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The agroecological transition
of agricultural systems in the Global South

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Chapter 8

Accompanying the agroecological transition of agroforestry systems in Central America

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Since its introduction and development in the 20th century, coffee production has not only become an essential source of stability of the balance of trade of some Central American countries (Nicaragua, Honduras), but has also grown into a cultural identity (Tulet, 2008) and a means to project power (Demyk, 2007).

While production methods vary from one country to another, much of the production originates from small producers. In general, coffee is grown on steep slopes and the labour required for manual harvesting results in significant seasonal migratory flows between countries, especially from Nicaragua (Baumeister *et al.*, 2008).

The coffee sector's institutional structures also exhibit diversity, ranging from coffee institutes, either representing the entire national chain (e.g. Icafe in Costa Rica) or only the producers (e.g. Anacafé in Guatemala), to weaker governance structures, as in Nicaragua.

The levels of State intervention and support also differ across countries. Nevertheless, some general trends can be observed: a general simplification of cropping systems, transitioning away from complex agroforestry systems that are not very intensive (in capital, in labour), which is still largely the case in Nicaragua, to systems combining fewer plant species and managed in an intensive way, as in Costa Rica or Guatemala (Jha *et al.*, 2014); and high sensitivity to world coffee prices which, in these perennial systems, is manifested primarily through modifications in cropping practices and, in the medium term, by a gradual decrease in cultivated acreages in favour of other agricultural products selected on the basis of location, farmers' strategies and opportunity costs of farmland and labour.

This chapter aims to analyse how the agronomic research carried out in Central America within the framework of a Research and Training Platform in Parnership (PCP AFS-CP) created in 2007 by CIRAD, CATIE (*Centro Agronómico Tropical de Investigación y Enseñanza*, a research, education and development organization) and their regional and international partners, supports Central American coffee cultivation in the context of current challenges facing the sector and, in particular, those of the agroecological transition.

The constraints and opportunities of coffee cultivation systems

Arabica coffee (*Coffea arabica*) is an indigenous plant from the dry forests of the highlands of the Horn of Africa, which is therefore adapted to certain conditions of altitude and forest shading. However, this species can be cultivated under the full sun, and since its expansion in Central America in the mid-19th century, coffee cultivation systems have evolved in a wide range of conditions, from cultivation under forest trees or planted trees to monoculture systems under full sun (Samper, 1999). These changes in farming practices have been encouraged by public policies, especially between the 1940s and 1960s, that supported the development of large plantations owned by political and economic elites and foreign investors (Italians, Germans, North Americans, Britons, etc.), who set up small planters at the same time to assure themselves of the crucial labour force required for their own plantations. Today, coffee production in Central America has essentially passed into the hands of these small and medium producers.

Coffee cultivation is subjected to various kinds of pressures (Figure 8.1). Two of them, arising from external conditions are important determinants of technical choices: international prices and climate change. These conditions affect the decisions on the major aspects of coffee plantation management. While these plantations are recognized as biodiversity havens, they also represent points of tension given the desire to decrease the use of pest control products. More generally, their sustainability – environmental, social and economic – is subject to controversy. The research activities we undertook on these issues, their interconnections and their relationships to the design of agroforestry systems are shown in Figure 8.1.

Since 1998, the international price of coffee has fallen steadily, well below production costs in Central America (Figure 8.2). However, options for reducing production costs remain limited: in particular, mechanization is difficult because of the topography, with plantations generally located in steep, mountainous areas, and manual labour used for harvesting continues to be the main expenditure head. Strategies were adopted between the mid-1990s (first price crisis) and the early 2000s (second crisis), based on the recognition of the extrinsic production quality (related to production conditions, social as well as environmental, giving a significant impetus to agroecology) and the intrinsic quality (cup quality).

The long coffee price crisis only came to an end in the late 2000s, with prices peaking in 2011. However, the increase in prices paid to producers led to contradictory effects on the adoption of practices encouraged by certification labels: the economic focus was then put on the quantity of production rather than on its intrinsic or extrinsic quality. Thus, the average premium obtained by coffee originating from Costa Rica (linked to the general reputation of this area of production in the global market), as well as the minimum price guaranteed in the context of Fairtrade, can be compared to the evolution of price (Figure 8.2). It is understandable that, at the turn of the decade, producers intending to recapitalize after nearly a decade of very low prices sought to maximize their production without any restriction on their cropping systems. However, prices have been less favourable since 2012, and strategies for promoting coffee quality are once again gaining importance.

