far in animal production.

Germplasm collection expeditions were conducted since the early 60´s in Brazil (Hymowitz, 1971; Schulze-Kraft *et al.*, 1984) and more recently, by Australian researchers (Edye and Maass, 1997) resulting in very complete collections, representing the array of natural genetic variation. Valuable information on the mode of reproduction, ploidy levels, floral biology and artificial pollination was summarized in *The biology and agronomy of Stylosanthes* (Stace and Edye, 1984), thus this stage in the process of developing new cultivars was well covered (Figure 3).

Germplasm was intensively exchanged and evaluated in regional trials (Stages 1 and 2 in Figure 3) and despite identification of several interesting ecotypes, the need to incorporate disease resistance became evident in order to assure its contribution to the production systems (Miles and Lapointe, 1992).

The breeding of *Stylosanthes* has been extensively reviewed (Cameron *et al*., 1984, 1997; Miles and Grof, 1997). The ideal situation to define specific breeding objectives includes identifying which original germplasm has displayed adaptation to the particular production system for which a new variety will be bred. That is usually not the case since no commercial cultivar has become widely used, maybe with the exception of *S. guianensis* var. vulgaris cv. Mineirão in Brazil.

A joint project between CSIRO, EMBRAPA and CIAT in underway, combining efforts in molecular biology, phytopathology and agronomy to study the pathogen, and screen populations of *Stylosanthes* spp. with the objectives of creating and selecting genotypes with good quality forage, persistence (i.e. disease and pest resistance) and good seed production. An entire issue of *Tropical Grasslands* (**31**, 5, 1997) was dedicated to reviewing the current status of research in Stylosanthes presented in a workshop and provides a comprehensive summary on plant improvement and cultivar development of Stylosanthes as a pasture legume.

Strategies to breed *Stylosanthes* include utilization of the pedigree method (as normally used for autogamous crops) and for quantitative attributes, recurrent selection was employed using genetic markers to identify hybrids. Recent work with molecular markers in Australia aims at studying variation and epidemiology of the pathogen and at improving efficiency in combining genes for anthracnose resistance into a single line (Manners and He, 1997; Cameron *et al*., 1997).

A different approach towards a disease resistant Stylo has culminated with the release of a multiline in Brazil (Embrapa Gado de Corte, 2000; Grof et al., this issue) consisting of a combination of selected *S. capitata* and *S. macrocephala*. Both species were worked upon separately and through five cycles of recombination (polycross of several selected accessions) and selection of the most resistant and productive plants which tended to flower simultaneously, populations with horizontal type of resistance were produced. Seed of each species was multiplied separately and then mixed for planting in pastures associated with *Brachiaria decumbens*. Grazing studies now carried for three years in acid sandy soils have confirmed the superior animal performance in the grass legume pastures and continued contribution of the legume to the mixture, which attests to its persistence under grazing (Embrapa Gado de Corte, 2000).

Miles and Grof (1997) discussed the various breeding projects, particularly in tropical America and came to the conclusion that the lack of success was not related to genetic diversity of the germplasm involved or to the breeding procedures employed but most probably to not knowing exactly why the legume failed in mixed pastures, which possibly relates to reseeding ability, plant vigor in competition, strategy of nutrient assimilation and partition and most certainly to disease resistance.

The concerted effort being allocated to *Stylosanthes* in the international project mentioned abroad should produce valuable results in the near future and could very well function as a model to the scientific community on how to approach tropical germplasm development.

Outlook and Concluding Remarks

Forage plants as cultivated pastures continue to play a major role in animal production in the tropics and this scenario will probably be even more accentuated as a move towards more sustainable production systems are demanded by world population growth and environmental awareness. “Green beef” or “ecological meat” is becoming a jargon to illustrate the desire of the consumer for pasture produced meat. In that context, contributions of introduced species to pastoral systems will remain large in terms of animal output per area in contrast to production from native pastures. American legumes have been an important contribution to pastures in Australia and Southeast Asia, and African grasses are the most important component of Latin American pastures. Despite extensive utilization of introduced species, the diversity of cultivated pastures in the tropics is precariously small, considering the heavy dependence on a few grass ecotypes of essentially apomictic plants and that these cover millions of hectares. In this aspect the perspective of increasing diversity through the release of new cultivars is enormous.

