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From natural forest to tree crops, co-domestication of forests and tree species, an overview

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Abstract

The process of domestication of tree crops has only been given limited attention. This process starts with the protection of natural forests and ends with the cultivation of domesticated tree crops. In this evolutionary process three types of human-influenced forest environments may be distinguished: (a) conserved forests, (b) modified forests, (c) transformed forests. During the process of domestication an increasing input of human energy per unit of exploited forest takes place. Accordingly three phases in the domestication of forests may be distinguished: (a) an acculturalization phase in which social measures aimed at controlling the utilization of valuable tree species or patches of forests are implemented, (b) a phase of manipulation of wild tree species in which the socially-oriented management practices are enhanced with measures aimed at enhancing the (re)productive potential of valued species, (c) a phase of cultivation of genetically modified tree crops. As a result of the co-domestication of forests and trees various types of forests and/or tree cultivation systems can be distinguished. So far more attention has been given to understanding the characteristics of the early and end phases than to the various intermediate phases represented by indigenous forest management and agroforestry systems. These are characterized by a modification of the highly diverse natural forest ecosystems to a state in which the biodiversity has been somewhat reduced, but in which a larger proportion of useful resources are present. Such systems provide interesting examples of the wide range of options for managing forest resources with varying degrees of biodiversity and productive values.

Keywords: forest management, tree exploitation, agroforestry, people-plant interaction

Introduction

The dichotomy between wild and domesticated species has a long history in the European philosophy; this dichotomy reflects the conceived distinction between nature and culture which has firmly been established in Western thought since Classical times (Harris, 1996). In the past, this dichotomy has often been used by archaeologists, anthropologists and historians in a static sense to denote states of being. But since the nineteenth century biologists have started to use the term do-

mestication as a dynamic term referring to a process rather than state of existence. At present this dynamic interpretation of domestication is scientifically generally accepted (Harris, 1996).

Nonetheless, different interpretations of the concept of plant domestication still prevail (e.g. Leakey & Newton, 1994). This is not surprising in view of the fact that scientists from diverse disciplinary backgrounds, ranging from botany to anthropology, geography and agricultural sciences have been involved in describing the process of plant domestication. Some scientists have defined domestication in a relatively restricted sense as a biological process, while others interpret it in a comprehensive sense as an acculturalization process characterized by increasing human-plant interactions. These different interpretations can be related to two hierarchical levels. In the biological sense, domestication refers to the processes operating at species level: the cultivation and gradual adaptation of a species' morphological and genetic characteristics for specific uses as well as specific environments. Sometimes the concept of domestication is even restricted to the process of adaptation of the genetic make-up of a crop species. Cultivation in the sense of altering the location or growth habit of a crop may precede such domestication.

In its comprehensive sense the concept of domestication refers to processes operating at agro-ecosystem level. In this interpretation the concept refers to the changes in the plant's morphological and genetic properties brought about by changes in exploitation and management practices. Concomitant with changes in the biological properties changes in a plant's growing environment occur as well as a gradual intensification in cultivation practices. Thus, in its comprehensive sense, domestication is considered as a multidimensional process in which a progressively closer interaction between people and plant resources takes place (Table 1).

To date, most efforts to assess the various dimensions of the domestication process in its comprehensive sense, have dealt with the staple food (= field) crops (e.g. Harris, 1989, 1996; McKey *et al.*, 1993). Only relatively little attention has been given to the process of domestication of other crops such as tree crops (Leakey & Newton, 1994). As observed by Michon & De Foresta (1996, 1997) it is usually

Table 1. Dimensions of crop domestication in the sense of a process of increasing people-plant interactions

1. Modification of a plant's biological characteristics
   - human induced change in a plant's morphological characteristics and genetic make-up.