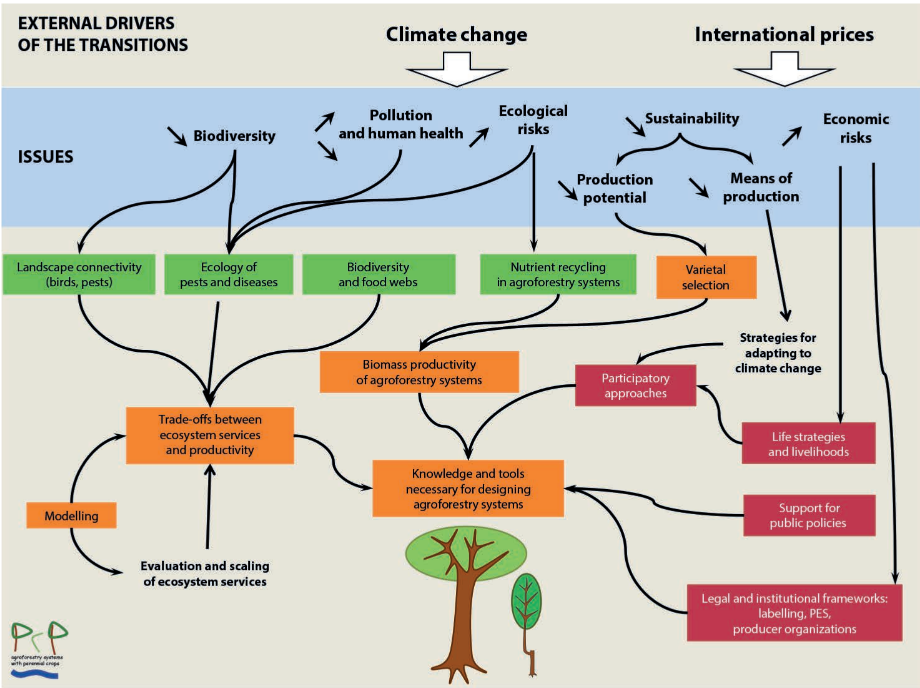

Figure 8.1. The multidisciplinary scientific approaches of PCP AFS-CP for supporting the transition of coffee-based agroforestry systems.

The research activities described are indicated according to the possible dominant disciplinary fields: ecology (green frames), agronomy (brown frames) and sociology and economy (red frames).

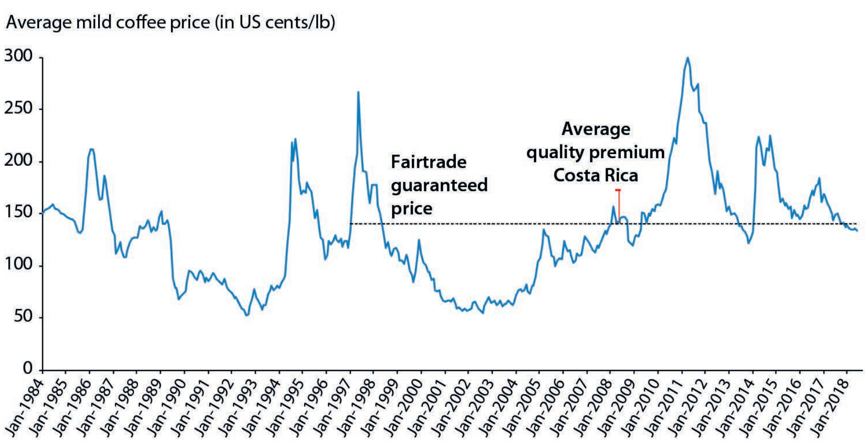

Figure 8.2. Evolution of the coffee price on the New York Stock Exchange (ICO) (Sources: www.ico.org, www.fairtrade.net, icafe.cr).

Climate change is another source of tension: Central America mainly produces Arabica coffee, and these coffee plants are sensitive to temperature. The expected rise in temperatures could render production areas at low altitudes unsuitable for production, decreasing the overall land available to cultivate this crop, thus increasing pressure on protected areas (Jha *et al.*, 2014). These changes translate into increased pest and disease pressures, for example the recent epidemic of coffee leaf rust, which is partly linked to climate change (Avelino *et al.*, 2015). Agroecology, and in particular the introduction of shade trees in plantations, is seen as a way of mitigating these changes by moderating diurnal temperature variations of coffee leaves.

To these external tensions are added internal changes. Natural resources are degrading, especially water (chemical and organic pollution attributed to the use of agrochemical products, dumping of crop residues and release of water used in coffee processing) and soil (erosion, landslides, loss of topsoil that is used by crops, soil compaction, etc.). Trees disappear from the landscape, either because of deforestation or due to felling in agricultural plots during a change of land use and/or a change of coffee variety, or even because of a change in shade management. These developments are not new, but their negative effects are increasingly being felt by urban and rural populations, while local environmental protection organizations are progressively gaining in influence. In addition, there are socio-economic difficulties, in particular, poverty amongst many producers, sometimes associated with food insecurity, aggravated by coffee price fluctuations and pest control problems, which restrict productive investment.

The research strategies in response to these pressures and developments are also schematically depicted in Figure 8.1, and have mobilized various disciplines.

The contribution of research to promote the agroecological transition of coffee cultivation systems

Technical solutions for the provision of ecosystem services

Coffee plantations in Central American cover over a million hectares, with a high diversity of production systems, ranging from plantations under full sun that have applied all the recommendations of conventional intensification advocated by the Green Revolution to agroforests with low levels of management and low productivity. With a goal of promoting the ecosystem services that these systems can provide to society, recommendations have been made to improve them that are in line with the two principal paths of agroecology (Griffon, 2013): a path of diversifying simple systems (coffee plantations under full sun in the shade of service plants), and a path of intensification of complex systems (agroforests in which coffee plants are managed more or less extensively under the shade of very diverse trees, often vestiges of the original forests).

These agroforestry systems, which mainly associate perennial plants, are complex, not only because of the association itself, but also due to the time steps that have to be considered. For example, the interactions between the roots of species we could observe in a ten-year-old plantation depend partly on the conditions of establishment of the association ten years earlier, e.g. if a species was established before another, it could spread into a volume of soil without interference. This complexity makes it more difficult to derive generic rules.

