CHAPTER 8
ABOVE-GROUND TRANSFORMATIONS IN
AGROFORESTRY SYSTEMS IN
WATERSHEDS: CASE OF COCOA
AGROFORESTS OF CENTRAL CAMEROON

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ACRONYMS

CFA  Communauté financière africaine
MT    median tree
NMT   non-median tree

Local knowledge passed down from ancestors to descendants indicates that a considerable proportion of the forest margins of central Cameroon was previously covered by forest savannah. These forest savannahs have since been occupied by pioneer settlers who have developed traditional agroforestry systems. These agroforests are simultaneous land management systems, in which tree components occupy the same area as crops and, sometimes, animals. Similar to home or forest gardens, the agroforests possibly constituted the first transformation of original vegetation into a consciously managed agroforestry system. To date, their value is based on their flexibility, both economically (i.e. flexible demand on labour) and ecologically (i.e. diversity of species and different harvest periods for products) and in terms of the adaptation of products to local and national markets as well as household needs (Minchon, Mary and Bompard, 1989).

Many of these traditional agroforestry systems experienced their second transformation approximately 30 to 50 years ago with the onset of cocoa plantations (Tonka, 2003). There was a move towards transforming forest savannah to cocoa agroforests. Indigenous trees in these cocoa systems continued to serve as medicine, fruit and food sources, with the vast majority set aside as shade trees for the cocoa crops. In this second transformation, the health and productivity of the cocoa crop was the main concern and driving force behind the management of these agroforestry systems.
The decline of the cocoa sector, which began in 1989, came to a head in 1995 with the quasi-liberalization of the production chain for cocoa. The devaluation of the Communauté financière africaine (CFA) franc in 1994 led to the doubling of Cameroon’s external debt, therefore the Government of Cameroon was forced to reorganize the sector by withdrawing subsidies to farmers. The combined crises of a failing international market, rigorous national policies, social pressures, low inputs and low yields at the farm level meant that farmers could no longer fully observe technical guidelines (Bernard, 2000), maintain the cocoa plantations and depend almost entirely on the cocoa crop for their livelihood. This period saw a gradual disenchantment by farmers with cocoa as a dominant livelihood strategy. In addition, cocoa is not directly used in indigenous culinary and health strategies.

These circumstances led to the third transformation, characterized by both the increasing diversification of the use of cocoa systems by integrating and managing greater numbers of indigenous fruit and medicinal trees, and the development of smallholder plantations. Both strategies were geared towards more profitable land use and greater food and health security. This third and latest transformation of agroforestry systems was accompanied by the spread of smallholder plantations and mixed systems, the latter being characterized by variations in three important above-ground factors:

- tree species diversity;
- spatial and horizontal disposition of trees;
- spatial and vertical stratification of the systems.

While the smallholder plantations tend to follow the lines of intensification (using less complex methods of monocultures, high-yielding varieties, regular spacing and single strata), the cocoa agroforests are characterized by a more complex and dynamic arrangement in which economic, ecological and management questions are less predictable. Two transformation processes are currently evident, smallholder monocultures and annual crop agroforests; the latter are by far the more complex, and therefore are analysed in this paper. Numerous factors are undergoing change in this current process of transformation of agroforestry systems. Even for annual tree crop-based agroforests such as the cocoa systems, tendencies are towards simplification of system structure, regularization of inter-tree distances, integration of more uniform and high-yielding trees, and greater domestication of the agricultural landscapes, largely for socio-economic reasons.

It is likely that other processes such as the environmental consequences of these transformations will tend to be less obvious, hence these tendencies and trends will form the basis for this research. The work was carried out in order to capture these latest transformations in agroforestry systems as they unfold, and to raise some pertinent research questions regarding the potential links that may exist between the visible above-ground transformations and the less visible systems, watershed properties, as part of a potential future research agenda for the region.

The study focused on the characterization of spatial, quantitative and qualitative aspects of indigenous trees within cocoa agroforests in the study sites. The following three specific hypotheses guided this above-ground characterization study:

1. The degree of variation in the horizontal inter-tree distances of indigenous trees is a measure of irregularities in their horizontal spatial distribution, and a cause of sparseness and/or clustering in different parts of the system.
2. The height distribution of the indigenous trees largely determines the vertical stratification of the agroforest system.
3. The knowledge of the species and the extent of their use by local communities is a strong determinant of management requirements and therefore of what practices are likely to be retained, eliminated, substituted or replaced.