2. Modification (or artificialization *sensu* Michon & De Forests, 1997) of the biophysical environment
   - human induced manipulation of biophysical environment in which a plant is growing in order to stimulate its production through (i) homogenization of species composition by selective removal of non-valued species and stimulation of valued crops, (ii) control of pests and diseases, and (iii) homogenization and enhancement of the physical growth conditions

3. Acculturalization of a crop to a social management environment
   - increased adaptation of crop species to specific uses
   - incorporation of a species in a human-controlled production environment through the formulation of access rules for crop utilization and the formation of management organizations

assumed that the biological processes and technical options for domestication of tree crops can be considered as replicates of the process of domestication of the field crops. In this paper it will be shown that the processes of domestication of tree crops and field crops are only partly analogous. Essential differences are brought about by the degree in which the biophysical environment is changed during the process. Using the natural forest as a starting point, the evolutionary process in forest - people interactions will be characterized as a process of co-domestication of forests and trees. Various phases in this process will be identified. It will also be discussed how these different phases of exploitation of tree crops are reflected in the present disciplinary approaches towards management options for forests and tree crops.

Domestication of field crops and tree crops

As indicated, it is often assumed that the process of crop domestication basically follows the same trends. However, such an assumption is only warranted in case of the restricted meaning of domestication of changing a plant's biological characteristics. In case domestication is considered in an agro-ecological sense, some important differences in the process of domestication of food and tree crops may be distinguished. The change from natural ecosystems to agro-ecosystems may take two different forms. It may involve a process of ecosystem manipulation in which a natural ecosystem is transformed into a largely artificial one created and maintained by man. Or it may involve a process of ecosystem transformation in which a part of the wild species are substituted by improved cultivars or with higher valued species, but in which the natural ecosystem is only partially changed (Geertz, 1966; Harris, 1978; Michon & De Foresta, 1997).

These two contrasting types of crop production can be related to the two prototypical models of agriculture, i.e. 'agriculture' in the etymological sense of the cultivation of 'ager' (= a tilled, totally cleared fields), and 'horticulture' in the etymological sense of the cultivation of "hortus" (= a garden containing multi-species tree and tuberous crops) (Barrau in Michon & De Foresta, 1996). The 'agricultural' model of agricultural development concerns the production of staple food crops such as grains or tubers and various industrial crops. For these crops the process of domestication starts with harvesting of untended wild plants in their natural environment, which predominantly exist of open grassland or pioneer vegetation. It proceeds with the extension of the crops to the forest environment, where crops are cultivated in cleared plots, and ends with the breeding of high-yielding varieties. A major feature in this domestication process is thus the clearing of fields from the forest followed by cultivation of crops on artificially homogenized fields which are largely dissociated from the pre-existing environment.

In contrast, the process of domestication according to the 'horticultural' model involves a more gradual transfer of the natural environment. Many horticultural species producing fruits, vegetables or ornamental flowers have their origin in natural forests. The utilization of such species usually starts with their exploitation from the natural forests. Prance (1994) considered such extraction as the initial phase of

domestication of valuable forest species. Descriptions of the subsequent process of their domestication have mostly focused on tree species. At first, uncontrolled utilization of the wild tree products is changed to controlled exploitation. Subsequently, native trees may be cultivated in an enriched forest or in (indigenous) agroforestry systems such as forest gardens (e.g. Homma, 1992). The cultivation of selected varieties of trees in either mixed tree plantations (e.g. of fruit trees) or commercial mono-crop plantations (e.g. rubber, oilpalm, coffee) is the last phase of this domestication process. In this final phase the process involves the breeding of selected genotypes resulting in rather uniform tree populations with a narrow genetic base (Verheij, 1991; Leakey & Newton, 1994; Wiersum, 1996).

Thus, historically, the concepts of 'agriculture' and 'horticulture' were distinguished not only on basis of the kinds of crops being considered and their specific cultivation practices, but also on basis of differences in their origin and prevalent growing conditions. As a result of modern cultivation practices using genetically-selected crops and highly specialized management practices, this prototypical differentiation has gradually been replaced by a differentiation in commodity groups mainly. In this interpretation 'agriculture' denotes the cultivation of staple food and industrial crops, while horticulture refers to the growing of vegetables and fruits. In order not to confuse these different interpretations, and to focus the discussion specifically on tree crops, in this paper a differentiation will be made between a 'field-crop based' and a 'tree-crop-based' pathway of agricultural development.