In order to be able to provide useful elements for the design of agroforestry systems, we have studied the ecosystem services provided, the relationships between these services, and the conditions necessary for the provision of services, of course in the context of the presence of trees in coffee plantations. Various types of services, defined by the Millennium Ecosystem Assessment (2005), were thus studied:
– provisioning services, and most importantly coffee productivity (Bhattarai *et al.*, 2017), as also the comparative productivity of different types of products obtained from plantations, whether sold or not;
– provisioning of groundwater recharge, with an assessment to compare the contradictory effects of agroforestry systems, in which the presence of trees generally increases water consumption, but also improves rainwater infiltration (Padovan *et al.*, 2018);
– climate regulating services, with work on carbon sequestration in agroforestry systems, as also emissions of other greenhouse gases (Hergoualc'h *et al.*, 2012);
– regulating services for controlling pest and diseases in agroforestry systems, with detailed studies of the effects of associations on the epidemiology of certain diseases, such as coffee leaf rust in coffee (Lopez *et al.*, 2013; Boudrot *et al.*, 2016), as also on pest complexes that attack the coffee plant and interact with each other (Allinne *et al.*, 2016);
– support services, mainly nutrient recycling (highly modified by the presence of shade trees and the rooting of trees and coffee in the soil profile, Padovan *et al.*, 2015), the production and recycling of biomass, fundamental elements in the lifecycle of agroecological systems (Defrenet *et al.*, 2016).

The first takeaway from these assessments of the services provided by agroforestry systems is that these systems are truly complex and it is difficult to draw generic principles of action from this complexity. In particular, it is difficult to find synergies between productivity and ecosystem services pertaining to environmental protection. Even though it is well understood that biodiversity forms the basis of the services provided, determining how to use it at the local level remains a complex undertaking and good practices are especially difficult to extrapolate due to the large number of interactions. Furthermore, the broad ecological hypotheses are of little help in developing generic rules that can be applied to these highly anthropized systems.

Several paths of innovation have been studied with producers, and have been tested in long-term trials (Figure 8.3). To attain the objective of increasing the presence and diversity of trees in plantations, the most common current practices are to cultivate coffee plantations in association with service trees of the genus *Erythrina* (*Erythrina* spp., Photo 8.1), or some species of Inga. These trees, almost exclusively grown for shade, can be 'managed' in a relatively comprehensive manner based on the needs of coffee plants and nitrogen fixation. However, they generally do not generate any additional income, except for certain Inga species whose logging residues can be used as firewood, essential in some countries of the region.

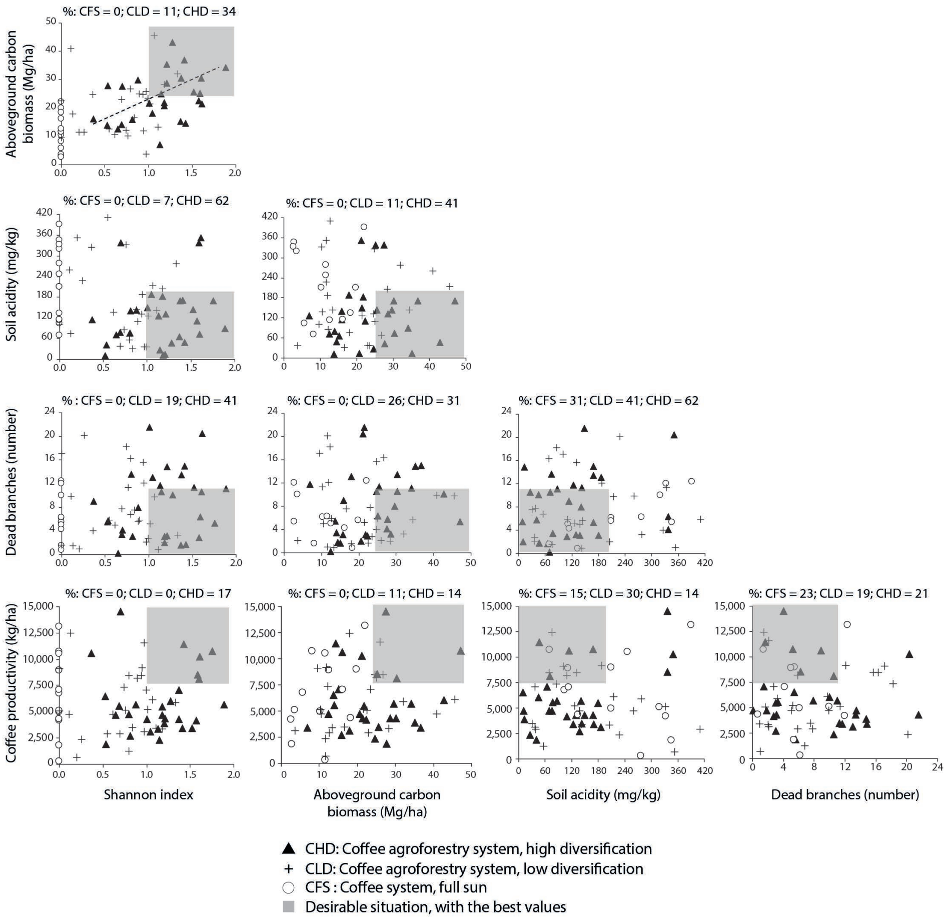

Figure 8.3. Relationships between ecosystem services provided by coffee plantations based on their level of diversity (Costa Rica, Cerda *et al.*, 2017).

