ISSN 1020-3362

Plant Genetic Resources Newsletter

Bulletin de Ressources Phytogénétiques

Noticiario de Recursos Fitogenéticos

No. 135, 2003

IPGRI

Food and Agriculture Organization of the United Nations and the
International Plant Genetic Resources Institute
Organisation des Nations Unies pour l'alimentation et l'agriculture et
l'institut international des ressources phytogénétiques
Organización de las Naciones Unidas para la Agricultura y la Alimentación y
el Instituto Internacional de Recursos Fitogenéticos

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Cover: *Musa* spp. germplasm maintained at the INIBAP Transit Centre is conserved *in vitro* in the form of proliferating shoot tips (*C. Boursnell/IPGRI*). Van den houwe et al. discuss the importance of this world collection of banana, pp. 18–23.

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The Plant Genetic Resources Newsletter Web portal, with contents and summaries of all articles from issue 104 and full text from issue 121, can be accessed at http: //www.ipgri.cgiar.org/pgrnewsletter/

Characterization of germplasm according to environmental conditions at the collecting site using GIS—two case studies from Brazil

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Summary

Characterization of germplasm according to environmental conditions at the collecting site using GIS—two case studies from Brazil

The limited use of large germplasm collections has been attributed to limited information regarding the germplasm conserved. Information about environmental conditions of germplasm collecting sites may be important additional data, because those conditions are normally associated with the patterns of genetic variability. Through the use of geographic information systems (GIS), overlaying environmental maps with geographic data of the accession collection points, it is possible to estimate these environmental conditions. This constitutes an uncommon type of characterization: ecological descriptors. In this paper we present two examples of the use of this methodology: (1) the definition of an ecogeographic stratification for the landraces of the Brazilian Cassava Collection for the development of the Brazilian Core Collection of Cassava; (2) the identification of rice landraces collected in areas with specific environmental conditions or stresses, to be used as sources for breeding. To develop the Core Collection of Cassava, landraces were stratified into ecogeographic regions of origin. These regions were obtained through the combination of different maps of vegetation and climate of Brazil (scales from 1:5 to 1:2 million). For the rice study, maps of vegetation, climate, and zoning of Brazil were used (scales from 1:5 to 1:2 million). Rice accessions collected in regions with cooler thermic regimes, soil salinity, very low fertility in the Cerrados, and semi-arid regions, were identified. The characterization of germplasm according to origin through GIS is a tool that may help in understanding and accessing the genetic variability of large germplasm collections.

Key words: cassava, ecogeographic regions, ecological descriptors, geographic information systems (GIS), rice

Résumé

Characterisation de germoplasme en fonction des conditions d'environnement dans les lieux du prelevement utilisant le SIG—deux etudes au Bresil

L'utilisation limitée de grandes banques de germoplasme a été attribuée aux infomations limitées concernant le germoplasme conservé. Des informations sur des conditions d'environnement dans les lieux du prélèvement de germoplasme sont des dates supplémentaires importantes, car ces conditions sont normalement associées au modèle de la variabilité génétique. L'utilisation du SIG (Système d' Information Géographique), superposant des cartes d'environnement avec des données géographiques sur les lieux de prélèvement, il est possible d'estimer ces conditions d' environnement. Cela représente une manière pas comune de charactérisation: description écologique. Dans ce travail nous présentons deux exemples d'utilisation de cette métodologie. (1) La définition d'une stratification écogéographique pour les variétés locales de la Collection de la Cassave Brésilienne pour le développement du sous ensemble brésilienne de la Cassave. (2) L'identification de variétés locales de riz collectionnées dans des régions avec des conditions particuliers d'environnement ou de stress, que sont utilisées comme source pour le cultive. Pour le développement du sous ensemble de la Cassave, variétés locales ont été stratifiées selon des régions écogéographiques d'origine. Ces régions ont été obtenues à travers de combinaison de cartes différentes de végétation et de clima du Brésil (1:5 a 1:2 million). Quant à l'étude sur le riz, cartes de végétation, clima e zones du Brésil ont été utilisées (1:5 to 1:2 million). Accessions du riz collectionnées dans des régions avec des régimes thermique plus froides, salinité du sol, une fertilité très réduite dans le Cerrado et des régions semi-arides, ont été identifiées. La characterisation du germoplasme en fonction de l'origine à travers le SIG est un instument que peut contribuer à comprendre e accéder à la variabilité génétique de grandes collections de germoplasme.

Resumen

Caracterización de germoplasma de acuerdo con las condiciones ambientales del lugar de origen usando SIG: ejemplos aplicados a dos colecciones de germoplasma de Brasil

El limitado uso de las colecciones de germoplasma ha sido asociado a la escasa disponibilidad de información sobre el germoplasma conservado. La información sobre las condiciones ambientales de los lugares de colecta puede ser un dato adicional de gran valor, ya que normalmente esas condiciones están asociadas a los patrones de diversidad genética. Usando GIS (sistemas de información geográficos) se pueden superponer mapas ambientales con la información geográfica de los lugares de colecta, y de esta forma es posible estimar las condiciones ambientales. Estos constituyen un nuevo tipo de caracterización: descriptores ecológicos. En este artículo presentamos dos ejemplos del uso de esta metodología: (1) La clasificación ecogeográfica de las variedades criollas de la Colección Brasileña de Mandioca para desarrollar una Colección Núcleo; (2) La identificación de variedades criollas de arroz colectadas en áreas con estresses o condiciones ambientales epecíficas, para ser usadas en programas de mejoramiento. Para desarrollar la Colección Núcleo de Mandioca de Brasil, las variedades criollas fueron estratificadas en regiones ecogeográficas de origen. Estas regiones fueron obtenidas mediante el uso de una combinación de diferentes mapas de vegetación y clima de Brasil (escalas entre 1:5 a 1:2 millones). Para el estudio de arroz, se usaron mapas de vegetación, clima y de regionalización de Brasil (escalas entre 1:5 a 1:2 millones). Se identificaron accessiones de arroz colectadas en regiones de regimenes térmicos frios, de suelos salinos y de muy baja fertilidad dentro del Cerrado y regiones semiaridas. La caracterización de germoplasma de acuerdo a su origen usando SIG, es una nueva herramienta que permitirá entender y acceder a la variabilidad genética conservada en grandes colecciones.