The legitimacy of these hypotheses can be found in observable characteristics in the cocoa systems and in current scholarly knowledge on the potential effects of trees and tree systems on components of the hydrological cycle (interception, percolation, transmission, retention, discharge, evapotranspiration), as well as the ways in which these influence the water budget of a farming system on a watershed. Trees on farms can have these effects in their influence on water-related properties of the soil (Stevenson and Cole, 1999; van Noordwijk et al., 1999) such as organic matter content or their hydraulic conductivity (Angers and Caron, 1998).

According to the hypothesis, the greater the variations in inter-tree distances, the more irregularly the soil surface of the farming system is likely to be covered, resulting in sparsely covered or exposed areas and densely covered or choked up sections. This creates a patchwork of tree cover as a result of both farmer intervention and natural processes that stem from the need to provide shade to cocoa crops.

In tree-based systems with minimal undergrowth, the more developed the stratification or height class distribution (light and heavy crown) of the trees, the more developed the system’s mosaic or overlapping characteristics. An increase in raindrop interception (achieved mostly by trees in the highest stratum) results in a reduction in impact velocity. This leads to less surface crusting of the soil, greater percolation and infiltration to the soil, and reduced runoff resulting in a potential increase in groundwater.

Farmers are able to influence the properties of soil in the cocoa systems in the choice of trees to introduce. Deciduous, broad-leaved and fruit producing trees create larger amounts of biomass that is added to the soil. Similarly, the even distribution of these trees over the farm surface will result in fewer disparities in such factors as organic matter accumulation, soil surface exposure and wetting and drying cycles of the soil. These factors affect the hydraulic conductivity of soils (Angers and Caron, 1998), however; the overall water retention and discharge within a cocoa system can be indirectly managed. This is achieved through factors affecting reception and infiltration, soil retention, evapotranspiration and discharge to groundwater, resulting in reduced variation across agroforests in important watersheds throughout the African humid tropics.

RESEARCH METHODS

Research site and sampling design

Thirty cocoa farms were selected systematically within the forest savannah study site (Figure 1). The general characteristics of the forest savannah showed little or no variation in dominant tree or herbaceous species; therefore, no vegetation-based stratification was deemed necessary. Instead, stratification was carried out at the community level where three villages, each between 2 and 3 km apart, were selected for the study. The basic rule was that no two farms
were to constitute a contiguous block. Ten farms were selected per village by randomly selecting numbers from a list of all cocoa producers within that village.

Within each cocoa farm, a median was estimated with the help of the farmer, and all trees within 8 to 10 m on either side of the median were characterized. This study transect (20 m wide), cutting across all 30 farms, covered a total distance of more than 1,000 m, thus constituting a total study surface area of more than 20,000 m² or 2 ha.

**FIGURE 1**

Forest savannah zone where study was carried out.

**Data collection**

A research team consisting of three people (including the farm owner) carried out the data collection. In order to maintain the median of the cocoa farms or subplots, a series of median trees were identified throughout the length of the farm (Figure 2). Non-cocoa indigenous trees within this median were referred to as median trees (MTs). All other trees on the left and right of the MTs were referred to as non-median trees (NMTs). The following measurements were then taken within these transects:

- Tree heights were estimated using an improvised “thumb method”. A stake 1.8 m tall was placed against the tree and used as a yardstick for measurement. Two or three people independently estimated the height of the tree by mentally counting the number of yardsticks that would correspond to the height of the tree. This number could not differ by
more than 2. The two or three readings were then averaged and multiplied by 1.8 m to get the estimated tree height.

- Single horizontal distances between MTs of heights greater than 3 m were measured using a measuring tape.
- Single horizontal distances between NMTs of heights greater than 3 m were also measured using a measuring tape.
- All trees that were measured were also identified by their local name. Those not known by the farmer were recorded as “unknown”.