Trials were conducted to replace these species with timber tree species (Photo 8.2; Haggar *et al.*, 2011). The revenue generated can be significant, especially in times when planters are particularly vulnerable, such as in the event of a sharp decline in coffee prices or a total renovation of the plantation (Beer *et al.*, 1998). This strategy was tested in Honduras, which has taken up a nationwide programme to establish coffee agroforestry plantations. Timber productivity was assessed on these plots (Jiménez *et al.*, 2012) and, as per our expectations, the productivity per tree was higher than the productivity measured in forest plantations (less competition for light due to low densities, and effects of fertilization of coffee). To our knowledge, trade-offs with coffee productivity have not been assessed. While, however, the biological performance of this innovation appears correct, its economic performance is controversial. It is more difficult than expected to derive value from the timber produced, partly because the quality of the timber decreases with fewer straight boles, and also because the timber sector is very different from the coffee sector, and it is not easy for a coffee producer to negotiate the sale of his timber. However, policies to combat

Photo 8.1. Typical coffee plantation in the Tarrazú region, Costa Rica: high coffee-plant densities on sloping land, associated with heavily pruned *Erythrina* (*E. poeppigiana*) and some banana trees. © Bruno Rapidel/CIRAD.

Photo 8.2. Commercial coffee plantation in Masatepe, Nicaragua, under shading by a timber tree (*Tabebuia rosea*). © Bruno Rapidel/CIRAD.

deforestation and strengthen controls on origins of timber (and in some cases certification) could stimulate demand for cultivated timber. Finally, the production of coffee under mature trees requires a periodic pruning of trees, in addition to thinning. This pruning poses considerable technological problems and requires significant amounts of labour (Photo 8.3). Mechanized cutting systems are, however, being tested.

Photo 8.3. Pruning of shade trees in Nicaragua: the producer, perched on the forks of branches, must not only ensure his own safety, but also take care that falling branches do not damage the coffee plants. © Bruno Rapidel/CIRAD.

Another strategy consists of promoting the diversification of tree species planted for shade. This strategy, widely promoted by several labels (Rainforest Alliance, Bird Friendly), produces very diverse systems in selected tree species and densities. However, studies generally show that further room for manoeuvre is still available to produce sets of ecosystem services without the limiting factors (mutual co-limitations) being reached (Cerda *et al.*, 2017). This strategy is also observed in the field with the association of fruit species, when the agri-chains are organized: in particular, dessert bananas are frequently associated with coffee plants in very variable densities, from an almost continuous cover over coffee plants in certain regions of Nicaragua

(Photo 8.4) to a few dozen pseudo trees per hectare in other cases. The income from banana production, spread out over the year, supplements coffee revenues, which are concentrated over two harvest months. This diversification is also observed with other fruit species, which are planted less densely and are more varied. The fruits produced are usually for self-consumption by the family, contributing to the diversification of its diet (Cerda *et al.*, 2014; Notaro, 2014).

Photo 8.4. Coffee plantation in La Dalia, Nicaragua, under simple shade: agroforestry system associating coffee and banana, a good economic complementarity. © Bruno Rapidel/CIRAD.

Strategies of adaptive management of plantations have also been implemented, so that their management can be based on the current or expected future state of the biophysical or socio-economic environment. In the short term, especially in order to take advantage of periods of high coffee prices, these strategies consist of adapting the pruning of the coffee plants and shade trees[1]. In the medium term, fertilization of the plantation can also be adjusted according to shade management: when prices are high, shading is reduced and fertilization is increased at the same time; when prices go down, denser shading increases nutrient recycling, but also reduces production and production costs. While the results of these strategies are yet to be analysed, they are already being practised by some producers.

1. It is necessary to prune coffee plants at certain intervals, every 4 to 7 years depending on the situation. However, since coffee flowers bloom only on branches one year old, the plant will not be productive in the first year following renovation, even if it catches up to its potential in the subsequent year. Producers therefore tend to hold off on renovation in years of high prices, expecting them to be transitory. We also observed producers slowing down on the pollarding of shade trees during periods of ENSO (El Niño - Southern Oscillation) in anticipation of long, dry seasons.

Finally, other complementary strategies focus on the coffee plant rather than on shade trees. Until now, coffee varieties were selected for very low shading conditions or for cultivation under full sun. By chance, some of these new varieties performed well in very shaded conditions (Bertrand *et al.*, 2010). It is only recently that breeding programmes have been taken up with the aim of offering varieties that are specifically adapted to the conditions of agroforestry systems (see Bertrand *et al.*, Chapter 9 in this book). However, the additional investment needed to buy seedlings from these new, sometimes hybrid, seeds often discourages small farmers.

Better understanding of and support for innovation

The technical innovations presented above have different origins: some were directly proposed by the research community, especially the use of shade species that generate marketable products or remunerative services, but many originate from production environments or from economic operators (e.g. the diversification of shade species initiated by Rainforest Alliance). The modalities of supporting the adoption of these innovations have to be adapted to the context.