Introduction

The limited use of large germplasm collections is a fact well known all over the world. This situation has been attributed in part to the limited information regarding the germplasm stored in those collections. Nass et al. (1993) carried out a survey among maize and soybean plant breeders of Brazil to evaluate the use of germplasm collections to identify the sources of variability that had been used in breeding programmes, and concluded that the amount of genebank use was proportional to the availability of information of the respective genebank.

The type of information available in genebanks is also an important issue. The common germplasm descriptors usually do not supply the most useful information for breeding programmes. The usual morphological descriptors, and even the new molecular characterization, are very useful for understanding the structure of genetic variability of large germplasm collections, but still fail in providing the information that is requested by the breeders. Peeters and Williams (1984) concluded, based on a survey of opinions, that characterization data in germplasm banks was often incomplete and, as a consequence, it normally did not have any real significance to the breeder. They also found out that the information currently provided was not the information that was requested by breeders, and suggested that a new approach towards information capture in genebanks was required. This situation has not yet been overcome since the lack of characterization, evaluation and documentation are considered by the FAO (1998) to be among the major constraints to the utilization of germplasm in national genebanks.

Information about environmental conditions of germplasm collecting sites may be important additional data for the germplasm collections, as normally those environmental conditions are associated with the different patterns of genetic variability, reflecting processes of adaptation of germplasm to the environmental factors. Peeters and Williams (1984) pointed out the importance of passport data for selection of germplasm for evaluation purposes, considering ecogeographic backgrounds of germplasm accessions. In the survey of opinions carried out by Peeters and Williams (1984), documentation of climatic data for sites was identified as desirable; 56% of the replies indicated that provision of this information would lead to an increase in the use of collections.

Many studies support the hypothesis that resistance to abiotic stresses may be found in accessions previously exposed to the specific environmental stress (Hawtin et al. 1996). Sayed (1985) evaluated the diversity of salt tolerance in a germplasm collection of wheat composed of 5072 lines of different species and different ploidy levels, collected from 17 different countries. Entries from the USA and Egypt showed the largest proportions of tolerant lines. Most of the USA lines were from California and Montana, regions considered to contain the bulk of salinised areas in the USA. Egypt, where the second greatest proportion of salt tolerant lines was found, is widely known for the presence of salt-affected soils. The author recommended the screening of germplasm from arid and semi-arid regions, especially those with salt-affected soils, if the aim is to find salt-tolerant germplasm.

Beebe et al. (1997) evaluated genotypes of common bean (landraces, cultivars and wild genotypes) to phosphorus (P)-efficiency and found that P-efficiency in landraces was related to geographic origin: genotypes from soils that are not acid (with no fixation of P through aluminum and iron oxides) generally lacked tolerance to P deficiency; on the other hand, genotypes from acid soils and critically deficient in P presented tolerance to P deficiency. Wild beans in general performed relatively poorly, suggesting that P efficiency traits in *Phaseolus vulgaris* have been acquired during or after domestication. The authors suggest, also, that a refined definition of origin could result in a stronger relationship between origin and P efficiency.

Cocks and Ehrman (1987) evaluated frost tolerance of a large number of indigenous and introduced species of Mediterranean annual legumes. They found that in most of the indigenous species, there was a significant relationship between frost tolerance and the degree of cold in the collecting sites of the species (number of days of low temperatures).

Steiner and Greene (1996) discuss the importance of obtaining information with regard to environmental conditions of the germplasm collecting sites, obtaining what they called 'ecological descriptors'. Despite the importance of information on environmental conditions of the collecting sites to the germplasm, passport data recorded by the germplasm collector usually do not supply this information. When available, the description concerning environmental conditions of the germplasm collecting sites normally vary greatly from collector to collector. Steiner and Greene (1996) argue that the absence of a precise germplasm collection site description and the lack of standardization in such descriptive data, hinders the interpretation and use of this kind of information. These authors emphasize the importance of providing standardized and detailed ecological descriptors for collected accessions and suggested a revised form for accession data collection that can be used by germplasm collectors to describe the natural features of the collection site.

Through the use of environmental maps in geographic information systems (GIS), it is possible to estimate environmental conditions of the collecting sites This methodology may be considered, in general, a new type of characterization, additional to the traditional types of germplasm characterization, and is already reported in the literature (Steiner and Greene 1996). The authors named this kind of GIS-based classification, when applied after germplasm collecting, as 'retro-classification of accessions'. The advantage of using the retro-classification of accessions is the possibility of aggregating the ecological descriptors with the large germplasm collections already established. For many such large germplasm collections, the collecting expeditions occurred some time ago, so in many cases it is not possible, or even economically feasible, to return to the respective collecting sites to gather the ecological information described *in situ*. The standardization of ecological descriptors is greatly facilitated when such descriptors are obtained through the use of environmental maps and databases in GIS.

Greene et al. (1999b) describe the use of geographical information of collecting sites in the decision about the inclusion of new germplasm accessions of forage in the *ex situ* collections; the geographical information was obtained either locally, during collecting expeditions, or later on, derived from GIS.

Information on environmental conditions of the collecting sites may be also useful in the development of core collections. The development of Core Collections, suggested by Frankel and Brown (1984), is a strategy largely approved in the context of increasing the use of large germplasm collections, and can be considered a form of 'rationalization' of such large collections. The initial demand in the development of a core collection is the division of the germplasm collection into groups that are genetically as distinct as possible. This fact has motivated a large effort into finding out new types of descriptors, external to the germplasm itself and easily obtained, which in general can be identified with the structure of the genetic variability of germplasm collection. Two groups of relatively new descriptors can fit into this category: those that recover the use, management and specific characteristics of the germplasm in their original communities (ethnobotanical descriptors) and the ecological descriptors. Many studies carried out to develop core collections found the ecogeographic origin to be a good component for germplasm classification and stratification (Charmet et al. 1993; Cordeiro et al. 1995; Tohme et al. 1995; Abadie et al. 1998; Balfourier et al. 1999). According to a global survey conducted by IPGRI about the core collections developed all over the world, geographic origin of the accessions is the most common criteria used to divide the whole collection into groups (Brown and Spillane 1999). In this survey, it was found that from the 63 core collections maintained all over the world, 57 used this criteria, corresponding to 95% of the total.

Since 1996, Embrapa Recursos Genéticos e Biotecnologia has been using environmental maps in GIS to carry out ecogeographic studies of Genetic Resources. A routine methodology was developed to overlay the geographic sites of genetic resources collecting with different environmental maps, using GIS (Melo et al 1998). More recently, GIS programmes developed specifically to carry out studies on genetic resources have been made available, such as FloraMap (Jones and Gladkov 1999) and DIVA-GIS (Hijmans et al. 2001). Guarino et al. (2002) extensively reviewed the use of GIS in the activities of conservation and use of plant genetic resources.