Domestication of forests

In addition to the 'agricultural' and 'horticultural' prototypes of land-use, still a third prototype of land-use has been distinguished, i.e. 'silviculture' in the etymological sense of the cultivation of 'silva' (= forest). In analogy to the 'agricultural' and 'horticultural' models of domestication, it seems therefore logical also to distinguish a 'silvicultural' model of domestication. Indeed, it has been proposed to use the term domestication not only with reference to plants, but also with reference to forests (Lamprecht, 1993; De Graaf, 1994). According to this view, the term domestication may not only be used to refer to the process of changing wild plant species to cultivated species, but also to the process of changing 'wild' forest into managed forests. This process can be characterized as the transformation of a natural forest into a forest in which the original structure and composition has been changed to better suit specific human purposes. It involves the following changes in forest composition and productive capacity:

- a homogenization of products and stands according to species and tree age
- a concentration of production on specific tree species
- an enhancement of productivity through the improvement of site specific production factors.

The process of domestication of forests starts with the stimulation of growth and yield of species occurring naturally, and ultimately it may involve the cultivation of

selected species or cultivars in plantations. Thus, although the term domestication of forests seems at first impression to refer to a process at ecological level, in reality it involves the same two levels as for domestication of agricultural crops, i.e. the species and ecosystem levels. At both the ecosystem and species levels the 'silvicultural' development pathways are identical to those of 'horticultural' pathways. In both cases the exploitation of the valued tree species starts with the extraction of wild products from the forests. Subsequently, the wild trees are brought under some form of management. In a later stage of the process first native species and later exotic tree species or cultivars are cultivated. In contrast to agricultural production, the introduction of exotic tree species or cultivars does not necessarily involve planting in open fields, but may take the form of enrichment planting in the existing forest. Such cultivation modifies the composition of the forest vegetation, but maintains at least part of the basic forest structure. It also leaves the forest soil and microclimate conditions more or less intact. Ultimately, also monospecies plantations may be established on cleared fields. In this case the original vegetation structure and composition is totally transformed, but soil conditions remain more or less intact.

Irrespective whether wood or non-wood products are involved, the process of domestication of tree crops proceeds along basically similar pathways. Rather than being based on differences in the development pathways during the process of domestication, the distinction between 'silviculture' and 'horticulture' is based on commodity considerations and the prevailing intensity of cultivation. Whereas in the 'horticultural' model attention is given to fruit production, in the 'silvicultural' model attention has traditionally predominantly been focused on timber production. Mainly because fruits have a higher market value, the management intensity of the 'horticultural' tree crops is higher than that of timber trees. Moreover, the stimulation of fruit production and the handling of the, often perishable, products requires different management practices than for timber production. Consequently, a disciplinary distinction has been made between fruit tree production as a horticultural activity and timber production as a silvicultural activity. This distinction was further emphasized, when, for historic reasons, different institutions developed for the research and production of the different types of commodities.

However, this distinction is gradually becoming blurred, because at present increasing attention is being given to the management of forests for the production of non-timber products such as foods, gums/resins, medicinal products and fodder rather than for wood only (e.g. Ros-Tonen *et al.*, 1995). During the last two decades increasing attention has also been given to the development of agroforestry as a means for sustainable land-use. In such agroforestry systems tree species are grown in mixtures or in association with other crops (Wiersum, 1985; Sanchez, 1995). In these systems trees often have a multipurpose or auxiliary function rather than a monospecific commodity function.

As a result of these new trends in forest management and crop production, the traditional disciplinary distinctions between 'horticultural' and 'silvicultural' models of tree crop cultivation need to be reassessed, and renewed attention should be given to identify basic common features in tree production processes. The similarities in the domestication process of timber and non-timber producing trees are in-

creasingly being acknowledged. It seems therefore relevant to characterize the domestication process of tree crops on the basis of general agro-ecological and management characteristics.

Evolutionary pathways in the exploitation of field crops and tree crops

In order to clarify the specific features of the various phases of plant domestication, Harris (1989, 1996) has proposed a classification model in which various evolutionary phases of plant exploitation are arranged sequentially along a gradient of increasing input of human energy per unit of exploited land. He identified the following four progressive phases of plant exploitation:

- procurement of wild food plants
- production of wild food plants with small-scale clearance of vegetation and minimal tillage
- cultivation of native food plants with larger-scale clearance and more intensive tillage
- cultivation of domesticated crop plants.