In terms of achievements, in the last two decades, considerable efforts were devoted to assembling a broad valuable germplasm base for tropical pasture development, with an emphasis on acid and low-fertility soils. Maintenance and conservation of these collections are time-consuming and expensive activities therefore to optimize the effective utilization of such resources, pasture programs around the tropical world need to be able to access this variability, evaluate and develop new cultivars for the benefit of the producer and ultimately the consumer.

An impressive body of knowledge has been produced through the stages of evaluation depicted in Figure 3 for the more widespread forage species. Genetic diversity available in the germplasm collections of the few most important tropical forages has been evaluated and will be the source of new cultivars for the immediate future. However, for an effective return on the investment made so far in germplasm collection, conservation and evaluation, breeding programs need to be pursued so as to introduce traits not found in original accessions and to create diversity adapted to specific production demands. Two critical aspects in accomplishing this task are the retraction of investment (funds and personnel) in germplasm conservation and characterization worldwide and, as stressed before, the shortfall of tropical forage breeders.

Not to mention, that there is however, a wealth of untapped diversity in other forage plants to be collected and explored. Despite limitations in assessing some countries and regions, and retraction of funding, it is imperative that global efforts be directed to coordination and cooperation in the efficient use of genetic resources. By the same token some form of stimulating countries with diverse but unexplored forage resources need to be envisioned so as to avoid permanent losses to genetic diversity. Perhaps, by ascribing value to biodiversity, the means and stimuli will be created, it remains to be seen.

In comparison with temperate forage resources there is still a lot to be learned and tackled in tropical forages thus whatever progresses are made, these represent a large step towards impacting a wide and heavily populated region of the planet. Team work in developing cultivars is essential and defining priorities closely linked to future use of the developed forage, very wise, especially in these times of little investment and nearly no renewal of personnel. In this context, it is essential that the private sector be made a partner in developing new cultivars, especially considering the adoption of newly produced technologies.

The perspectives of utilizing genetic resources in the development of new cultivars in the tropics are very favorable, more so for grasses than for legumes, since these are not readily accepted by the farmers and demand somewhat higher levels of investment and technological expertise on the part of the producer. However this scenario is also changing since more crop-pasture rotation systems are advertised, more sustainable production is being imposed as requirements for national and international funds investments and there is an increased awareness on the benefits of legume utilization.

To summarize achievements and perspectives concerning genetic resources for tropical areas, the following points should be highlighted: it is evident that whereas a significant progress has been made in terms of assembling, characterizing, exchanging and evaluating the most widespread tropical forages, there are still untapped resources to be identified, specially if trees and shrubs are considered. The scenario in terms of funding for germplasm collection and maintenance is not auspicious, therefore it is imperative that international organizations coordinate efforts to at least maintain the resources already gathered and data banks be organized and made accessible worldwide. It is also important that countries with unexplored biodiversity be stimulated to collect or preserve, maybe through legislation declaring value or bonuses for forage natural resources. For genetic resources to be fully utilized, breeding activities need to be pursued. Therefore the inclusion in agronomy and animal science curricula, of forage breeding courses with consequent positions for breeders in the staffs of major universities in the tropics is vital. Animal production in the tropics is heavily dependent on pastures and improved forages have had a major impact on productivity, meat quality and the seed market, especially concerning grasses. The perspectives of new improved cultivars resulting from germplasm selection in the short term and to bred cultivars in a longer term are very large particularly as new techniques such as molecular markers, tissue culture or assisted selection using QTL´s become available. There is still a lot to be done but each step is a giant one towards narrowing the gap between the temperate and tropical world as forage resources are concerned.

