Chapter 17
Agricultural Biodiversity and Rural Systems of Seed Production

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The domestication of plants and animals, and the selection and exchange of these domesticated populations between farmers, along with the movement of genetic resources during human migration and the adoption of various strategies to protect against sanitary risks (Chap. 16) have been occurring throughout the history of agriculture. This long process of domestication gathered momentum in the second half of the twentieth century under the impetus of agricultural modernization, or at least as was experienced in one part of the world in the 1950s (Chap. 2). The Green Revolution, which took root especially in the countries in the South, is based on the key role of modern varieties and hybrids (Bonneuil and Thomas 2012). No doubt, agricultural research has, on the whole, supported the Green Revolution, with the creation of CGIAR (Consultative Group on International Agricultural Research) reflecting the desire to use genetic progress as the spearhead of the agricultural revolution. In this way, agricultural research has overwhelmingly embraced modern plant breeding concepts; – concepts that are based on intensive cultivation (irrigation and chemical inputs) of high-yielding varieties.

Two strategies are combined to support this modern plant breeding model: first, the conservation of germplasm collections of major crops at locations other than the production locations (ex situ) and, second, plant breeding, varietal selection and a professionalized production of seeds (Chap. 13) (Louafi et al. 2013). This research

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and development strategy, associated with research on genetics and breeding, has been widely adopted in the North and partially so in the South, within the framework of an intensive and standardized industrial agriculture.

A different viewpoint of mankind's relationship with nature has, however, emerged with the signing of the Convention on Biological Diversity (CBD) in 1992 (Chap. 13) which offers an alternative approach to current varietal research. The generalization of the concept of "agrobiodiversity" reflects the need to understand the diversity of cultivated plants in the context of agricultural history with its stages of agricultural domestication and selection, while revisiting the link between the cultivated space and its environment. The relationship between the loss of biodiversity, loss of cultural diversity and loss of knowledge is being increasingly documented (ISE 2013), despite it being subject to some controversy.[1] Recent "biocultural" studies reveal the growing importance of the new paradigm of "ecological and integrated management of natural resources for food and environmental preservation" in contrast to dominant approaches (Chevassus-au-Louis and Bazile 2008). In the report by the CBD Secretariat (Secretariat of the Convention on Biological Diversity 2010), the in situ maintenance of a dynamic agricultural biodiversity is described as the major component for adoption and sustainability of agricultural and food systems. Agricultural research must therefore offer synergies between agriculture and biodiversity that promote and support agricultural and rural development (Hainzelin 2013).

Research can help family farming find answers to these complex questions. Indeed, research on plant breeding now takes criteria defined by family farming into account for the adoption, conservation and dissemination of agrobiodiversity in diverse situations (Chap. 13). Using actual examples, this chapter illustrates this development in different plant breeding situations for crops predominantly cultivated by family farmers. It shows how small farmers are involved in the processes of creating and disseminating new varieties of coffee and cocoa in agroforestry systems which, in turn, fulfill functions pertaining to food, the environment, energy, medicine and culture. An economic dependence of these systems on export crops makes them vulnerable to price fluctuations in international markets. Moreover, these systems are constrained by the inability of farmers to invest in their cultivations. In such situations, any research intervention has to be contextualized and tailored to existing dynamics. Food problems assume enormous proportions in dry areas that support large populations. This is why emphasis is given to participatory breeding methods for traditional food crops which have multiple traditional uses, for example, sorghum in Africa and quinoa in The Andes. Finally, this chapter discusses how research, through companion modeling, encourages local seed production systems, and promotes their development by improving knowledge exchanges between actors in these systems, their training and nurturing of new partnerships.

[1] Thus Kohler (2011) developed the concept, now found frequently in the literature, of "a particularly forced analogy between cultural diversity and good environmental health," and stressed the dangers of such an analogy. The criticism and debates that followed this publication demonstrated the extent of the controversy.

17.1 An Innovative Partnership in Coffee Production in Central America

The fall in coffee prices in the late 1990s forced many small Central American producers out of the international market because their production costs were higher than in other coffee growing regions like Brazil and Southeast Asia (Kilian et al. 2006). In Nicaragua, Arabica coffee traditionally constitutes the bulk of the coffee production, 80 % of it being grown by small family farmers in agroforestry systems with less than 3.5 ha of land.