In this model the main variables distinguishing various phases of plant domestication are the manner in which fields are cultivated and the in situ or ex situ origin of the crops. Thus, this model typically represents the 'field crop' model of domestication.

Wiersum (1997) has adapted this model to represent the various phases of exploitation of tree crops. Whereas in the Harris model most attention is given to the manner in which fields are cultivated and to the change from wild to domesticated crops, in this 'tree crop' model special attention is paid to the ways in which the biophysical environment is brought under human control and on the impact of plant exploitation on the original forest vegetation (Boerboom & Wiersum, 1983; Hladik *et al.*, 1993). By focusing on (i) the transition from open-access to controlled exploitation of tree crops, (ii) the transformation of natural forests to tree crop plantations, and (iii) the modification of a plant's biological characteristics, six consecutive phases in tree exploitation were distinguished. Similar to the field crop model, at first products from wild trees are extracted in an uncontrolled manner from the natural forests. In the second instance, a change from uncontrolled utilization of the wild tree products to their controlled exploitation takes place. This is accomplished by defining user rights and formulating regulations on extraction practices. The third phase consists of the protection and tending of naturally regenerated individuals of valuable tree species in semi-natural forests. Subsequently, purposeful in situ cultivation of native trees takes place in either resource-enriched forests or forest gardens. The cultivation of native and later also genetically modified trees in association with field crops or in commercial tree-crop plantations are the last stages of this domestication process. In the same way as in the field crop model, these stages can be conceived as representing progressive phases with respect to the input of human energy per unit area of exploited forest (c.f. Gilmour, 1990; Shepherd, 1992).

When comparing the field crop and tree crop models of plant exploitation (Table

Table 2. Comparison of phases in the exploitation of field crops and tree crops

	Field crops (Harris, 1989)	Tree crops (Wiersum, 1997)
Phase 1	Procurement of wild-food by gathering/collection	Uncontrolled, open-access gathering of forest products
		Controlled gathering of wild tree products
Phase 2	Production of wild-food with small-scale clearance of vegetation and minimal tillage	Systematic collection of wild tree products with protective tending of valued tree species
		Selective cultivation of valued trees by artificial in-situ regeneration of native trees
Phase 3	Cultivation of native food plants with larger-scale land clearance and systematic tillage	Cultivation of selected native tree species in artificially established plantations
Phase 4	Cultivation of domesticated crop plants	Cultivation of domesticated tree crops in intensively managed plantations

2) it is clear, that the distinction between these two models should rather be considered as an analytical one than as an absolute one. During the early phases of either field crop or tree crop exploitation products are extracted from the natural vegetation. While at the final stages genetically modified field crops as well as tree crops are established on homogenized open fields. The earlier identified dichotomy between the ecosystem-transformation and ecosystem-manipulation modes of domestication (Harris, 1978) thus represents a contrast in the degree of agro-ecological change induced during the intermediate phases of plant domestication rather than a contrast in end phases.

The distinction between a field-crop and tree-crop-based model of domestication may be useful for obtaining a better understanding of the diversity of people - plant interactions. It demonstrates that plant domestication involves various pathways which differ in respect to the degree of manipulation of crop biological and agro-ecological characteristics respectively. For instance, the intermediate phases of tree-crop-based pathways are characterized by a generally higher biodiversity than the similar field-crop-based pathways (Michon & De Foresta, 1997). The understanding that the tree-crop-based pathway allows better opportunities for biodiversity conservation might be helpful in developing new cultivation techniques which do not aim at optimizing productivity, but at joint optimization of productivity and ecological values. For instance, it has been proposed that forest management systems directed at non-timber forest products can significantly contribute towards sustainable forest management as well as biodiversity conservation (Plotkin & Famolare, 1991; Nepstad & Schwartzman, 1992; Ros-Tonen *et al.*, 1995; Van Valkenburg, 1997;

Boot, 1997). Similar arguments have been made with respect to multistoreyed agroforestry systems (Van Noordwijk, 1996; Michon & De Foresta, 1997).

Stages in the co-domestication of tree crops and forest ecosystems

From the description of the tree-crop-based model of plant domestication it is evident that this process consists of changes in a tree species' morphological and genetic characteristics and changes in the forest environment. During this co-domestication of tree crops and forest ecosystems an increasing input of human energy per unit of exploited land takes place. On the basis of these principles, the various phases in the exploitation of tree crops indicated above can be further elaborated into a hypothetical model of various stages in tree exploitation practices (Table 3).