Several approaches were implemented locally to encourage coffee producers to reflect on their practices and on ways of improving them. In Costa Rica and Nicaragua, following a characterization phase, and a subsequent study of the diversity of coffee plantation management practices (Meylan *et al.*, 2013), we decided to model the choice and effects of various practices. The aim was to integrate the full range of technical issues of homogenous farmer groups into the farm structure and choice of practices. This conceptual approach helped producers not only come up with solutions to the problems they faced, but also to envisage the evolution of their practices in response to various public policy instruments. While the model that was used, and subsequently modified, was not designed for this, and did not take into account all the necessary processes, it facilitated, following a progressive process of learning, an interaction between producers regarding technical processes they could not observe on their own (mineralization of organic matter, symbiotic fixation of nitrogen from the air). This model finally played the role expected of it: that of representing interactions in the cropping system, and conducting virtual experiments on the initiative of the producers. It also served as a platform for exchanges between researchers and producers, as a training tool, and has helped propose experiments for the future, as shown in Table 8.1 (Meylan, 2012).

The labels we mentioned as promoting agroecology also play a role in providing support. Very often, for the small producers, the contracting and management of these labels is carried out by cooperatives, which maintain registers and communicate with the certifiers. In some cases, multiple certifications are obtained (e.g. Fairtrade and Starbucks Café Practice) with only part of the production sold under any one label. The cooperatives, which maintain certification registers, are also in charge of verifying that agricultural and social practices correspond to the labels' requirements, and, above all, of training producers in these practices. This role of cooperatives as intermediaries between certification companies and small producers (role of a broker) is essential and allows these labels to have a positive effect on the agroecological transition. Specialists from the cooperatives fulfil a role that producers do not have time to assume, and do it probably more effectively, thus reducing the transaction costs of certification. However, we also note that many labels certify already existing activities and often do not contribute to an evolution of the practices: Fairtrade certification is often sought because the producer knows that he already fulfils the criteria (Quispe, 2007). However, certain labels certify agroecological orientations with criteria that are sometimes considered not sufficiently rigorous, but they do so with the intention of promoting a gradual modification of the practices towards standards that match the requirements of certification that the producer has already held for a long time. This is the case, for example, with the Rainforest Alliance, which awards its label without certain certification criteria being fulfilled, but on the condition that the producer demonstrates that he is taking action to meet these criteria in the future, with subsequent verifications to confirm this evolution. In such cases, it is virtuous trajectories that are being certified rather than existing situations.

Table 8.1. Some examples of the results of participatory simulation workshops on the effects of coffee cultivation practices on productivity (in tonnes of cherries), the nitrogen cycle and erosion (Llano Bonito, Tarrazú, Costa Rica, according to Meylan, 2012).

Group of producers	Initial practices	Modifications tested	Simulation results	Critical evaluation of the results by the group of producers
Not intensive	2 × 60 kg N/ha/year 60% pruning of shade trees (average) in May and October	40, 46 and 60 kg N/ha/year pruning of shade trees in March (increased to 80%) and September	Productivity increased from 4.15 to 5.26 t/ha/year (average over 7 years) Leaf area index (LAI) of shade trees lower, but LAI of coffee higher Higher runoff at first, then lower Higher N mineral (≈ × 2)	Attracted by the higher productivity, but apprehensive of additional fertilization Lack of conviction on the benefit of reduced shading (less shading would tire the plants in the long term)
Labour intensive	82/82/58 kg N/ha/year 300 trees/ha pruned in June, September and November	58/58/58/58 kg N/ha/year Pruning of trees twice a year (3 weeks before flowering, then in August) during an El Niño year	Productivity increased from 7.25 to 7.57 t/ha/year on average over 7 years LAI of shade trees higher, but pruned just before flowering Late application of fertilizer, promoting the growth of coffee cherries	Logically devised trials to lower fertilizer applications and the frequency of pruning of shade trees
Dense shading	3 × 83 kg N/ha/year 800 trees/ha pruned 3 times/year, to 40%	66, 50 and 83 kg N/ha/year First pruning of shade trees 3 weeks before flowering of the coffee plant 600 shade trees/ha pruned to 50%	Productivity increased from 7.22 to 7.41 t/ha/year Erosion not significantly higher Higher N mineral	Trials proposed to decrease fertilization on the basis of simulation results
Intensive in inputs	3 × 75 kg N/ha/year Shade trees pruned to 70%, 3 times/year	4 × 50 kg N/ha/year Shade trees pruned to 60%, 2 times/year	Productivity increased from 6.96 to 7.20 t/ha/year on average Decreased soil erosion Higher N mineral (significant)	Proposed trials to split fertilization while maintaining total quantities Lack of effect of weather conditions on N mineralization rate

Innovation platforms and support for adoption processes

Innovation platforms have been set up in Nicaragua, in coordination with a cooperative in the La Dalia region, north of Matagalpa. The coffee plantations are managed under shading that is often dense and diversified, but with a reduced productivity, generating insufficient income.

Innovation platforms initiated by researchers

The modifications proposed are aimed at two things. On the one hand, it is a matter of selecting the associations of species that are most beneficial for the producers, so as to protect these associations within the context of an intensification approach that conserves the essential functions of the complex agroforestry systems. On the other hand, we attempt to adjust the rules governing variations in fertilization based on the degree of regulation of tree shading. These modalities were planned following diagnostic work in the region (e.g. Notaro, 2014). Under the joint initiative of the research community and the cooperative's management team, producers interested in collaborating with the researchers were identified and contacted, and their production systems were documented. A day-long meeting was organized to enable the different actors to select research themes. Research modalities were discussed and each producer optionally registered in one of the groups. Initial protocols were drafted and fine-tuned after the meeting. Periodic meetings were organized for each group as the research activities progressed. The experiment is still ongoing as part of the Stradiv project (System approach for the Transition to bio-diversified Agroecosystems), co-financed by the Agropolis Foundation.