In this paper we present examples of characterizing accessions of large germplasm collections according to environmental conditions of the collecting sites, for two purposes: (1) to define an ecogeographic stratification for the landraces of the Brazilian Cassava Collection for the development of the Brazilian Core Collection of Cassava; (2) to identify Brazilian rice landraces collected in areas with environmental conditions of stresses related to the objectives of breeding programmes of rice in Brazil, selecting accessions for future agronomic evaluation.

Characterization of cassava landraces according to environmental conditions of origin (ecogeographic regions) to develop the Cassava Core Collection

The Brazilian Collection of Cassava is the largest national collection of this culture (Costa and Morales 1994), and contains genetic variations strategic for the development of breeding programmes at national, regional and global levels (Fukuda et al. 1997). The collection currently consists of 2931 landraces, conserved under field conditions in seven regional genebanks located at: western Amazonia (Manaus, AM), eastern Amazonia (Belém, PA), the Northeast (Cruz das Almas, BA), semi-arid northeastern Brazil (Petrolina, PE), the Cerrado (Planaltina, DF), the Subtropical Region (Itajaí, SC) and the Southeast (Campinas, SP). *In vitro* collections are also maintained at some research centers.

The importance of ecogeographic criteria for understanding the structure of genetic variability for cassava clones has been studied by several authors. Cordeiro et al. (1995) used multivariate analyses of morphological and agronomic data to evaluate the ecogeographic classification of a large sample of cassava clones (n=389) from the collection of Embrapa, representing a wide range of areas of Brazil. These authors observed that the classification produced by considering this data corresponded to the proposed ecogeographic stratification, and also observed that the proximity between some groups of accessions that were generated through this classification corresponded to the geographical proximity of the clones' areas of origin. Colombo (1997) evaluated 126 clones from different geographical sites with RAPD markers, and observed that accessions tended to group according to the ecological conditions (precipitation, temperature and ecosystem) of their areas of origin. Cury (1998) evaluated the structure of genetic variability for cassava, analyzing samples of ethnovarieties from Amazonia (two distinct basins) and from the Southeastern Region of Brazil (coastal São Paulo State). The results showed that 49% of the total genetic variance (average) for the agronomic criteria was associated with differences among the three regions.

Material and methods

Cordeiro et al. (1995) carried out an extensive study to establish the sampling strategy for developing the Brazilian Core Collection of Cassava, but at that time the actual Core Collection of Cassava was not established. In 1997, a project was conducted to develop the Core Collection of Cassava and a hierarchical stratification similar to that proposed by Cordeiro et al. (1995) was used. Two key criteria were used for the stratification of accessions: category and origin. According to category, the accessions were classified as landraces or breeding materials. Within the landrace group, the accessions were classified according to ecogeographic origin (ecogeographic regions), using GIS. The complete description of the development of the actual Brazilian Core Collection of Cassava is described in Cordeiro et al. (2000).

The ecogeographic regions defined for the stratification of the cassava collection were similar to that in Cordeiro et al.

(1995), but supplemented with new regions. Cordeiro et al. (1995) defined the following ecogeographic regions to stratify the cassava collection: Agreste, Amazon, Caatinga, Cerrado, Subdeciduous Tropical Forest, North Littoral, South Littoral and South. With the availability of GIS, environmental maps and databases, it was possible to establish new ecogeographic regions for the stratification of the cassava collection, in an attempt to consider other environmental factors that have been recognized as determinants of possible selective pressures capable of causing discontinuities in the genetic variability of cultivated cassava clones. These new ecogeographic regions are: Subtropical, Campinas of Negro River, Mosaic Vegetation, Hypo Xerophytic Caatinga and Hyper Xerophytic Caatinga

Information of original vegetation (biomes) from the Map of Federal Conservation Units of Brazil (IBGE 1994), at a scale of 1:5 million, was used to define the ecogeographic regions for most of the country. For the Brazilian Northeast Region, information of predominant original vegetation from the map of Agroecological Zoning of Northeast (Silva et al. 1993), at a scale of 1:2 million was used. The Climatic Map of the State of São Paulo (Camargo 1993), at a scale of 1:2.5 million, and the Agroclimatic Zoning Map of Minas Gerais (Queiroz et al. 1980), at a scale of 1:3 million, were used to define the subtropical region. With the exception of the Agroecological Zoning of Northeast, all those maps were digitized at the Laboratory of GIS studies of Embrapa Recursos Genéticos e Biotecnologia, using SPRING GIS (INPE—Instituto Nacional de Pesquisas Espaciais, Brasil). The contours of the Agroecological Zoning of Northeast were digitized at Embrapa Solos—Escritório Regional de Pesquisa e Desenvolvimento Nordeste—ERP/NE, and the information about the predominant vegetation was organized at Embrapa Recursos Genéticos e Biotecnologia, using ArcView (trademarks of ESRI; http://www.esri.com). These maps were combined with the aid of GIS programmes Arc/Info (http://www.esri.com) and ArcView, to produce the map with ecogeographic regions used to stratify the landraces of the cassava collection. The description of attributes and respective maps used to define each ecogeografic region is summarized as follows:

- Agreste—region localized between the most arid region (hyper xerophytic caatinga) and the Littoral, in which predominate, according to the map of Silva et al. (1993), the forms of vegetation of hypo xerophytic caatinga, deciduous forest and subdeciduous forest; it was considered that this region extends between the states of Rio Grande do Norte and the North of Bahia;
- Amazonia—contour obtained from the map of IBGE (1994), with the exception of the state of Maranhão, where the map of Silva et al. (1993) was used;
- Campinas of Rio Negro—corresponds to 'Campinarana' of map of IBGE (1994);
- Cerrado—contour obtained from Embrapa Cerrados;
- Hyper Xerophytic Caatinga—contour obtained from the map of Silva et al. (1993);
- Hypo Xerophytic Caatinga—region defined according to the map of Silva et al. (1993), considering predominantly the forms of vegetation of hypo xerophytic caatinga, but also small areas in which predominate deciduous forest, caatinga of altitude and sub-perennial forests of Piauí state;
- Mosaic Vegetation—region localized in Maranhão and Piauí states and defined according to the map of Silva et al. (1993), considering the predominant vegetation as being semi-deciduous forest (*cocal* or *babaçual* forests), grasslands and small areas of cerrado;
- North Littoral—extends from the state of Bahia through the North of Brazil, up to the state of Amapá; for the states of the Northeast region of Brazil, according to the map of Silva et al. (1993), it was considered that the forms of vegetation that predominate are perennial and semi-perennial forests; by the coast it was semi-deciduous forests, *Restinga* (relatively dense woody vegetation occurring on flat stretches of coastal plain further from the beach on sandy soils) and mangrove swamp; for the states of Pará and Amapá, it was considered to be the contours of biome Coastal vegetation, according to the map of IBGE (1994);
- Pantanal—contours obtained from the map of IBGE (1994);
- Semi-deciduous Tropical Forest—the contours of this region were defined as the biome Semi-deciduous forest (*Floresta estacional*) from the map of IBGE (1994), but excludes the states of the Northeast of Brazil and the ecogeographic regions Subtropical and South, described below:
  - South—contours obtained from the map of IBGE (1994), with the biomes Pine forest (subtropical forest with *Araucaria*), Grasslands, Grasslands of Rio Grande do Sul (*campos da campanha gaúcha*) and the area of Semi-deciduous forest (*floresta estacional*) that occupies the states of Santa Catarina and Rio Grande do Sul;
  - South Littoral—extends from the state of Espírito Santo through the South of Brazil, to the state of Rio Grande do Sul; the contours were obtained considering the biomes Atlantic forest and Coastal vegetation of the map of IBGE (1994), but excluding the ecogeographic region Subtropical, described below;
  - Subtropical—includes areas in the states of São Paulo and Minas Gerais, in which the annual mean temperatures are 19°C or bellow; contours obtained from the Climatic Map of the State of São Paulo (Camargo 1993) and with the Agroclimatic Zoning Map of Minas Gerais (Queiroz et al. 1980).

The map with the final ecogeographic regions used to classify the Brazilian Germplasm Collection of Cassava is presented in Figure 1.

The germplasm passport information was obtained through the inventory of the germplasm collection provided by the curators of regional Genebanks, up to July of 1998. The coordinates of the germplasm collecting sites were obtained in three different ways: (i) when distances of the collecting site from a specific site in a specific direction were reported in passport data, the coordinates of the collecting sites were estimated consulting a map at a scale of 1:1 000 000, the Carta do Brasil ao Milionésimo (IBGE 1972); (ii) when the specific information of collecting sites was not available in the passport data, the location of the respective municipal city was used, obtained from a digital Brazilian gazetteer (list

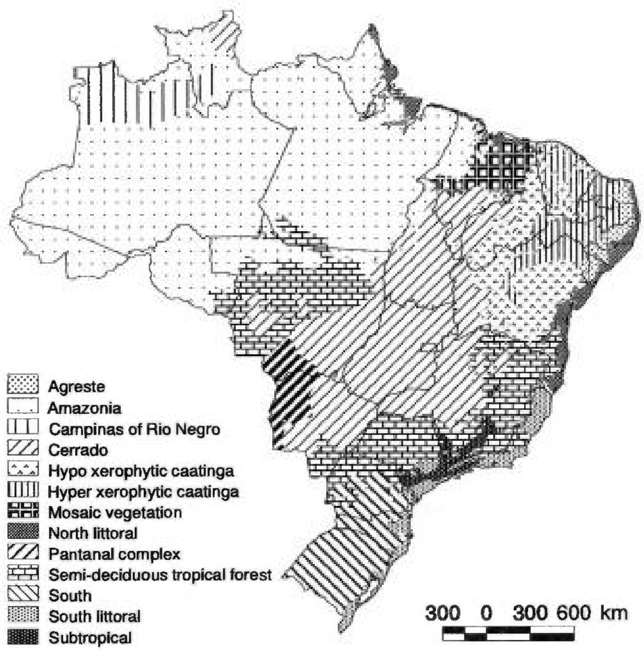

Figure 1. Ecogeographic regions used to stratify the landraces of the Cassava collection.

of geographic names and their coordinates), Cidades e Vilas do Brasil (IBGE 1995); (iii) through Electronic Global Position System (GPS) measurements (collections after 1995).

The accessions were classified into ecogeographic regions, by overlaying, in GIS Arc/Info, the geographic data of the accession collection points (origin as given by passport data) with the map of ecogeographic regions.

Other environmental factors that have been recognized as determinants of possible selective pressures were also considered, though they were not represented in the ecogeographic map. In the case of the Cerrado region, the clones were classified according to soil fertility, using information through the overlay, in GIS, of the germplasm origin with the map of Macroagroecological Delineation of Brazil (Embrapa 1992/93), at a scale of 1:5 million. The accessions were classified into two main subgroups: (1) soils with very low fertility and (2) soils with a large range in fertility (low, medium or high fertility, according to the Macroagroecological Delineation Map). In the Amazonia, South and South Littoral regions, the accessions were divided into ecogeographic subgroups, according to information available in the passport data from the collector. In the Amazonia region there were two subgroups subject to flooding conditions: dry lands (*terra firme*) and low lands (*várzea*). In the South and South Littoral regions the accessions were also classified in subgroups according to altitude (<200 m; 200–600 m; >600 m).

Results and discussion

The classification of the landraces of the Brazilian Cassava Germplasm Collection, according to ecogeographic conditions of their collecting sites (origin), is presented in Table 1.

With the availability of environmental maps in GIS, it was possible to get a more refined ecogeographic description of the regions. The Northeast of Brazil, for example, is a region of very diverse ecogeographic conditions, with a large number of cassava accessions collected. With the availability of the map of Agroecological Zoning of Northeast, it was possible to improve the discrimination of this ecogeographic diversity. Inside the Northeast of Brazil, besides the previous ecogeographic regions defined by Cordeiro et al. (1995), Agreste and North Littoral, it was possible to discriminate the Mosaic vegetation region and the different forms of Caatinga. Mosaic Vegetation is a region of ecological transition in Maranhão and Piauí states. The different forms of Caatinga, Hypo Xerophytic Caatinga and Hyper Xerophytic Caatinga, reflect the different levels of water stress in the semi-arid region. Another important region that could be established through the use of GIS is the Subtropical region. This region was established to separate the cooler regions inside São Paulo (where there is a large number of collections) and Minas Gerais states, which was considered very important by the Curator of the Southeast Regional Genebank—Campinas/SP (T.L. Valle pers. comm.). The discrimination of this region was possible using the climatic maps of São Paulo and Minas Gerais states.