**FIGURE 2**

*Cocoa farm transect characteristics*

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**Data analyses**

An analysis of variance in inter-tree distances was carried out using GENSTAT (Edition 6). Tree height classes were sorted using Microsoft™ Excel, and a diagrammatic representation of a compressed “unit” cocoa agroforest was generated. Additional quantitative analysis was carried out using Excel. The main results are presented in the following.

**RESULTS AND DISCUSSIONS**

Table 1 shows that a relatively wide range of indigenous trees were encountered on the study site farms; however, farmers generally use only trees that they know, while others remain to provide shade for the cocoa crop.
With the present transformations in the cocoa system, more than half of the indigenous trees are unknown to the farmer and remain in the agroforest only to provide shade for the cocoa crop. Indications are that as the value of the cocoa crop continues to be uncertain, trees within this category are most likely to be replaced. Of the 22 most used species the vast majority were indigenous and exotic fruit species (Figure 3). Farmers claimed that “duplicates” for these trees occurred in the woodlands nearby. Their performance in terms of form, height and productivity was generally poor. Trees were too tall and impossible to climb. Fruits were generally small for the species, and management was non-existent. Indications are that these fruit trees were not fully valued by the farmers as they generally performed badly in the cocoa systems. Therefore, with the introduction of even a mildly more profitable alternative land use, farmers may not hesitate to transform the system further at the expense of these trees.

**TABLE 1**

<table>
<thead>
<tr>
<th>ITEM STUDIED</th>
<th>RESULT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total number of different species of trees encountered</td>
<td>162 (100%)</td>
</tr>
<tr>
<td>Number of species unknown to the farmers</td>
<td>96 (59%)</td>
</tr>
<tr>
<td>Number of species known but not used</td>
<td>44 (27%)</td>
</tr>
<tr>
<td>Number of species most used by the farmers</td>
<td>22 (14%)</td>
</tr>
</tbody>
</table>

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**FIGURE 3**

*Uses of most-used species*
Therefore, unless new steps are sustained in the diversification and intensification of the cultivation of high-value trees, the cocoa systems and the trees in them are likely to see increasing instability in the years to come.

In terms of the spatial arrangement of the trees, the irregularity was very marked (underlined by variations in inter-tree distances). As Table 2 indicates, the distances between all the categories of MTs and NMTs varied considerably \( (p < 0.001) \). This is a strong indication of the potential for clustering in some parts of the farm and/or sparse distribution in others, which was supported by direct observations on the farms. Generally, the horizontal spatial distribution is irregular for all the trees, irrespective of species.

TABLE 2
Extent of variations in inter-tree distances in cocoa agroforest

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Results for inter-tree distances between MTs (MT-MT)</th>
<th>Results for inter-tree distances between NMTs (NMT-NMT)</th>
<th>Results for inter-tree distances between MTs and NMTs (MT-NMT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Values (n)</td>
<td>234</td>
<td>506</td>
<td>351</td>
</tr>
<tr>
<td>Mean</td>
<td>7.466</td>
<td>7.008</td>
<td>8.387</td>
</tr>
<tr>
<td>Probability</td>
<td>(&lt; 0.001)</td>
<td>(&lt; 0.001)</td>
<td>((0.001))</td>
</tr>
<tr>
<td>Standard error</td>
<td>3.702</td>
<td>3.448</td>
<td>4.180</td>
</tr>
<tr>
<td>Coefficient of variation</td>
<td>49.6</td>
<td>49.2</td>
<td>49.8</td>
</tr>
</tbody>
</table>

In light of the current transformations in new plantations within the zone of study and elsewhere, there is a tendency towards conscious regularization of inter-tree distances in order better to manage space, tree growth and maintenance activities. This is very marked, particularly in new oil-palm-based plantations.

In terms of vertical stratification, a clear and consistent structure could not be discerned in the agroforests. One precondition for optimum use of vertical space is the three-tier model proposed for the “ideal” agroforest (Minchon and De Foresta, 1997). These cocoa agroforests show a great dominance within the 10 to 20 m height class.