Innovation clusters initiated by the private sector

The private sector implements very different systems for promoting innovation, often in the form of clusters, i.e. groups of farmers selected based on company-specific criteria, which may themselves be based on the terroir and farming practices. These farmers receive special support, often seasonal loans repayable in the form of coffee delivered at harvest time. These initiatives are obviously very market-related, since they aim to ensure, for the buyer, a supply of coffee of predictable quality. This, for example, is the case of the Nespresso company. Its technical recommendations not only include elements aimed primarily at ensuring the coffee's organoleptic quality, but also, in an ancillary way, respect for the environment, thus coming closer to agroecological practices. Very similar to this scheme, and at the initiative of the Moringa Foundation (an investment fund founded by the Edmond de Rothschild Group and ONF International), an agroforestry farm in Nicaragua called La Cumplida was partially purchased and an agroforestry area was earmarked around the farmland. Under a temporary lease, coffee plots were completely renovated with recent varieties (F_1 hybrids [Bertrand *et al.*, 2010] or varieties of the Catimor family) and planted with forest species with high added value. Investors have a network that ensures access to profitable export markets. Specific monitoring is undertaken by a subsidiary of Moringa, with which CIRAD is associated within the Matrice project (Matagalpa Agroforest Resilient Landscape program) to guarantee the sustainability of farming practices. In the first phase, this cluster only brought together large and medium-sized farms (between 20 and 100 ha, covering about twenty producers). The contract specified that the profits of the first five years would be entirely allocated to the repayment of investments, thus requiring the owners to have additional means of subsistence independent of the plots allocated to this renovation scheme. The project recently started including small producers (about 50) under a more flexible contract.

The actors promoting agroecology and organic farming

Institutions and public policies

As in many other parts of the world, the trajectories of agricultural and rural public policies and the actors involved in these processes are context-specific and strongly tied to national histories. Nevertheless, it is possible to analyse a number of convergences in the Central American countries.

To begin with, and much like other nations of the Global South, Central American countries have been engaged in processes of economic liberalization and privatization of the agricultural sector driven by the structural adjustment policies of the 1990s. These processes have resulted in a more or less marked weakening of the State[2], in particular of the public establishments for agricultural research and extension[3]. At the same time, local actors, social movements and technical cooperation actors have, through development projects, favoured the emergence of production methods alternative to those of the Green Revolution (Sabourin *et al.*, 2017). In some countries, economic, political and environmental crises have facilitated this search for solutions in a context of a shortage of foreign exchange, as in the case of Nicaragua (Fréguin-Gresh, 2017). It is in this context that the concepts of organic farming and agroecology emerged in the region in the 1990s (see Chapter 17).

However, even if in some cases these production models are encouraged in national political agendas, they currently remain relatively marginal in practice. One explanation for this limitation could lie in the desire to maximize productivity in a context in which the import of agrochemical inputs is subsidized, and in which the orientation of coffee cultivation is partly provided by the sellers of agricultural inputs, either through field technicians or simply as a service at the time of selling inputs across the sales counter. This situation is obviously not conducive to the large scale dissemination of an agricultural model that is less dependent on inputs. Another part of the supervision and guidance is provided by cooperatives and coffee processing plants, which are primarily interested in fulfilling their export contracts and thus have specific interest in the quantities produced and supplied to them. In principle, they are less interested in the direct sale of inputs, especially when they are also responsible for certification. However, their sensitivity to the volumes of coffee produced may also encourage them to promote the consumption of inputs, especially fertilizers.

2. In the region concerned, however, two countries have been less affected than others, probably because the State has historically been less present in the domain: Guatemala and Honduras.
3. Quasi-public structures supporting coffee cultivation developed early, funded by a tax levied on coffee exports, and have retained a significant presence in the field, e.g. Anacafé in Guatemala and Ihcafe in Honduras.

A success

However, some policy instruments have made considerable progress in the development of agroforestry systems, including, among others, the programmes for the payment for environmental services.

Even though the first national system of payments for environmental services was set up in 1992 in Costa Rica to protect a forest for the purpose of tourism, it was only in 1997 that a more successful form was devised, with the sale of the precursors of carbon credits to Norway. In that same year, the national programme for payments for environmental services was created, spearheaded by forestry companies and under the aegis of Fonafifo (National Forest Financing Fund). It targeted the provision of different ecosystem services (climate regulation, water quality, biodiversity conservation, natural beauty) and assumed different forms (support for plantations, for conservation, and, from the beginning, the planting of trees in coffee and cocoa plantations). The programme was initially funded by international entities, and later by a tax on petrofuels, a move that was socially well accepted in Costa Rica. Apart from the relatively marginal modality of encouraging tree planting in agroforestry plots, this payment for environmental services is, for the most part, oriented towards forestry activities (reforestation, conservation). Nevertheless, a new modality for agroforestry coffee cultivation consisting of providing a payment based on the acreage of the agroforestry coffee system (and not merely for planting trees in plots of agroforestry systems) was introduced in 2011 and is now accessible by coffee growers[4].

These experiences of payments for environmental services, which are particularly advanced in Costa Rica, have been adopted, in various forms, in almost all the Central American countries. They were usually set up at the initiative of forestry companies, except in Nicaragua, where the first programmes were clearly oriented towards agroecology and were created at the municipal level.