Other advantages of performing the classification of germplasm accessions according to ecogeographic conditions in GIS, when compared with the ecogeographic classification performed visually, are the improvement of accuracy and the automatization of the process. GIS guarantees a more precise cartographic representation of the ecogeographic regions and of the germplasm collecting sites. After the establishment of the map with the final ecogeographic regions (Figure 1), the classification of the 2617 accessions of cassava was performed very rapidly, when compared with the ecogeographic classification performed visually in the previous study with cassava (Cordeiro et al. 1995).

Mapping the collecting sites of cassava landraces with GIS allows the identification of regions that are underrepresented in the collection, which is important for planning new collecting expeditions Considering that cassava landraces are

Table 1. Classification of the landraces of the Brazilian Cassava Germplasm Collection according to ecogeographic regions

Ecogeographic regions	Number of accessions
Agreste	122
Amazonia	511
Campinas of Rio Negro	87
Cerrado	284
Hyper Xerophytic Caatinga	191
Hypo Xerophytic Caatinga	282
Mosaic Vegetation	29
North Littoral	263
Semi-deciduous Tropical Forest	258
South	175
South Littoral	390
Subtropical	25
Total	2617

cultivated almost all over the country, the regions that need more collecting expeditions are Amazonia, Cerrado and Semi-deciduous Tropical Forest, which are mainly the parts of this region that occupy the West of Brazil (Figure 1). On the other hand, it is possible to see that some states, such as São Paulo, are possibly overrepresented in the collection.

Characterization of rice landraces according to environmental conditions of origin with emphasis on stresses related to the crop breeding programme in Brazil

The search for genetic variation is of great importance for rice breeding. Pedroso (1990), Guimarães (1993) and Rangel et al. (1996) have reported on the narrow genetic base of irrigated and upland rice cultivars that are most cultivated in Brazil. Rangel et al. (1996) observed that 68% of the gene pool of irrigated rice analyzed were derived from only 10 ancestors. The genetic bases of upland rice cultivars is even narrower, as just 10 ancestors account for 78% of the genes (Montalaván et al. 1998). Rangel et al. (1996) suggest some alternatives for achieving a broader genetic base for rice genetic breeding, and one of them is the use of landraces in multiple crosses with inbreed elite lines.

The Rice Germplasm Collection of Embrapa has almost 9500 accessions, of which 3920 were introduced, 3400 are improved cultivars and 2212 are landraces. Those landraces were collected in different regions of Brazil. It should be mentioned that the cultivated rice (*Oryza sativa* L.) has been grown in Brazil for more than 400 years. Pereira (2002) reports that cultivated rice was introduced into Brazil in the XVI century. These landraces have been characterized morphologically and agronomically in Embrapa Arroz e Feijão since the 1970s. Approximately 3000 accessions have been characterized for at least seven morphological descriptors of rice. Agronomic evaluation focused mainly on diseases, levels of lodging, seed dormancy and fenology (Fonseca et al. 1981, 1982; Fonseca and Bedendo 1984). Some accessions were characterized to survive under specific adverse conditions, such as water stress. More recently, studies of genetic analysis using molecular markers were conduced on wild species (Buso et al. 1998) and on landraces of rice (Ferreira et al. 1996; Silva et al. 1999).

The correlation between rice genetic variability and geographic origin has been studied by several authors. Buso et al. (1998) studied the genetic variability of four South American wild rice populations (*Oryza glumaepatula*) with isozyme and RAPD markers. In this study it was found, with both types of markers, a pattern of greater variation between than within populations, and the AMOVA analysis indicated that a large portion of the total genetic variation was attributable to regional divergence. These results suggest that, as strategies for future collecting expeditions, the focus is on as many populations as possible from both regions (Amazon River and Paraguay River basins). Glaszmann (1988) studied the pattern of variation among Asian rice landraces (natives) based on isozyme analysis and found that the geographic pattern of variation among varieties was largely related to the existence of varietal groups. Considering the species as a whole, this study found that isozyme polymorphism exhibited strong correlations with both environmental (e.g. altitude) and macrogeographic (e.g. latitude) parameters.

The Brazilian breeding programme of irrigated rice focuses on obtaining cultivars adapted to the abiotic stresses related to low temperatures and soil salinity (Rangel 1994). Problems of soil salinity are normally more accentuated under conditions of irrigation. The breeding programme of upland rice focuses on obtaining cultivars resistant to water stress and cultivars adapted to soils with very low fertility (low levels of phosphorus, potassium, calcium and magnesium and high aluminum saturation).

The landraces rice from Brazil were mapped geographically, and the complete results of this mapping is presented in Burle et al. (2001). In this paper we present the results that are concerned with the identification of accessions collected in regions with adverse conditions related to the actual breeding programme of rice in Brazil: regions with cooler thermic regimes; regions with soil salinity; semi-arid regions and regions in which soils of very low fertility predominate; and the original vegetation of Cerrado.

Materials and methods

The passport information was obtained through the inventory of the germplasm collection provided by the curator of the Rice Genebank, in Embrapa Arroz e Feijão. For the majority of the rice accessions, the only information in the passport data was the name of the municipal district in which the collection occurred. Therefore, in these cases, the coordinates of germplasm collecting sites were taken as those of the respective municipal city obtained from a digital Brazilian gazetteer, Cidades e Vilas do Brasil (IBGE 1995). For 106 rice accessions, the passport data had some more detailed information about the collecting sites (such as distances in kilometers from a city or through a specific highway) and, in these cases, the coordinates of collecting sites were estimated by consulting the maps of Carta do Brasil ao Milionésimo (IBGE 1972). For the accessions collected in 1998, collecting sites coordinates were based on electronic global position system (GPS) measurements.

For the classification of accessions according to thermic regimes, the 'Brasil Climas' map at a scale of 1:5 million (IBGE 1978) was used, which considers the climatic classification described by Nimer (1979). This map was digitized in the Laboratory of GIS studies of Embrapa Recursos Genéticos e Biotecnologia, using Arc/Info. According to this classification the following climatic domains are the cooler ones in Brazil: Soft mesothermic (at least one month shows a mean temperature lower than 15°C) and Medianum mesothermic (at least one month shows a mean temperature lower than 10°C; summer has milder temperatures, as the mean temperature of the warmer months oscillate around 20°C).