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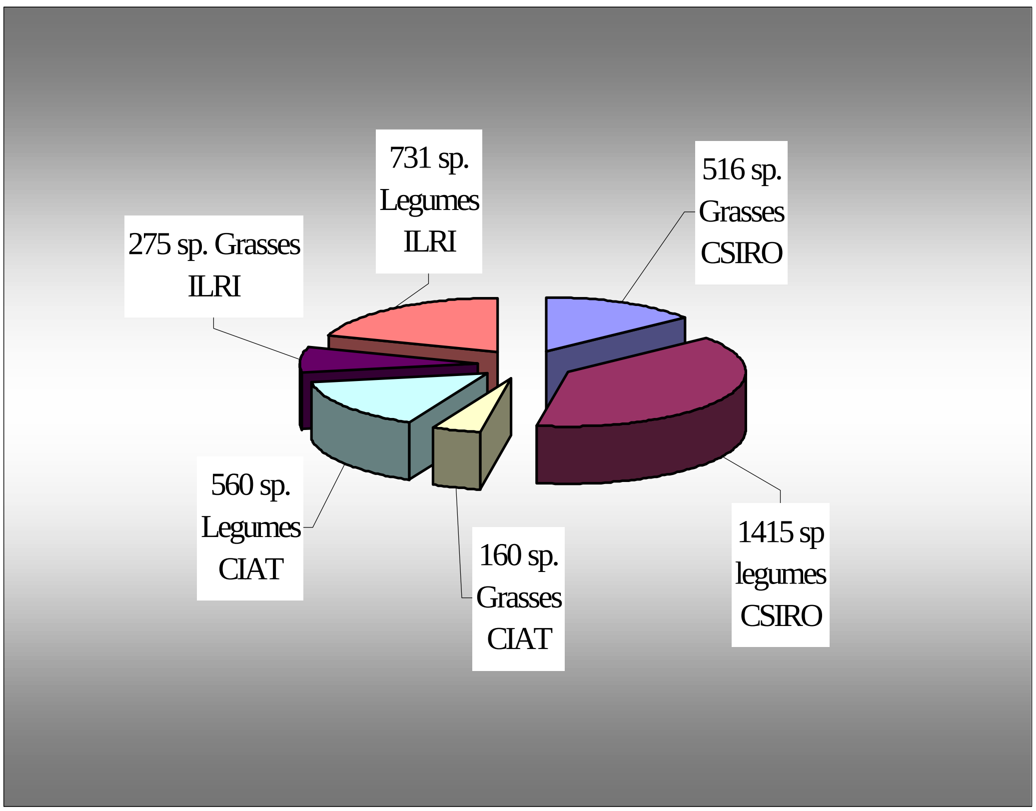

Figure 1 - Number of legume and grass species represented in three most relevant world collections of tropical forages (Source: Schulze-Kraft et.al., 1993)

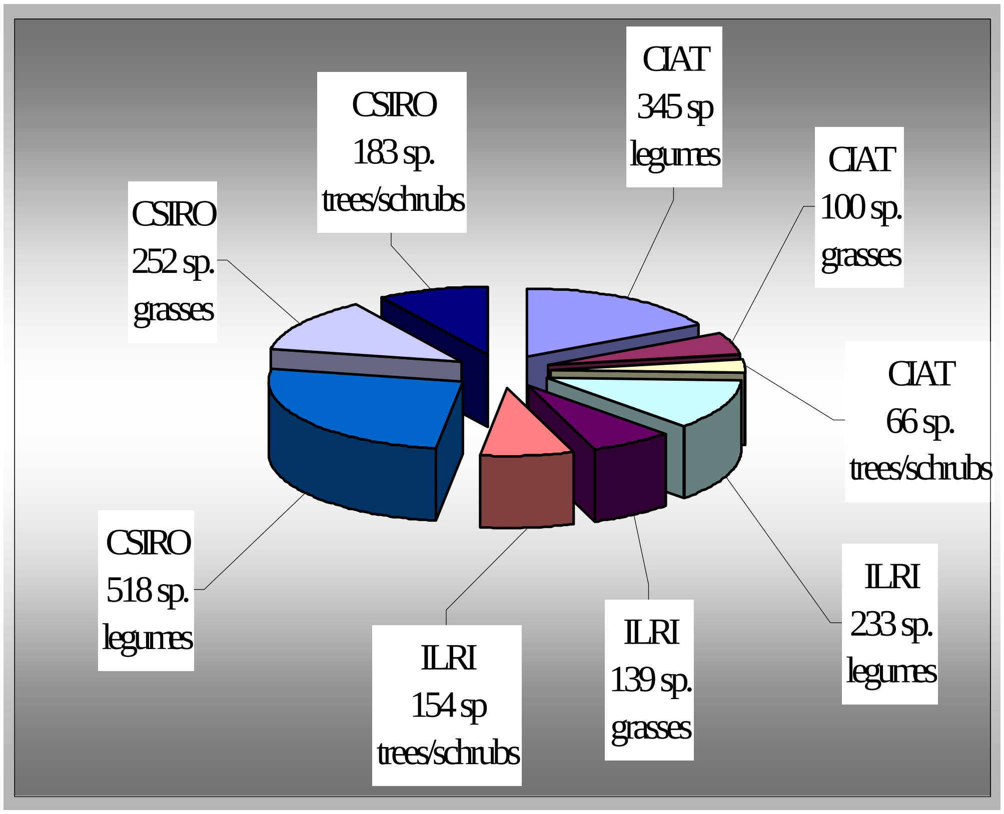

Figure 2 - Number of species of the most important genera of tropical legumes (22), grasses (12) and shrubs and trees (14) represented in the three most relevant world collections of tropical forages (Source: Hanson and Maass, 1999).