As indicated in this model, a great diversity of tree-based cropping systems exists. Unfortunately, in comparison to field-crop-based plant exploitation systems only very limited attention has been given to the identification and systematic description of different forest/tree-based exploitation systems. In many cases, the presence of such systems has not been recognized or even denied (e.g. Peluso, 1992; Fairhead & Leach, 1996). Nonetheless, during recent years a number of descriptions of indigenous management systems for forest resources and tree crops have been published (e.g. Anderson, 1990; Gomez-Pompa & Kaus, 1990; Redford & Padoch, 1992; Shepherd, 1992; Hladik *et al.*, 1993; McKey *et al.*, 1993; De Jong, 1995; Padoch & Pinedo-Vasquez, 1996; Michon & De Foresta, 1997). In a review of such studies, the following four major categories of indigenous forest/tree management systems were distinguished (Wiersum, 1997):

- protected natural forests: sacred forests, water(shed) protection forests, clan/village forests
- resource-enriched native forests: enriched natural forests, enriched fallow vegetations
- reconstructed forests: forest gardens, planted temple forests, fortification forests
- mixed arboriculture: home gardens, mixed smallholder plantations.

In addition also different types of indigenous agroforestry systems in which trees are grown in association with field crops have been identified. As indicated in Table 4, it is possible to categorize these different (agro)forestry systems in conformity with the various stages of tree crop exploitation as hypothesized in Table 3.

The model indicating different stages in tree exploitation practices is an analytical one. It should not be regarded as an explanatory model indicating unidirectional and deterministic trends in which the various phases represent pre-ordained steps on a ladder of increasingly 'advanced' stages of general societal development (cf. Harris, 1989). In fact, in many areas different forest types and/or tree cropping systems may co-exist, with each type occupying a specific landscape and/or tenurial niche (Chase, 1989; Fortmann & Nihra, 1992; McKey *et al.*, 1993). Most tree exploitation systems form but one of the components of an integrated land-use system and the evolutionary trends in forest/tree management are anything but straightforward. Depending on their role in the local land-use systems, the management practices of

Table 3. Stages in tree exploitation practices

Uncontrolled procurement of forest products	Forest/tree crop management			
	Protection of forest resources	Cultivation of native trees	Cultivation of domesticated trees	
	Protection of patches of forest against unauthorized collection of products			Forest conservation
Casual/opportunistic gathering/collection of wild forest products	Controlled gathering/ collection of forest products	Enhancement of (re)productive potential of valued species through ecosystem manipulation		
		Purposeful dispersal of seeds/seedlings of wild species in natural forests	Cultivation of exotic or local cultivars in forest environment	Modification of forest
		Purposeful incorporation of valued species in fallow fields		
			Plantations of selected & improved cultivars – timber plantations – fruit orchards – treecrop plantations	Forest transformation
		Purposeful regeneration of native species on cleared fields – home gardens – agricultural fields		
			Growing of domesticated trees on croplands	
				Increasing manipulation of forest ecosystem
	Initial acculturalization	Controlled regeneration	Cultivation of genetically selected tree crop	Increasing input of human energy per unit area of exploited forest

Table 4. Examples of indigenous (agro)forestry management systems in tropical regions (after Wiersum, 1997)

Intensity of forest manipulation	Forest/tree crop management		
	Protection of forest resources	Cultivation of native trees and palms	Cultivation of genetically selected trees
Forest conservation	Sacred/temple forests Spring forests		
Modification of forest	Village forests Grazed woodlands Protected forest belts	Enriched natural forests e.g. with native fruit trees	Forest gardens with exotic tree species, e.g. jungle rubber gardens in Indonesia
		Enriched fallows, e.g. Casuarina fallows Rattan-enriched fallows Tree-crops enriched fallows: oilpalm, damar gum	
Forest transformation (= reconstructed forest)		Planted temple forest	Plantations of selected & improved cultivars – smallholder plantations – (mixed) fruit orchards
		Multistoreyed tree cropping systems, e.g. homegardens	
Scattered tree growing	Individual trees on agricultural fields	Growing of genetically modified trees on cropland	

forests and/or trees may either be intensified or extensified in response to agricultural intensification (Belsky, 1993) or more general changes in socio-economic conditions (Gilmour, 1990; Belsky, 1993; Dove, 1994; Arnold & Dewees, 1995; Wiersum, 1997; Filius, 1997). Nonetheless, the model may assist in clarifying the various stages in the process of the domestication of tree crops. It illustrates the various phases in the process of domestication of tree resources, and indicates for each phase the general characteristics of the type and intensity of tree management practices and forest ecological conditions.