Research and collaborations have helped improve coffee varieties for over 50 years. Numerous research institutions (ORSTOM, CIRAD, CNRA/Côte d'Ivoire, Madagascar) worked between 1960 and 1990 to identify wild coffee varieties and analyze their phenotypic diversity. These activities were "academic" in nature, that is to say they were oriented towards gathering knowledge and not towards development. CIRAD and Promecafé[2] worked in partnership from the 1990s to breed new F1 hybrid varieties in Central America to expand the tiny genetic base of Central American coffee varieties. These hybrids were derived from crosses between American varieties and "wild" coffee varieties from Sudan and Ethiopia (identified by FAO and Orstom in 1967). Genetic material from Sudan and Ethiopia is endowed with added resistance to certain diseases and has important organoleptic qualities. "Standard" practices to improve varieties are based on intensification principles and help develop hybrids derived from crosses between lines with a narrow genetic base. F1 hybrids are designed for very intensive cropping systems that receive full sunlight, corresponding to an intensive and artificialized form of agriculture. In the case of Arabica, the hybrid program in Nicaragua sought to improve productivity and quality (Bertrand et al. 2005) while respecting the typical agroforestry systems of family farming. The results of 20 years of experiments in controlled environments and in producers' fields have shown a 30–60 % increase in yield for F1 hybrids, obtained from crossing between American varieties and wild coffee from Ethiopia, as against the best varieties in the American small-scale farming systems, an achievement that involved no fertilizers inputs which are, in any case, beyond the reach of small coffee growers (Bertrand et al. 2012).

The development of a vegetative (or clonal) propagation method through research then opened up the possibility of producing hybrid plants on a large scale, even though hybrid material is usually reproduced by seeds from crosses. However, the in vitro somatic embryogenesis technique that was developed had the drawbacks of being inherently complex and of needing a significant initial investment – with uncertain returns – from financially strapped family farmers. CIRAD was therefore on the lookout, since 1999, to team up with a private partner to commence large-scale multiplication of F1 hybrids. A contract was signed with

[2] An agreement for cooperation that bring together the governments of several coffee producing countries in the region with the purpose of increasing coffee cultivation as a socio-economic activity through a transition to agroforestry-based ecologically intensive agriculture.

Ecom Coffee in 2003 (Étienne et al. 2012) to mass produce F1 hybrid plants for the market. A laboratory for in vitro micropropagation was established in Nicaragua and began production in 2006. Along with the creation of the hybrids in the laboratory, they were also being tested extensively on farms. Field results confirmed that F1 coffee hybrids met the expectations of productivity and of organoleptic qualities. The model to produce hybrids in laboratories and nurseries became operational and reproducible in 2011 (Étienne et al. 2012).

All actors in the network, ranging from the research consortium to the users, have been involved since 2006 in the process of disseminating hybrids to the farmer. The research team not only provided advice to fine-tune adaptation of hybrids to climatic and soil conditions, but also initiated fresh research to develop new varieties and concepts (catalogs of varieties, technified nurseries, etc.) in order to address local issues.

A posteriori, one of the major obstacles encountered in transferring this technology was the inability to scale up as fast as necessary. The adoption of these plants at the individual level was supported by Sustainable Management Services (SMS, a subsidiary of Ecom), whose brief included disseminating plants as well as transferring the knowledge generated to help producers in their training. In return, the institutions could use field results and the changes and limitations observed to develop measures to fine-tune the approach. A process of hybrid awareness (*conciencia híbrida*) was initiated among farmers and the demand for hybrids rose steadily. This resulted in the "hybrid variety" becoming a scarce resource and Ecom's credibility as a supplier of high-yielding varieties began to suffer. The partnership with CIRAD thus became strategic in order to ensure a greater diversity of supply and to meet an increasingly specific and growing demand.

In order to leverage the value of these highly desired hybrids, the Diamond Coffee certification label was registered in 2012 for coffee made from these hybrids. This label describes original coffee that has been cultivated at a minimum altitude of 1,100 m above sea level, under shade and complying with stringent specifications. Under these conditions, Diamond Coffee develops organoleptic qualities which are considered to be unique. The hybrid coffee's high productivity and rarity seem to offer a new market opportunity to some producers, as also the possibility of creating a cluster to enjoy particular services and benefits (funding, specific business opportunities, etc.) provided by the trading company. Unfortunately, this "elitist" approach of the Ecom Group de facto cut off access to innovation for producers who were located outside the favorable areas. However, these farmers were all potential suppliers and customers of the trading company. As a result, further research was conducted to produce high yielding line-varieties that could be adapted and adopted by all types of farmers. The *Marsellesa* line-variety was thus introduced in 2013. This variety is resistant to many diseases and has a productivity midway between those of hybrid and traditional American varieties. It produces a coffee with a high sensory quality. An added advantage for producers, when compared to hybrids, is that it can be reproduced through seeds. Once they acquire the initial plants, producers have the right to reproduce the variety for their own needs. Ecom-SMS supports this activity by offering a premium to producers who cultivate *Marsellesa* coffee.