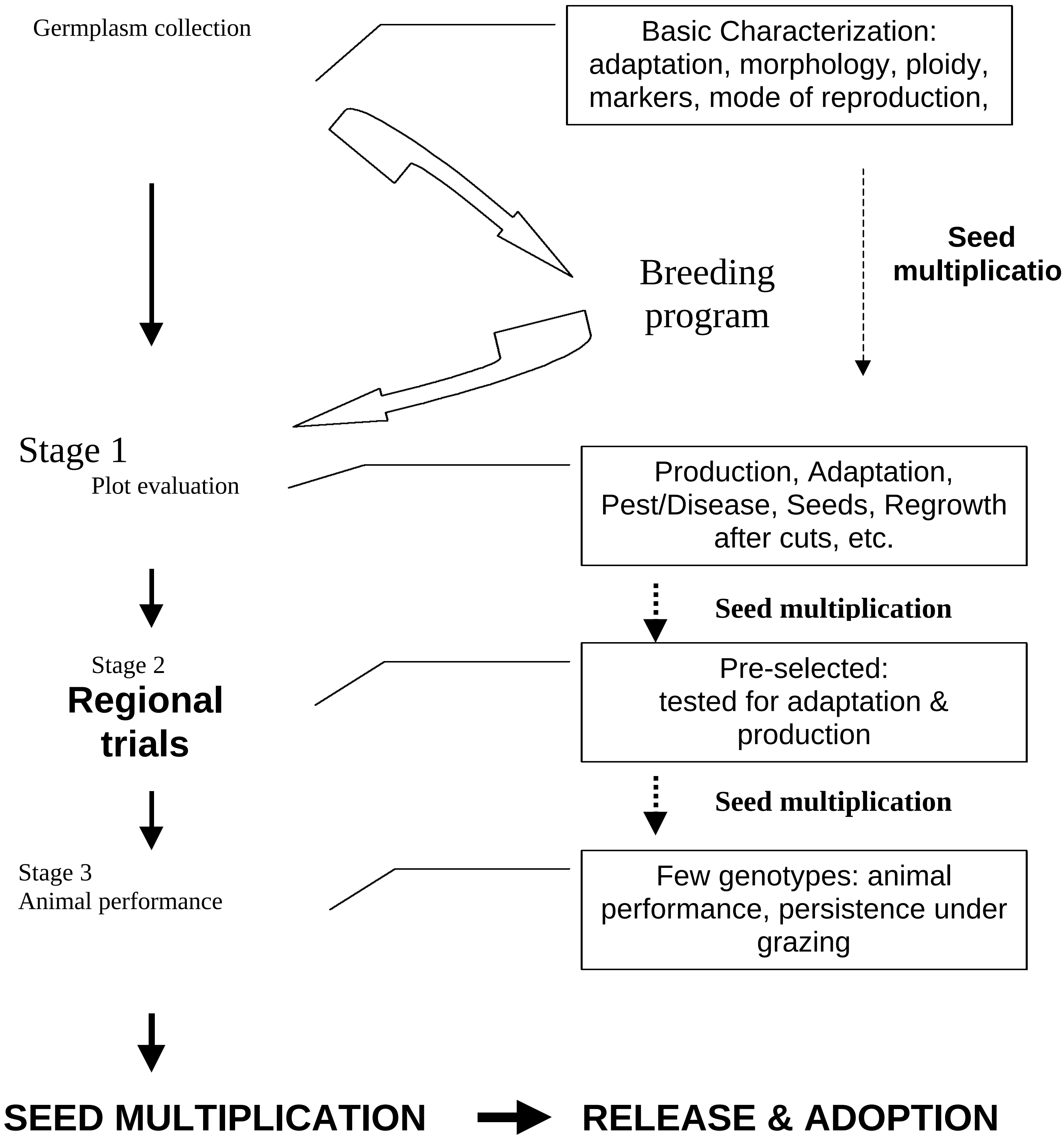

Figure 3 - Scheme of evaluation of forage germplasm leading to the release of new varieties.