The map of the Agroecological Zoning of the Northeast (Silva et al. 1993), at a scale of 1:2 million, was used to identify accessions collected in regions in areas where saline soils (which is predominantly in the Northeast region of Brazil) and the semi-arid regions occur. This zoning defines Geoenvironmental Units, entities in which the types of soils and their distribution according to topography, natural vegetation and rainfall precipitation regime constitute a homogeneous set, with minimum variability, according to the cartographic scale. For the identification of accessions collected in regions of soils with salinity, the units were considered as 'Geoenvironmental Units with salinity', i.e. those units that present at least one type of soil with salinity. For identification of accessions collected in semi-arid regions, the consideration was areas in which predominate, as original forms of vegetation, those typical of the Brazilian semi-arid, such as Hyper Xerophytic Caatinga, Hypo Xerophytic Caatinga and Deciduous Forests. Within the regions where Deciduous Forests predominate, only the regions with mean annual rainfall precipitation lower than 1000 mm were considered as semi-arid regions in this study. The contours of the Agroecological Zoning of Northeast were digitized at Embrapa Solos—Escritório Regional de Pesquisa e Desenvolvimento Nordeste—ERP/NE, and the information of each Geoenvironmental Unit, with regard to the predominant original vegetation, edaphic conditions and mean annual rainfall precipitation, was organized at Embrapa Recursos Genéticos e Biotecnologia, using ArcView.

Edaphic and original vegetation information from the map of Macroagroecological Delineation of Brazil (Embrapa 1992/93), at a scale of 1:5 million, was used to identify accessions collected in regions that show low fertility and acid soils, typical of the Cerrado environment. The regions in which this delineation classifies the soil fertility as very low and the original vegetation as Subdeciduous cerrado ('Cerrado subcaducifólio') or Cerrado grasslands ('Campo cerrado') were considered as regions of acid soils and soils with low fertility. For the accessions collected in the Northeast Region of Brazil, information regarding original vegetation from the map of Agroecological Zoning of the Northeast was used (Silva et al. 1993). The map of Macroagroecological Delineation of Brazil was digitized in the Laboratory of GIS studies of Embrapa Recursos Genéticos e Biotecnologia, using SPRING GIS.

The overlays of the germplasm collecting sites and the environmental maps were also performed in Arc/Info. The final maps presented in figures, consultations and corrections of the database were performed in ArcView.

Table 2. Number of accessions of rice landrace germplasm collected in regions with adverse conditions

Adverse conditions	Number of accessions			
	Upland rice	Irrigated rice	Both systems	Total
Cold climate	50	20	19	89
Soil salinity	49	28	4	81
Semi-arid region	29	20	3	52
Low fertility of soils and Cerrado	358	13	10	381

Results and discussion

Accessions of cold climate

Eighty-nine accessions of rice germplasm collected in regions classified as cold climatic domains (Mesothermic) were identified (Table 2). From those, 50 are of upland rice, 20 of irrigated rice and 19 of both systems, irrigated and upland rice.

In the cooler climatic domain (Medianum mesothermic), in which even the summer presents milder temperatures, just two accessions of rice were collected, in the region of 'Serra da Mantiqueira' in the state of Minas Gerais. The accessions classified as Soft mesothermic domain were collected in the following states: 43 in Minas Gerais; 29 in Santa Catarina; 11 in Rio Grande do Sul; and four in Paraná.

The regions of Brazil occupied with the Mesothermic climatic domain and rice germplasm collecting sites within these regions are presented in Figure 2. It can be identified that these regions had not been well sampled for rice germplasm, although there is information of rice landraces cultivation in such areas. An example is 'Serra Gaúcha', represented in Figure 2 by its main towns. Those regions should be a priority for future collecting expeditions if the aim is to get rice germplasm adapted to cold conditions.

Accessions of regions with soil salinity

Eighty-one accessions of rice were identified as having been collected in regions of the Northeast of Brazil in which soils with salinity occur, mainly in the State of Piauí (69 accessions).

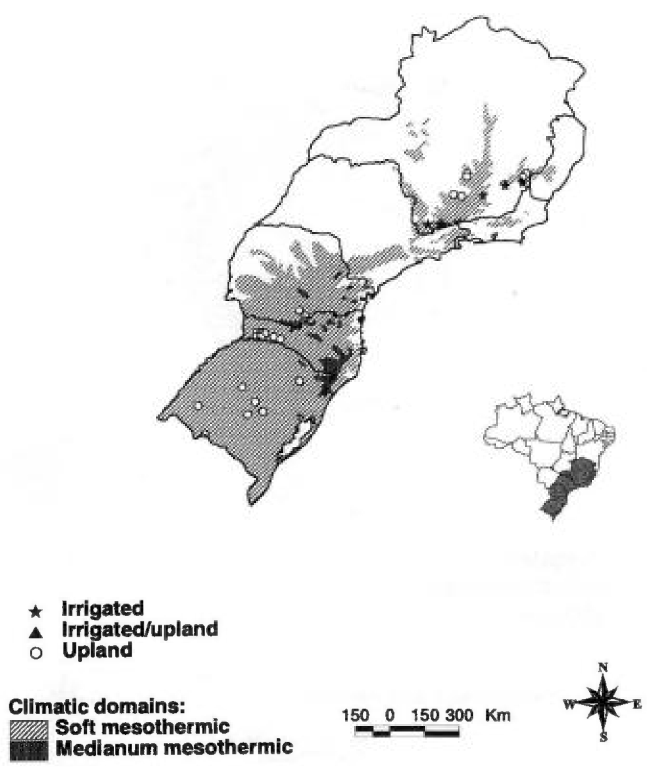

Figure 2. Regions of Brazil with cooler climate (Mesothermic climatic domain), and rice germplasm collecting sites of these regions and towns of 'Serra Gaúcha'.

From the accessions, 49 are of upland rice, 28 of irrigated rice and four of both upland and irrigated systems (Table 2).

Due to the low scale of the map used for identification of regions with soil salinity, and considering the high spatial variability of soils, it is not possible to affirm that all of those 81 accessions identified had been cultivated under soil salinity conditions. Nonetheless, if the aim is to find resistance to this stress condition in the whole genebank, those should be the first set of accessions to be submitted to agronomic evaluation for soil salinity resistance. As the problem of soil salinity is more pronounced in conditions of irrigation, it is expected that accessions of irrigated rice collected in this region are stronger candidates for adaptation to soil salinity.