It is still too early to judge the impact of this public/private partnership on coffee-based agroforestry conservation systems or on the economic benefits for small farmers who did, or did not, adopt these hybrids or the new *Marsellesa* line. However, an initial sociological study conducted in 2012 and 2013 showed that innovation and collective learning processes that marked the release of new coffee varieties to small Nicaraguan family farmers led to innovative practices and adaptation strategies. The study clearly showed that small farmers who adopted the new varieties enhanced their production potential (Alami et al. 2013). The role of intermediation played by researchers has led to a broader vision and a transfer of the research and development model to Mexico, where the project is currently experiencing a particularly good growth. These small farmers were able to convey their requirements to the trading company and the public research support community, which ultimately resulted in a wider dissemination of genetic progress.

17.2 Management of Cocoa Varieties in Cameroonian Agroforestry Systems

Three million small farmers cultivate about seven million hectares of cocoa (*Theobroma cacao* L.), with 85 % of this production coming from family farms of a few hectares. Global demand, particularly in Europe, is continuously rising and the area under cultivation is expanding rapidly. Although the plant is native to the Amazon regions in the northern parts of South America, Europe gets the bulk of its supply from West Africa which, with two million cocoa farmers, accounts for over two-thirds of the world's total production.

Cocoa farmers in Africa have little capital at their disposal and the needs of the family are met from forest produce during the initial years of cultivation. It is an economic system based on "forest income" in which forest resources help offset the lack of income until the plantation can start producing cocoa. The family farmers' know-how and experience is what amounts to capital in this system. Cocoa is grown mainly "under cover," i.e., in the shade of trees within the complex agroforestry systems. Production is based on the association between cocoa and various perennial fruit and forest species. Fruit trees provide a valuable dietary supplement and an additional income, all the more useful to family farmers whose main income is from cocoa, which materializes only in the last quarter of the year. Forest species are useful in various ways (shade, improved soil fertility, pharmacopoeia, firewood, timber). Cocoa-based agroforestry systems are considered a good alternative land use to cope with climate change because of their high levels of species diversity, of soil cover they maintain throughout the year and the carbon they help store below and above the ground (Somarriba et al. 2013).

Low prices of cocoa in the 1990s led to a drastic decline in funds for cocoa breeding programs. The first project of the Common Fund for Commodities (CFC), associated with the International Cocoa Organization (ICCO) and the International Plant Genetic Resources Institute (IPGRI, later renamed Bioversity International), brought together ten countries: Papua New Guinea, Nigeria, Ghana, Côte d'Ivoire, Cameroon, Brazil, Venezuela, Ecuador, Trinidad and Tobago, and Malaysia. When this project got underway, most of its constituent partners and the major cocoa producing countries, namely Cameroon and Nigeria, were facing a virtual standstill of their cocoa breeding programs. Amongst these countries, only Brazil and Malaysia have extensive industrial-type plantations. The cocoa crop there came under great pest pressure which affected yields and product quality. The spread of pests and diseases was of particular concern in new areas that were rapidly being brought under cocoa cultivation (Eskes 2011). The second phase of the CFC/ICCO/Biodiversity project (Eskes 2011) continued and intensified breeding activities and developed participatory approaches such as farm surveys and the direct participation of farmers in the selection of trees on their farms. CIRAD, in association with the Cameroonian Institute of Agricultural Research for Development (IRAD), supported various participatory projects on breeding and crop production.

Several research projects conducted in Cameroon since 2003 had an on-farm research component to evaluate the cultural and sanitary aspects of these systems and suggest improvements. The agronomic and economic performance of these systems exhibited a wide variation depending on regions and cultivation techniques (Jagoret et al. 2009). A major source of variation was discovered to be the density of shade trees used which, when it is too high, greatly reduces the cocoa yield (Jagoret 2011). The effect of shade trees on damage caused by phloem-feeding insects – the mirids (*Sahlbergella singularis* and *Distantiella theobroma*) – was studied. These insects damage plants and pods, often even leading to the death of trees. Yields can drop by as much as by 40 % in West Africa. Mirids are generally more numerous in plots that are less shaded. Open, illuminated areas that are a result of canopy gaps and the presence of certain species, like the kola, encourage the presence of these insects (Babin et al. 2010). These multidisciplinary studies have highlighted the importance of proper shade management to control these major cocoa pests. A similar study is currently underway on black pod rot, a major disease caused by the fungus *Phytophthora megakarya*.

The continuous rise in cocoa prices (+66 % since 2007, according to ICCO), partly due to the negative impact of diseases and the climate on crops, has led to an increase in farm gate procurement prices. The rapidly increasing demand for cocoa has led to a vast expansion of new cocoa plantations in recent years. At the same time, access to improved varieties has been very limited. State entities, the National Cocoa Development Company (SODECAO) and the Cocoa and Coffee Seed Project (CCSP) that are in charge of managing seed production fields and disseminating these varieties manage to meet only 20–30 % of the national demand (Asare et al. 2010). Since 2006, CIRAD, in partnership with IRAD, has therefore initiated various participatory programs to breed, evaluate and produce plants to help farmers obtain the varieties best suited to their needs.