Programmes for the payment for environmental services, when made part of national standards, are useful tools for promoting agroecology. A participatory simulation (a kind of role-play, initiated by the research community) was implemented to explore the potential effects of a change in the institutional environment of producers (several types of instruments and rules were tested) on the adoption of practices, including shade management, reduction of fertilizer doses and protection of watercourses (Bonifazi, 2015). The simulations carried out during sessions which brought different producers together helped identify this potential for influencing the management of agroforestry systems (fertilization, management of weeds and shade), the planning of plot lay-outs and the provision of services (coffee production, biodiversity) and 'disservices' (soil erosion, nitrogen pollution). While increased control of river protection areas has positive influences on biodiversity and reduces problems of erosion and nitrogen pollution, it also negatively affects coffee production by the simple effect of reducing coffee acreages.

The introduction of positive and targeted incentives ('green credits' or payments for environmental services) seems, however, to have stronger effects than measures of normative controls in terms of improving ecosystem services. These incentives greatly reduce disservices (soil erosion and nitrogen pollution) by increasing the provision of

4. https://www.fonafifo.go.cr/es/servicios/actividades-y-sub-actividades/ (retrieved on 3 May 2019).

support services (biodiversity) and supply services (coffee production). The balance between different services depends, however, on the type of positive incentives and the targeting of these incentives in terms of practices: green credits (lower borrowing rates for loans that meet environmental criteria) lead to an increase in coffee production that is higher than that observed in the payment for environmental services scenario, while payments for environmental services result in a larger increase in support services (biodiversity) and reduction of disservices (soil erosion and nitrogen pollution).

Certification and label incentives

Following the crisis of coffee prices that began in the late 1990s, strategies were put in place by the private sector to promote and enhance the environmental and social quality of this product by setting standards for its production and by creating labels to certify compliance with them (Soto and Le Coq, 2011).

Consequently, the production of 'organic' coffee saw a huge increase starting in the 2000s, partly due to better prices, with the organic price premium helping to offset, in case of low prices, the shortfall resulting from lower productivity (but without offering sufficient compensation in case of high prices). Organic plantation systems use denser and more diverse shading to help control pests, diseases and weeds. A large number of other practices are also adopted, such as foliar applications of elicitors of natural plant defence mechanisms and microorganism cultures sourced from forests, whose effectiveness, however, has yet to be tested.

In addition, other labels have been created for the coffee sector, which often combine environmental and social standards: Fairtrade (Max Havelaar established in 1988 for coffee from Oaxaca, southern Mexico), Rainforest Alliance (the first agricultural certifications in Central America, first for banana, then for coffee in 1995), Smithsonian's Bird Friendly coffee in 1996 and finally UTZ Certified (originally Utz Kapeh, created for coffee in Guatemala in 2002). All these standards impose, to varying degrees, environmentally friendly coffee practices within the production chains. The main practices modified are the use and diversification of shading, as also the discontinuation of the use of certain pesticides or the regulation of chains of contamination resulting from their use.

Another major strategy has been based on the promotion of coffee quality and, in some cases, on its improvement. It is mainly linked to companies downstream of the chain. For example, Starbucks, a chain of cup-based coffee retailers, based primarily in the United States but which has global ambitions, created the Coffee And Farmer Equity (C.A.F.E.) standard. Only growers adhering to these practices can offer to sell their coffee to Starbucks. In a similar strategy, Nespresso created the AAA programme, promoted largely in the context of coffee clusters, i.e. groups of producers who already produce a quality coffee and who receive special technical assistance related to the sale of their production to Nespresso.

For the past ten years, designations of origin have also appeared, based on a reputation for quality and a specific history of coffee cultivation in the regions concerned. While these designations pertain primarily to the area of origin of the coffee, they also tend to mandate certain practices, specifically the cultivation of certain varieties.

These different strategies, which all claim to promote the sustainability of coffee production, do not have the same effects on the adoption of agroecological practices. They try to reduce (totally in the case of organic practices) the use of chemical products, but their contribution to the increase of biodiversity varies: restricted in the case of exacting certifications like Bird Friendly, negotiated more on a case-by-case basis for market-related certifications, such as Rainforest Alliance, Starbucks Café Practice, or strategies based on the designation of origin.

On the other hand, the cooperative sector has gained in importance over the decades. In Nicaragua, following the relative fiasco of the Sandinista agricultural cooperatives promoted by the State in the 1980s, NGOs took over in the liberal years (1990s and 2000s) and encouraged the emergence of cooperatives to support coffee production and exports. Some cooperatives have flourished, become highly professionalized, especially as concerns the promotion of quality coffee and negotiations for exports, and become effective production support structures. In Costa Rica, cooperatives have largely developed with State support, and control much of the coffee export. CooCafé, a federation of cooperatives, has set up its own certification, Café Forestal, based on agroecological criteria. These cooperatives, where they exist, are key actors in accompanying innovation and for access to certifications (Faure *et al.*, 2012) and thus in the promotion of agroecological practices.

Lessons learned

This brief summary of the principles of the association of species and of the ways of promoting it provides us with some conclusive inferences.

There is a reservoir of knowledge and of practices of agroforestry producers that is yet poorly exploited. The systems are very diverse and some producers have practices that deviate from the standard. All marginal practices are not beneficial, of course, but we must equip ourselves with the means and methods to explore and evaluate these practices and this knowledge.