The regions in the Northeast of Brazil in which the Agroecological Zoning of Northeast describes the presence of soils with salinity, besides other types of soils, are presented in Figure 3, together with the collecting sites of rice landraces of such regions. It can be observed that these regions have minimal sampling for rice germplasm, although there is information of cultivation of rice landraces in them. These regions should be a priority for future collecting expeditions if the aim is to get rice germplasm adapted to soil salinity.

Accessions of semi-arid region

Twenty-nine accessions of upland rice were identified as having been collected in the Brazilian semi-arid region in which the original vegetation is composed, mainly, of caatingas and deciduous forests and mean annual rainfall precipitation ranges between 600 and 960 mm (Table 2). Besides those accessions of upland rice, another 20 of irrigated rice and three of both upland and irrigated cultivation systems were collected in this semi-arid region.

In Figure 4, the semi-arid region and the collecting sites of rice landraces are presented. This figure also illustrates the types of predominant original vegetation of the semi-arid regions, which can give an idea of the different degrees of water stress in this region. The most arid region is where the predominate vegetation is Hyper Xerophytic Caatinga, with mean annual rainfall precipitation ranging from 370 to 970 mm. Although there is information about rice landraces cultivation in the semi-arid region of Brazil (predominantly irrigated rice, but also a lower proportion of upland rice), it can be seen that most of this region has not been sampled for rice germplasm, and should be a priority for future collecting expeditions if the aim is to get rice germplasm adapted to semi-arid conditions.

Accessions of regions with soils of very low fertility and original vegetation of Cerrado

A total of 381 accessions of rice germplasm were collected in regions with a predominance of soils with very low fertility and original vegetation of Cerrado (Table 2). Of these, 358 accessions are of upland rice, 13 accessions are of irrigated rice and 10 are of both systems (upland and irrigated). In the same way as mentioned for the aspect of soil salinity, because

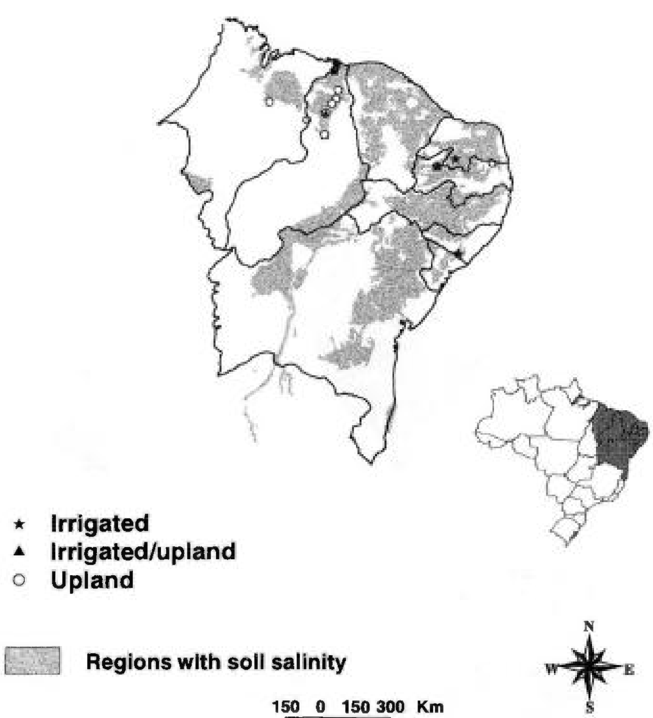

Figure 3. Regions in the Northeast of Brazil with presence of soils with salinity, and rice germplasm collecting sites of these regions.

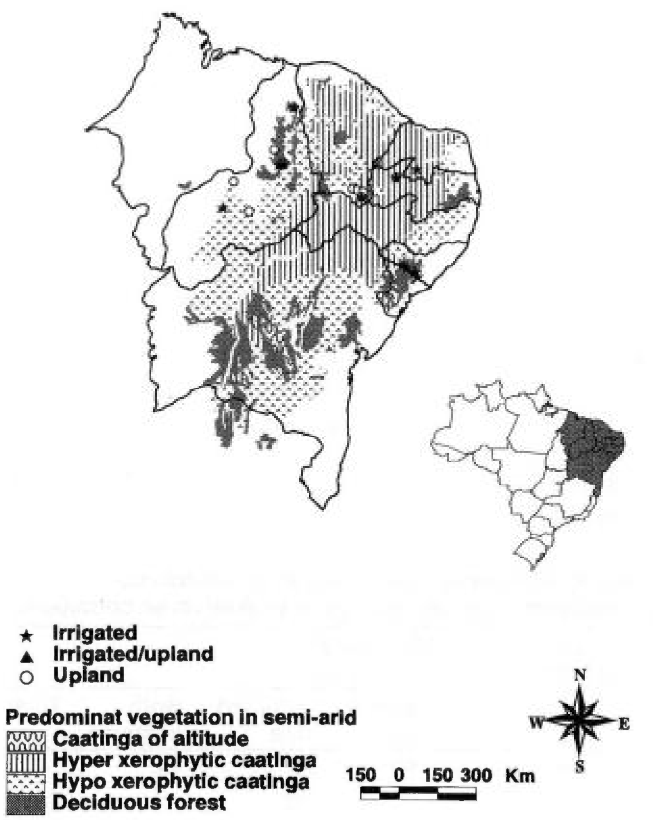

Figure 4. Semi-arid region of Brazil classified according to the predominant original vegetation, and rice germplasm collecting sites in this region.

of the scale of the map used for identification of regions with soils of very low fertility, and considering the high spatial variability of soils, it is not possible to affirm that all those accessions identified had been cultivated under these specified conditions. Nonetheless, if the aim is to find rice germplasm adapted to this stress condition in the whole genebank, those should be the first set of accessions to be submitted to agronomic evaluation for this purpose.

The regions in which soils with very low fertility and original vegetation of Cerrado predominate, according to the Macroagroecological Delineation of Brazil and rice germplasm collecting sites of such regions, are presented in Figure 5. Large areas in these regions can be identified as being under-sampled for rice germplasm, such as in the states of Mato Grosso, Mato Grosso do Sul, Tocantins, Minas Gerais and Maranhão.