Plant breeding activities are mainly carried out in a network of 80 coparative progeny trials. These trials are spread out over three *départements* of the Center Region of Cameroon and correspond to three different environments. About 150 progenies of various origins were studied. They were either progenies of released varieties obtained from seed production fields, created through manual crossing at the research station, or created from open-pollinated pods harvested from tree species jointly selected by producers and breeders (the selection is based on productivity and tolerance to black pod rot) or, finally, originating from open-pollinated pods harvested from trees selected randomly from farmers' plots. This latter progeny type corresponds to planting material generally used by small farmers who do not have access to commercial varieties.

Another factor behind the low production of agroforestry-based cocoa farms is their advanced age of the trees. Research has been conducted since 2007 on a regeneration technique based on coppicing cocoa plants, followed by grafting shoot rejects using grafts taken from selected trees. These regenerated plots are used for clonal trials in different environments to compare clones bred at research stations with those bred on farms. Genetic resources are conserved and improved planting material disseminated using a similar method in small seed production fields managed by farmers. Pods (or seedlings from such pods) are sold by farmers or farmers organizations (FO), which may stock these resources to establish new plots. Clones and progenies thus acquired enable family farmers to regain access to planting material in an independent manner, a freedom that was forfeited when they chose to use hybrids produced at a research station (Ruf 2011). This operation began in 2008 and resulted in the establishment of seed production fields in five *départements* of the Center Region of Cameroon.

The impact of projects implemented since 1998 has been significant as much in terms of planting material quality as of the partnerships forged and the training of farmers and technicians (Efombagn et al. 2011). Participatory programs resulted in an increase in multidisciplinary activities involving plant pathologists and entomologists. A hundred small cocoa farmers were involved in these programs. Not only did they gain access to improved varieties and technical training on cocoa (nursery, plantation, plot management, grafting, vegetative propagation), but also to the development of other components and aspects of the agroforestry system (oil palm, fruit trees, plantains, quality of shade, control of predators). These activities were developed through new partnerships with local NGOs, IRAD researchers, the World Agroforestry Centre (ICRAF) and the International Institute of Tropical Agriculture (IITA). These partnerships help mobilize various actors and provide access to different funding sources.

17.3 Biodiversity and Participatory Breeding of Sorghum in Africa and Central America

Local varieties of pearl millet and sorghum developed and implemented by family farmers in the Sahel possess a high degree of plasticity toward environmental changes over time and space due mainly to their photoperiodism (Sissoko et al. 2008). These two cereals constitute the basic diet of the rural populations and are frequently grown in association with legumes such as cowpeas and groundnuts. They can either be grown monovarietal or as a varietal mixture of the same species.

Participatory breeding is a method that was principally developed in Central America and West Africa for the purpose of making available varieties that matched farmers' expectations and thus facilitated their adoption. In the case of sorghum, conventional breeding so-called "standard" or "formal" breeding) has only explored and exploited a fraction of the available diversity of genetic resources, focusing mainly on the productive potential, resistance to biotic stress and grain quality for limited uses. However, issues such as adaptation to complex cropping systems and specific usage by particular target groups (women, local processors, etc.) are yet to find a place in these conventional breeding programs. In order to address these shortcomings, participatory sorghum breeding programs introduced farmers to many different varieties with new agro-morphological characteristics or combinations of such characteristics. This diversity can be in the form of traditional or improved exotic varieties, or even of forgotten or little-known local varieties.

A key point of the participatory breeding process is to allow farmers to assess these different varieties in their environmental conditions and according to cropping practices specific to their production systems. The selection criteria are thus related to grain yield as well as to various other uses of different parts of the plant. The assessment of this new diversity provides an opportunity for an exchange of know-how and knowledge between farmers and plant-breeder researchers. Breeders can accordingly fine-tune their perceptions of farmers' selection criteria while farmers can improve opportunities for innovation that will meet their needs.

The significance of photoperiodism, one of the new criteria being taken under consideration in breeding programs, is worth exploring. As a character trait in traditional varieties, it allows the control of flowering in relation to variations in day length. In Sudano-Sahelian Africa, the length of the agricultural season depends to a large extent on the arrival of the first rains. This date depends on the latitude, and varies greatly from year to year, unlike the end date of the rainy season which is more constant. In order to address these climatic variations, farmers have, over time, bred pearl millet and sorghum varieties that are sensitive to photoperiodism; plants that mature at the right time, that is, at the end of the rainy season when the family workload is less. This criterion is an advantage, especially in the context of climate change.