Discussion

As discussed, to date, mainly the domestication processes of food and industrial crops have been studied. Consequently, attention has been focused on the processes operating at the later stages of plant domestication, characterized by crop cultivation on open, and often homogenized, fields using selected, high-yielding crop varieties. At present it is increasingly acknowledged that this approach of optimizing crop production may need to be modified to protect the environment. This means that new approaches to domestication are needed, which give more attention to the agro-eco-

logical dimension of the crop domestication process. For instance, sustainable land-use is now often considered to be only feasible provided that sufficient natural components are maintained in the agricultural landscape to maintain biodiversity and to act as ecological buffers. But opinions differ on whether such natural elements should be incorporated in the agricultural landscape at the level of crop systems or at a higher hierarchical level.

To answer such questions, it may be considered whether certain stages of domestication can be used as examples for the development of 'nature analogous' cropping systems (Oldeman, 1983), in which both production and environmental concerns are optimized. Due to the ecological characteristics of tree crops the different stages of tree exploitation deserve special attention. As demonstrated by the example of the oil palm (Gerritsma & Wessel, 1997) trees are often more favorable crops from an energy standpoint than field crops, as they maintain longer photosynthetic activity during dry periods and have lower energy demands in both cultivation and harvesting (Wiersum, 1985). Trees also protect favorable soil and micro-climate conditions. And they are relatively easy to cultivate in mixed-species agro-ecosystems (Wessel, 1992). The cultivation of tree crops therefore causes less environmental disturbance and maintains a higher biodiversity than the cultivation of most field crops. Such favorable characteristics are also present in many agroforestry systems in which trees are used to strengthen the ecological basis of annual crop production.

An important question when considering options for optimizing productive and environmental values of cropping systems, is whether the earlier phases of tree crop exploitation still offer scope for development under the present socio-economic conditions (Michon & De Foresta, 1997). These stages are often considered as being less progressive and more or less outmoded. However, this opinion may need to be reassessed in view of the present environmental concerns. An example of a return to an 'earlier' phase of tree exploitation is the transformation of monocultural timber plantations into mixed-species and uneven-aged forest stands. This 'Pro Silva' trend is taking place in many European countries (Anonymous, 1993). It is not only prompted by ecological considerations, but also by economic considerations as it will decrease management costs and contribute to higher quality production. Also in the field of agroforestry research efforts are now undertaken to better understand the precise characteristics of the intermediate phases of tree crop domestication and to assess their scope for contributing towards ecologically-balanced land-use patterns (Van Noordwijk, 1996).

In order to contribute towards a better understanding of the characteristics of various tree crop systems, in this paper an analytical model is presented of the various phases of tree exploitation. The model illustrates how as a result of the co-domestication of forests and trees various types of forest and/or tree cultivation systems may be distinguished. Up till now most scientific attention has been given to understanding the characteristics of tree exploitation in either the early or end phases of domestication. The attention to the early phases is reflected by the efforts in forestry to develop "naturgemässe" forest production systems. While the attention to the end phases is reflected in the efforts in both forestry and horticulture to develop highly productive cultivation systems of specific tree-based commodities (timber, fruits, or

cash crops). So far limited scientific attention has been paid to the various intermediate phases. Nonetheless, the viability of these phases is demonstrated by a variety of indigenously-developed forest management and agroforestry systems. The model may assist in helping to provide a systematic and comparative answer to the following major questions:

- What are specific management characteristics of the different stages of tree exploitation and what is their relation to sustainable land-use and biodiversity conservation?
- What are the driving forces behind a change from one stage to another?
- What is the potential of the various stages for further optimization of both productive and ecological characteristics and for contributing towards sustainable land-use patterns?

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