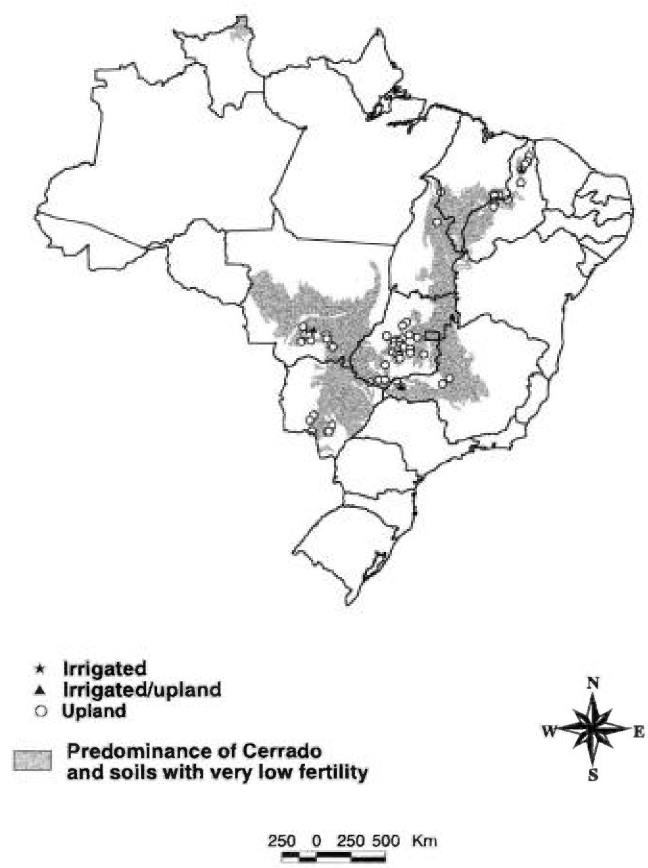

Figure 5. Regions of Brazil in which soils with very low fertility and original vegetation of Cerrado predominate, and rice germplasm collecting sites in these regions.

Final considerations

The characterization of germplasm according to environmental conditions of collecting sites through GIS is a new tool that may help in understanding and accessing the genetic variability of large germplasm collections. In addition, this new type of characterization supplies information to users that may help to define strategies to rationalize and intensify the proceedings of germplasm evaluation to specific purposes. As a consequence, this methodology may come to be used as an additional tool to intensify the use of such large germplasm collections.

The new type of descriptors obtained, the ecological descriptors, agree with the suggestions proposed by Peeters and Williams (1984) towards a better use of genebanks. These authors pointed out a number of constraints about the information of large genebanks, indicating that a new approach towards information capture in genebanks was required. We believe that the situation in genebanks has not changed too much since then. Those authors pointed out the importance of passport data for selection of material for evaluation purposes, emphasizing that by using this information samples can be taken on the basis of their ecogeographic backgrounds and this would increase greatly the chances of identifying particular genes or gene combinations needed by breeders.

The technology available through the use of GIS will certainly facilitate a widespread use of the ecological descriptors. Its use enables the establishment of new patterns of acquisition to these descriptors, using a minimum of field information and improving the quality and standardization of passport data in large collections. An important advantage of using GIS to characterize germplasm according to origin, using ecological descriptors, is the low cost of the methodology. The digital databases (maps) can be continuously updated and can be used in studies on other germplasm collections with almost no additional cost. The environmental maps digitized at Embrapa Recursos Genéticos e Biotecnologia had been used in other studies with genetic resources carried at this Embrapa research Center, e.g. preliminary ecogeographic studies with *Manihot* sp. (Burle et al. 1997) and *Arachis* sp. (Burle and Valls 1997), and are available to other institutions such as IBAMA, Ministério da Saúde and Universidade Federal de Viçosa.

van Hintum (1999) proposes the 'core selector', a system to generate representative selections of germplasm collections, as an important innovation in the attempts to make germplasm collections more accessible. In this system the accessions are classified into groups, with different priorities for selection. If the user is more interested in genotypes adapted to specific environmental conditions, the methodology described in this paper may be useful, generating environmental criteria for the core selector system.

Maps with scales varying from 1:5 million to 1:2 million were used for the classification of cassava and rice germplasm collections. Those regional-scale maps are limited in their degree of details. Greene et al. (1999a) used GIS databases varying from 1:2.5 million to 1:250000 in their classification of germplasm collected in Russia. It should be mentioned that the limited degree of details in available natural resources surveys in Brazil, results in low-scale maps. The Radambrasil was the only project in Brazil that carried out surveys of natural resources in broad geographic areas. Although the surveys from this project were performed at a scale of 1:250000, the resulting maps were published at a scale of 1:1 million, covering the themes of vegetation, geology, pedology and geomorphology. For most of the countries, all over the world, there is low availability of detailed surveys for broad geographic areas.

There is no doubt that more detailed maps are required for a more precise description of environmental conditions of germplasm collecting sites. Nevertheless, in the absence of more detailed environmental databases, we do believe that those regional-scale maps can aggregate some valuable information about environmental conditions of the many collecting sites of large germplasm collections. Beebe et al. (1997) compared the P efficiency of 364 accessions of bean germplasm, collected in a broad geographic range, and found a relationship between origin and P efficiency. In this study, soil maps were not used to classify accurately the origin of bean germplasm, and the authors argue that a refined definition of origin could result in a stronger relationship between origin and P efficiency.

In the future, a major emphasis should be put on the use of GIS databases that cover continental areas, rather than individual countries. This would bring the benefit of standardizing the description of ecological conditions of collecting sites, as suggested by Steiner and Greene (1996). Global interpolated climate databases are already available, as the CIAT climatic database (Jones 1991), and other climate databases referred to in Genetic Resources GIS programmes Floramap (Jones and Gladkov 1999) and DIVA-GIS (Hijmans et al. 2001).

After these case studies with cassava and rice, a similar study in the Brazilian germplasm collection of maize has been carried out in Embrapa Recursos Genéticos e Biotecnologia, with the objectives of applying the ecological descriptors and of studying the geographic distribution of diversity of such a germplasm collection, using also DIVA-GIS. As further studies, the authors plan, to use these environmental maps here referred and also DIVA-GIS and FloraMap, to carry on eco-geographic studies of wild species of *Manihot*, considering the large number of wild *Manihot* species that occur in Brazil.

We expect that the methodology described in this paper will find a large application in studies of genetic resources, contributing to a better access and use of large germplasm collections. From our point of view, there is no major limitation on the use of GIS in Plant Genetic Resources Programmes, especially considering that the technology involved is very cheap, compared with others. The success in the application of GIS in the future will mainly rely on an adequate communication of its potential and on the availability of friendly software and databases.

Acknowledgements

The authors would like to thank Sérgio Noronha for his help with the elaboration of the maps. The consultanceship of Dr Tabaré Abadie was supported by IICA-PRODETAB.

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