Box 17.1 presents an example of sorghum varieties obtained via participatory breeding approaches in Mali, Burkina Faso and Nicaragua. An interesting case here is the Coludo Nevado ("white tail") released variety which was disseminated in Nicaragua. In the course of a participatory survey conducted at the beginning of this program, farmers indicated the desired targets for their photoperiodic sorghums, which are generally sown with maize as part of a strategy to minimize climate risk. The aim was to reduce the plant height while at the same time retaining the compact panicles of the traditional cultivars, which are considered to be very productive, and improving both grain quality for the preparation of tortillas and straw quality for forage. Coludo Nevado was among the many African photoperiodic varieties which were evaluated with the involvement of these farmers in the next stage. Except for grain quality, Coludo Nevado exhibited none of the above characteristics. However, as a result of several years of in situ experimentation, farmers were able to uncover other qualities, such as its high plasticity in relation to soil types, drought tolerance, and easier harvesting despite its height (due to drooping panicles), as well as high, stable yield. Consequently, the Coludo Nevado variety was rapidly adopted in the northern region of the country.

Box 17.1. Participatory breeding, a method of dialogue and mutual learning

Kirsten vom Brocke and Gilles Trouche

The process of participatory breeding involves a continuous and long-term interaction between researchers and farmers. It leads to the joint production of varietal ideotypes that allows the breeding of new varieties adapted to changing family needs.

Participatory selection of breeding characteristics and joint experiments conducted in the fields of farmers has resulted in the success of three common varieties listed below.

Variety	Country or region	Breeding criteria and objectives set initially*	Key characteristics determining adoption of the variety
Soumba	Mali	Combining high yield potential and short height of caudatum varieties with the grain quality of guinea varieties (hardness, mold tolerance, quality of the porridge).	Stems resistant to breaking and less attacked by birds because grains are "hidden" by long glumes. ' Allows late harvest: Adaptation to harvest schedules, especially for individual fields belonging to women. Straw of good forage quality.
Coludo Nevado	Nicaragua	Shortening the height of photoperiodic traditional varieties while increasing the size and improving the quality of the grain and fodder value of straw.	Despite the criteria of a good height and a loose panicle being a priori rejected and having straw of low forage value, the variety is highly valued for its hardiness and drought tolerance, its productivity which is equivalent to varieties with compact panicles, its ease of harvest as stems bend when mature, and its excellent grain quality.
Gnossiconi	Burkina Faso	Abandoned by farmers 40 years ago due to its earliness which led to it being attacked by birds.	Earliness, regularity of yield and hardiness are essential criteria nowadays in the context of greater climatic variability, resulting in the readoption of the variety.

* By the sorghum breeder or a participatory diagnostic at the beginning of the project.

Most local varieties grown in Mali belong to the *guinea* race. They are tall, have loose and drooping panicles with vitreous grains. Varieties of the *caudatum* race, originating from Central and East Africa, have a short to medium height with rather compact and upright panicles and less vitreous grains. The adoption of improved varieties of the *caudatum* race is very limited despite their potential for higher yields. The Soumba variety was obtained from crosses of these two races with a phenotype more aligned to *caudatum*. In the context of declining cotton production, it was adopted by farmers in the Dioïla region of south-central Mali both for family consumption and for exchange. . The main reason for Soumba's adoption is that it combines certain characteristics that allow it to be successfully integrated into changing cropping systems. Owing to its good resistance to lodging, due to its strong stems, and its resistance to bird damage due to its long glumes that hide the grain, it can be left longer in the field without fear of damage until other harvesting work has been completed. This is an important feature for family farms which rarely use external labor. Moreover, the fact that the plant remains green when the grain matures is a well appreciated quality for animal nutrition that should not be overlooked when breeding sorghum varieties. Breeders had not considered these criteria when they created this variety. The flexible harvest date and the commercial appeal of this variety's large grains are two other advantages that have convinced women who sell their surplus production in the market to grow this variety in their fields.

The local *Gnossiconi* variety has been maintained in the gene bank of INERA (Environment and Agricultural Research Institute) in Saria for 40 years. It was reintroduced to its region of origin in Burkina Faso in 2002 through a participatory breeding program, and was subsequently adopted by farmers for the very reason it was abandoned 40 years ago: its earliness. Farmers explain that this characteristic was a major drawback in former times when more favorable rainfall patterns allowed the growing of late variety sorghums that were more productive than *Gnossiconi*, which was susceptible to bird attacks because of its early flowering. At present, in a context of less favorable and more irregular rainfall, farmers have readopted the variety because of its earliness, stability and productivity. The fact that a group of farmers in this area has adopted these early varieties greatly reduces the risk of bird damage, a risk that is aggravated when plots are few and far between.

This cooperation between farmers and researchers to create new varietal ideotypes was taken further in some participatory programs in Nicaragua and Burkina Faso. These programs have produced a new generation of varieties that are being disseminated in these countries.