The 10 to 20 m class shown in Table 3 is so large that in order to analyse it correctly, it required further division into subclasses. When related to the three-tiered model, two classes \((5 \text{ to } 10 \text{ m and } 20 \text{ to } 25 \text{ m})\) appear dispensable. According to the farmer, these two intermediate classes often constituted points of increased disease spread from tree to tree and from stratum to stratum. It is possible that the greater efficiency achieved by the ongoing transformations of improved space management and pest management may require these intermediate strata to be thinned out.
Figure 4 is a cross-section representing all the cocoa agroforests that were studied and showing the “smallest denomination” of these trees. Clearly, T1 and T2 are strata requiring elimination if the ideal three-tier structure is to be attained. Stratum B has also been found to be too dense, and may need to be thinned out. On the other hand, stratum C may be too thin.

**CONCLUSIONS**

The results of this research raise a number of important management questions that can be directed towards two main areas. The first is in terms of the hypotheses given at the beginning of the research, and the second in terms of the potential effects of these transformations on the watershed functions of these agroforests.

When reviewing the original hypotheses, the results show conclusively that there are highly significant variations in inter-tree distances within all height classes in traditional cocoa agroforest systems. This variation leads to considerable irregularity in the spatial arrangements of the more dominant components in these agroforests. The questions that are therefore raised are:

- How will such variations relate to vital watershed functions of these increasingly rampant and ubiquitous agroforests?
- How should they be managed in the coming years?

Second, the results show quite conclusively that vertical stratification in these agroforests is a function of the height class distribution within the system. Furthermore, although the maturity and productive form of some indigenous trees are known, heights of trees in systems such as those studied are equally influenced by competition (due to environmental factors) with other trees. Therefore, to develop and maintain a model structure with potential benefits for space
management would require intensive management of the agroforest. However, the management of such a system creates potentially contentious and critical issues. The farmer should be responsible for making decisions regarding thinning, eliminating, substituting or replacing trees within the agroforest system. The potential costs and benefits involved and the trade-offs necessary need to be evaluated to enable the farmer to take calculated decisions with balanced or more acceptable outcomes. This appears to be a classic case of the application of optimum pessimism: success results in moderate benefits and failure in moderate losses. Current possibilities would suggest a non-specific (generic) decision providing a range of options to farmers, with associated possible outcomes and different levels of risks. In a society where the level of production of cocoa for individual farmers may mean the difference between destitution and survival, care needs to be taken to unite better the environmental and livelihood objectives. Similarly, the level of management given to the cocoa may rely directly on the value given to the product by individual farmers. The value of a tree is directly related to accumulated knowledge relating to that tree by the farmer, thus playing a large role in the management decision-making process. Therefore, gaining additional knowledge relating to the indigenous trees within an agroforest system is beneficial in the management process.

In order for the potential effects of these transformations on the watershed functions of agroforest systems to be assessed, substantial medium- to long-term research must be carried out in order fully to support such theories. Important factors will need to be addressed relating to watershed functions that are relevant to the main components of the hydrological cycle. These factors can significantly influence the water budget of any agroforest system.
Additional and relevant research, modelling and management (at the local level) may be necessary to reach equilibrium in balancing both the costs and benefits accruing from agroforest systems. These can provide optimum benefits both for the environment and for the livelihoods of farmers. Current knowledge regarding the effects of trees and tree systems on components of the hydrological cycle (i.e. interception, retention, discharge, evapotranspiration, soil moisture storage, water deficit) that apply to existing situations is needed to support and justify future efforts.

The results of this study clearly indicate that transformations in agroforestry systems within the region are increasingly characterized by trends in spatial distribution of trees in agroforests from irregular to regular distribution. This was shown by a decrease in the variations between inter-tree distances and changes from complex to simpler vertical stratification (i.e. multi- to fewer strata). However, the issues relating to trends in tree diversity, an expanded knowledge base and indirect values of trees on farms are more varied and less conclusive. What is certain is that as transformations continue in agroforests, driven by economic considerations, transformations also occur in the biophysical processes within the system. Greater understanding of these processes is still required. Furthermore, these economically driven transformations tend to simplify the system from complex and dynamic to ordered, less complex and more predictable or “domesticated” systems. Tree domestication activities carried out by the World Agroforestry Centre tend to support a more ordered and predictable system, closely resembling traditional agroforests in both diversity and stratification. Questions remain to be answered relating to the optimum balance between sustainable livelihoods for farmers and an equitable environmental balance.

REFERENCES