It is not easy to find predictable ways of deriving value from additional products obtained from agroforestry. Vertical integration plays an important role: the more actors succeed in transforming products, the more they manage to reduce these uncertainties. This is especially true for timber produced by shade trees.

Practices concerning shade trees have to be easy to implement in order to ensure their adoption and use: not only reproduction and planting, but also, and above all, ease of management and flexibility in the choice of species in order to be able to adapt to constraints that vary over time. Thus, species that can withstand two occasions of near total pruning per year have met with approval by the producers, e.g. *Erythrina* and some species of Inga.

The perennial aspect of the systems forms the basis for the provision of numerous ecosystem services: protection against erosion, protection of biodiversity, nutrient recycling, etc. Nevertheless, there is a lack of clarity regarding a certain number of elements, arising from the differential effects of certain species or combinations of species on pests and diseases and on soil biology. Few studies have so far focused on the functional traits of shade trees that could increase the provision of these services.

The complementarity of the species depends on the complementarity of the niches explored (Sanchez, 1995), but it is necessary to extend this notion, used originally in ecology. While this notion can, no doubt, concern the niches explored by the roots and by the aboveground elements for capturing sunlight, it can also pertain to niches in the economic sense: in terms of annual distribution, the income from banana, for example, harmoniously complements that of the coffee plant.

Price is, without doubt, the main element to be considered in understanding the evolution of practices. This is as true for coffee cultivation in Central America as it is for other productions in other parts of the world. Even if some room for manoeuvre still exists, agricultural systems cannot comprehensively move towards a better consideration of environmental objectives in the current framework of price fixing and fluctuations. Given this context, we need to focus more on the economic assessment of agroecological options, especially agroforestry, for managing coffee plantations in order to better document these debates and inform public decisions.

Communication about the labels within organizations that administer them – cooperatives in particular – is essential. Much of their effect on changing practices depends on it: producers need to know the requirements of certifications. Furthermore, being certified endows producers with some pride, and this pride has beneficial effects on practices. Finally, the cooperatives that manage the application of these labels can become responsible for a good part of the training, a fundamental element of the agroecological transition.

The research community is still searching for generic principles of action for agroecology that can serve as a framework for the introduction of remunerative practices for producers. We must strive to understand the complexity in order to optimize it.

The general societal push for agroecology is an important element of the transition, even though its impact on practices remains difficult to assess. It facilitates the development of normative frameworks, the appearance of labels for domestic markets, as also the taking of concerns and practices of agroecology into account by producers. This is a development we have observed in Costa Rica and, to a lesser extent, in other Central American countries, where coffee cultivation is less intensive.

Conclusion

Coffee-based agroforestry systems represent agroecological options of great interest, combining the cultivation of quality coffee with other productions, diversifying in this way not only the producers' income sources but also the diets of their families. These systems are, however, complex and there is insufficient knowledge of their functioning and the conditions under which they could be improved.

Following a phase of acquisition and capitalization of knowledge on agroecology, the partnership platform (PCP AFS-CP) is moving on to another stage of the transition. This step consists of the implementation of options for changing production conditions, in a closer working relationship with public authorities, private operators and NGOs, which can give it the means for this scaling up. It is these new challenges that this platform has decided to address in its second phase, starting in 2017.

We have shown at the beginning of this chapter that prices, their changes over time, as also the ways of modifying them, are essential elements of an agroecological transition in this sector which is closely tied to international markets. Other drivers are becoming apparent, and they must be integrated into our work.

Thus, the first appearance of coffee leaf rust on coffee plants in Central America, in 1976 in Nicaragua, has resulted in the creation of a regional network of coffee research institutes to promote the development of innovations and the modernization of coffee production: Promecafé (*Programa Cooperativo Regional para el Desarrollo Tecnológico y la Modernización de la Caficultura de Centroamérica, República Dominicana y Jamaica*). While this disease kept a relatively low profile in Central America for decades (Avelino *et al.*, 1999), it resulted in significant losses in 2012-2013, and become a driver of changes in the region's coffee plantation systems. One of the reasons behind this increased damage from the disease may be climate change, since coffee and the coffee leaf rust agent, *Hemileae vastatrix*, are both very sensitive to temperature (Avelino *et al.*, 2015). An immediate outcome of the crisis was the development of the coffee genetic bank, with the rapid replacement of susceptible traditional varieties by resistant varieties. However, the disease seems to have already started overcoming resistance, indicating that integrated management of coffee leaf rust, based on shading and nutrition, and especially on soil conservation, is needed (Avelino *et al.*, 2006; Toniutti *et al.*, 2017). A systemic approach to the control of this disease has to be adopted (Lewis *et al.*, 1997). The transformation of the production system in its entirety has to considered in order to maximize the preventive forces of the control of diseases and pests, by mobilizing several ecological control/regulation mechanisms (Avelino *et al.*, 2011) that form the basis of the agroecological system, and using conventional control measures (chemistry, genetics) only as a backup or support. Their effectiveness could then be increased because of the reduced pressure of pests and diseases in these new systems. This strategy seems the only solution for pests and diseases for which no genetic control is possible (case of non-specific pathogens like *Mycena citricolor*) or because it has shown its limitations (case of coffee leaf rust). While shading is a key aspect in this approach, studies need to be conducted to identify shading ideotypes that achieve this goal of effective regulation of the pests-and-diseases complex.

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