17.4 Participatory Modeling Applied to Seed Systems: The Example of Mali

In spite of various public policies to support the establishment of national seed systems for disseminating varieties across West African countries over the last 30 years, the traditional seed system remains the primary route for the movement of seeds (Bazile and Abrami 2008) accounting for nearly 90 % of seed transfers (Delaunay et al. 2008). In large areas of Mali, there has been no adoption of improved varieties without local germplasms (Yapi and Debrah 1998), demonstrating the failure of the dissemination of "improved" varieties since the 1960s. Cropping systems continue, however, to incorporate a wide diversity of local species and varieties.

In such a context, new ways must be devised to manage this varietal diversity and disseminate seeds in order to address the needs of and changes in family farming. Current research describes farmers' seed systems either on the basis of genetic diversity models or according to business models in order to take into account the risks of agricultural production. These two approaches can be combined to describe the dynamics of family farming biodiversity in changing environments. Innovations in modeling research are, in fact, focused on linkages between national seed systems and traditional seed systems in order to better understand the various issues concerning a dynamic conservation (Wood and Lenne 1997), through a combination of the genetic and economic dimensions. New civil society actors (farmer organizations, cooperatives, associations, NGOs, etc.) are working together for a reconfiguration of seed systems, requiring us to re-evaluate traditional geographical and social networks (Subedi et al. 2003). Companion modeling approaches can help analyze the complexity of these dynamics.

Companion modeling is an inter-disciplinary approach which encourages a participatory management of renewable resources (Barreteau et al. 2013; Le Page et al. 2013). It results either in a collective representation of a problem in managing a shared resource, or in changes in organizational techniques (Bousquet et al. 1993). Effort can be directed to studying the dynamics of biodiversity resulting from interactions between populations and their environment (Étienne et al. 2003). The work by Vejpas et al. (2004) on rice in Thailand, and that of Bazile and Abrami (2008) on sorghum in Mali have shown a new method of applying the multi-agent modeling approach to the management of varietal diversity in family farming systems. This approach is used either for understanding knowledge of local management practices or for a simulation of scenarios. In the latter perspective, it is a matter of testing new strategies on family farms or assessing the impact of public policies (Bazile et al. 2012; Belem et al. 2011).

The representation of a situation and its dynamics are formalized in multi-agent systems (MAS).[3] However, the use of role-playing games (RPG)[4] based on the same conceptualization as MAS facilitates the representation of a complex situation in a controlled situation. The role playing game is created on the basis of the same assumptions as those of the model.

[3] MAS originate from the field of distributed artificial intelligence and are used to solve problems of coordination of independent heterogeneous agents. MAS are suitable for simulating different forms of coordination, especially changes in management rules and the overlapping effects of individual strategies and collective rules.

[4] MAS use role-playing games which correspond to the representation of a complex situation in a controlled space. The Seed-Div role-playing game was created on the basis of assumptions and is a model or archetype of reality. It allows one to step back from the real world and thus serves as an intermediary with the reality of the situations observed in order to discuss with actors the actions they have undertaken or to confront them with new situations.

In addition to examples of participatory breeding at the producer level – such as the sorghum example described above –, participatory modeling based on multi-level interactions of cereal seed systems of farmers, traders and institutions was developed in West Africa to support actors of seed systems in managing agrobiodiversity dynamically. This section of the chapter examines this experiment and its generic and operational lessons learned in Mali.

From 2004 to 2007, six workshops were held based on methodologies of participatory modeling, each of which were attended by 20–30 farmers and members from farmer organizations and NGOs in Mali and Niger. Specific role-playing games (each game with a question based on an hypothesis) were used which led participants to arrive at a shared vision of seed systems based on five criteria:

– a characterization of farm types according to the diversity found in their cropping systems;
– a classification of varieties in functional groups for exchanges;
– a description of three principal individual behaviors to manage varieties (farmer experimenter, imitator or conservator);
– an improved understanding of the decision-making processes involved in selecting a variety and the formulation of rules for conducting tests on a farm;
– a characterization of different seed supply sources and conditions to access them in these different supply chains.

One of the major lessons learnt from this dialogue between actors is that family farmers prefer to maintain their local system because its greater diversity leads to greater security and productivity for them in comparison to the national seed system. Families access a "formal" seed system only when it helps them meet new requirements and supply objectives. In order to develop, new seed systems must first validate the role of key farmers in seed exchanges and help them adjust to a framework of collective rules on a larger scale – different from that of their farm – but consistent at the scale of their community.

The Seed-Div role-playing game was co-constructed in a 3-day workshop held to encourage participants to come up with alternative systems for collectively managing pearl millet and sorghum seeds. This role-playing game was then used to simulate operating rules of different types of entities (village association, seed cooperative, farmer organization) to achieve seed conservation, multiplication and distribution objectives. The shared experience of the role-playing game allowed results of different management systems to be compared and discussed and to continue the simulations to adapt operating rules to targeted goals in order to actually create these institutions. Seed-Div is now used for training in France and elsewhere largely due to its generic nature. At the same time, research is continuing to formalize the MAS approach and role-playing game in seed systems (Box 17.2).

Box 17.2. Application of companion modeling for agrobiodiversity: the case of the IMAS project.

Group of researchers coordinated by Didier Bazile

A generic system was developed as part of the IMAS project (Impact of the modalities of seed access on the dynamics of agricultural genetic diversity, ANR 2008-2012) in order to link seed systems. It pertained to two contrasting situations: the *in situ* conservation of the diversity of traditional cereals (pearl millet and sorghum) in Mali and the revival of quinoa cultivation in Chile in association with *ex situ* conservation.

Two major findings emerged from the use of MAS and role-playing game:

– The development of a MAS application allowed the analysis of the dynamics of biodiversity using simulations of scenarios based on links with the market, the implementation of agricultural policies and the impact of climate change;

– The first permanent national roundtable on quinoa in Chile was created within ODEPA (Ministry of Agriculture in Chile) bringing together different public and private actors to boost regional and national groups (Bazile *et al.*, 2012).

The modeling is participatory because it was created jointly by many actors (farmers, FOs, NGOs, research groups, seed growers, etc.). It simulates favorable mechanisms for the conservation, maintenance and use of varietal diversity in family farming systems.

The simulations carried out in workshops contribute to a gradual increase of shared knowledge with the help of a model that is regularly re-evaluated by all actors. The researchers' representations of the system are subject to collective review, thus providing the farmers involved with a sense of active participation in the research process.

In addition to the analysis of agrobiodiversity determinants at the level of the family farm and the characterization of varietal dynamics in different agrarian contexts (agricultural, environmental and socio-institutional), this approach has provided a framework for discussion on how to monitor and problematize the impact of the introduction of an improved variety in a self-production situation which is, after all, the norm in family farming.

These participatory dynamics have engendered significant changes in seed systems in terms of access of family farming systems to quality seeds, by describing, highlighting and promoting the critical role of FOs (Box 17.3). In addition to its efficiency, the local dissemination of seeds through the FO network makes it possible to link the formal state systems (national seed system, NSS) and the traditional system, when the latter cannot cater to the demand on its own (Coulibaly et al. 2008). The activities of the FOs are not only based on an agroecological vision of farming surfaces, but also on locally respected organizations, thus recognizing the importance of the links of kinship between family farms. This articulation between different systems allows the emergence of a comprehensive seed system that includes and interlinks seed networks of farmers and of the State at the national level, with the FO responsible for local-level transitions.

Box 17.3. Seeds from the Association of Professional Farmer Organizations in Mali.

Didier Bazile

In the late 1990s, FOs wanted to come out from under the control of the Malian Textile Development Company (CMDT). CMDT had established village associations to monitor the distribution of agricultural inputs (including seeds) and harvests in the cotton growing region. In 1997, the Association of Professional Farmer Organizations in Mali (AOPP) identified the following problems at a national workshop with all FOs of the country present: disappearance of certain varieties, reduced seed quality (especially pearl millet and sorghum), decreased rainfall, lower yields, high cost of fertilizers and difficulty of access to credit.

AOPP suggested that its members initiate a discussion on certified seeds. This led to the creation of the grain commission which, in turn, developed a network, starting in 1999, of experimenter farmers, known as *Si fileli kela*. Every year, about 20 local FOs can nominate 15 of their member farmers to receive training. These farmers are then responsible to conduct comparative tests between their traditional seeds and certified seeds from the national seed system (NSS). This continuous training has created an extensive network of more than a thousand experimenters, or "testers" as they call themselves. AOPP requests the NSS technicians it selects to get the farmer himself to provide training on the use of certified seeds and the method of on-farm tests. AOPP buys certified seeds and distributes them to farmers. The farmers compare their best local variety with the improved variety proposed by the trainers for the region under consideration by cultivating it on a quarter hectare on their farms.

From 2000 to 2004, seed production (pearl millet, maize, groundnuts and sorghum) spread from Mandé to Bélédougou, in Tominian and in Seno in the Dogon area. The production of basic seeds started in 2005. Seven seed cooperatives with a suitable legal status were created under AOPP for this purpose (three in the Office du Niger area and four in upland areas for dry crops). In 2011, the program was extended to the regions of Koulikoro (four cooperatives) and Ségou (one cooperative). The focus is currently on ten major crops: pearl millet, sorghum, maize, rice, cowpea, fonio, groundnuts, sesame, okra and hibiscus. The members of seed cooperatives provide R1 or R2 seed that are packed in accordance with recognized and adapted standards with the AOPP label. Awareness is raised and certified seeds are distributed with the help of the AOPP networks and through radio announcements.

The support provided by AOPP to family farming systems in Mali demonstrates its dynamism in addressing the inadequacies of the formal seed evaluation and dissemination system. Local FOs now systematically review tests conducted after each cropping season. The quality of this network, developed with limited resources, shows the ability of family farming systems to organize themselves in order to develop their own monitoring and capitalization tools.

Different conditions need to be met in order for collaboration in a global and multi-actor seed system to be more effective. Companion modeling favors the implementation and sustainability of these conditions.

The production and dissemination of first and second generation seeds is currently undertaken primarily by decentralized cooperatives of the government seed system, which operates in parallel with the system of FOs and their network of experimenter farmers. Seed producers of the state system are supervised by NSS technicians and receive financial support for their crops. Although the quantity of seeds produced is significant, they represent very few varieties per locality. As a result, cooperatives have to deal with large quantities of unsold seeds. On the other hand, as the choice of the variety can vary greatly according to the annual climate, or even during replanting, the stocks held by NSS cooperatives prove inadequate to effectively meet unanticipated demand, which usually concerns a wide range of varieties.

Members of the AOPP network, with its experimenter farmers and seed cooperatives, encourage the dissemination of varieties beyond the limited scale of the family or the village. Simulations of the participatory model show us that aligning this system with the national system could lead to a balance between local production and demand. AOPP maintains tight control over its operations for breeding, distribution and marketing of seeds to achieve prices that are lower than those of the NSS, while providing suitable high quality seeds to family farms. It could take over the NSS's responsibilities. Conversely, the technical staff of the NSS could rely more on member-farmers of FOs for breeding and seed certification. Thus, each actor has a role to play but is also constrained. The institutional anchoring of AOPP at the national level legitimizes a process to disseminate improved varieties in the country that maintains a close and strong relationship with locally anchored family farming systems. Although FOs are actively involved in supplying improved seeds to their members, it is not easy for them to undertake nationwide operations. They also encounter technical difficulties occasionally. The NSS commands a wide network of technicians and enjoys institutional legitimacy. The varietal diversity maintained in family farming systems constitutes an extremely rich and diverse pool of genetic resources. This wealth often goes unnoticed by farmers themselves and is not always accessible to researchers and seed breeders for breeding programs. Moreover, family farms do not have the means to monitor the development of traditional varieties and plan a sound conservative management strategy at a scale that goes beyond their farm or, at best, the village.

Companion modeling allows actors to share each other's roles and constraints. It allows a systemic representation of the seed system, its different objectives and expected performance, both for the purposes of conservation and for increasing production and adapting to product valorizations, between consumption and commercialization. This sharing creates favorable conditions that encourage deliberations on strategic priorities and changes that could be made in the production and distribution of seeds. In Mali, for example, farmers noted that the workshops had helped them understand for the first time what the researchers wanted and did, which then allowed them to better explain their activities and roles in the system.

17.5 For Participatory and Multi-actor Research on Support

The new paradigm that integrates agricultural research and environmental protection assumes that research assimilates this development to create new knowledge by basing itself on interactions between mankind, societies and the environment. This widening of knowledge requires the creation of new analytical frameworks that incorporate the diversity of productions. A high biodiversity exists within these productions, to which is linked know-how that could provide new indicators for changes in biodiversity under different contexts.

In addition to the need for a multi-disciplinary approach, agricultural research must open itself to accommodate development and civil society actors in a more meaningful way if it has to have any hope of dealing with the agricultural system as a complex object. An agricultural system can no longer be considered as being contained only within the limits of a plot with production factors that are isolated from each other, foremost among which are cultivated species or varieties.

It is difficult to arrive at any genericity because of the many biodiversity management methods practiced in family farming systems, an aspect that results in criticism of participatory methods. However, as examples in this chapter show, innovative participatory methodologies are being developed which encourage dialogue between various actors to better lay out seed selection criteria and discuss links to markets and agricultural policies and the impacts of climate change. This dialogue also leads to a more accurate and comprehensive understanding of actors and issues of cultivated biodiversity, helping us understand the intrinsic characteristics of family farming models and their relationship with their living environment. From this viewpoint, the participatory approach, despite its limitations, seems essential and its discussion should not be limited to an activist discourse.

Support for family farming systems presented through these case studies is still in its nascent stages, but it points to a growing research effort that extends its approach beyond a mere management of the diversity of genetic resources, and which seeks to be practical, collaborative and inventive at the same time. This welcome reactivity and responsibility of research helps us reflect on the evolution of agricultural technical models as a whole with the help of debates on various perspectives of ecological intensification. This reflection is the subject of the next chapter.