MIXED PLANTATIONS IN CÔTE-D'IVOIRE RAIN FORESTS

The association in the same parcel of different species of planted trees is an old silvicultural technique. Early improvement programmes involving more racks and sub-forest plantations have helped to try out several mixed associations in Côte-d'Ivoire since the turn of the century. The species of trees used were timber species such as niangon (*Heritiera utilis*), bassam mahogany (*Khaya ivorensis*), framiré (*Terminalia ivorensis*), okoumé (*Aucoumea klaineana*), sipo (*Entandrophragma*), dibétou (*Lovoa trichilioides*), azobé (*Lophira alata*), bossé (*Guarea cedrata*), tiama (*Entandrophragma angolense*), etc.

Subsequently, with the development of totally open plantations from the 1960s on, numerous other tree species have been used for mixed planting : sapelli (*Entandrophragma cylindricum*), fraké (*Terminalia superba*), samba (*Triplochiton scleroxylon*), makoré (*Thieghemella heckelii*), doussié (*Afzelia spp.*), badi (*Nauclea diderrichii*), bahia (*Mitragyna ciliata*), ilomba (*Pycnanthus angolensis*), cedrela (*Cedrela odorata*), teak (*Tectona grandis*), gmelina (*Gmelina arborea*), Australian acacias (*Acacia mangium, Acacia auriculiformis*), cassia (*Cassia siamea*), and eucalyptus... In most instances, these associations involve either timber species, or timber and fuelwood species. Some 14,000 hectares associating more than 20 species have thus been planted since 1930.

WHY PLANT MIXED TREES TODAY ?

The problems arising in monospecific plantations are numerous (upkeep, pruning, structure of the different types of wood, proper use of thinned wood, parasite attacks...). In an attempt to deal with these problems, forest plantations associating several species of mixed trees are used. This shows, on the one hand, a desire to keep a certain diversity in the forest stand, and, on the other, a desire to limit the risks of problems inherent to monospecific plantations. Associations of mixed trees help in effect to increase the variability of the make-up, structure and architecture of stands planted. Nowadays, by associating several tree species in a plantation, the forester may have different aims :

- To restrict the impact of tree-protection problems linked with plantation monospecificity.
- To improve the way soils are protected from erosion, and restore soil fertility.
- To monitor the development of unwanted adventitious growth and reduce fire hazards.
- To improve the shape of future trees by creating an under-storey with a helpful role.
- To encourage the use of thinned wood as timber or firewood by the association of species with differing uses.
- To save on quality plant matter by the use of a second accompanying species as filler...

For the proper and sustainable management of mixed stands, they must be allocated a principal objective, before planting. This objective will dictate the type of silvicultural system to be applied to the stand. Whatever the objectives may be, the success of a mixed plantation will depend on certain elementary silvicultural rules.

SPECIAL FACTORS TO TAKE INTO ACCOUNT

Mixed planting presupposes a respect for the restrictions and special factors implicit in the mixtures in question. Needless to say, the choice of species to be associated is based first and foremost on a respect for their ecological requirements. For each and every species, compatibility between choice of species and planting site (climate, topography, soil, water supply) must be respected if optimum stand growth is to be obtained (DUPUY & MILLE, 1991 ; WORMALD, 1992 ; EWANS, 1992). For the introduction of a species for afforestation purposes, it is first important to take into account the general climatic conditions and the requirements peculiar to each species.

From a silvicultural standpoint, different associations must also be made based on land-use criteria. The forester operates on two levels to manage the mixture (DAUGET, DUPUY & N'GUESSAN, 1990) : the topographical distribution of the plants and the vertical structure of the stands.

For practical reasons to do with actual planting, mixed plantations are usually organized in lines or rows. The number of lines of each species varies, and helps to define different mixed levels based on the objectives set for the stand. Mixed plantation levels considered are between 50 % and 25 %.

Based on growth differentials between species associated, two major types of mixed stand vertical structure emerge : a single-layer structure and a two-layer structure.

□ **In single-layer stands,** the growth of two associated species is identical. At the end of rotation, the forester tries to obtain a mixture by patch or tree-by-tree of the two species which have simultaneously attained their loggable diameter. By associating two species with similar growth rates, it is easy to get rid of the species with the lesser growth rate during thinning.

□ **In two-layer stands,** the faster-growing species, called the principal species, is to be given preferential treatment during thinning. In due course, this species forms the dominant layer. The slower-growing species, called the secondary species, forms an under-storey, either temporary or permanent.

In a given ecological zone, one of the two main factors limiting the success of mixed cropping is the behaviour of each species in relation to light. In the life of a mixed plantation, a given species may have to be temporarily dominated by the other. Certain species will put up with a certain cover, such as *Heritiera utilis, Khaya ivorensis, K. anthoteca, Entandrophragma utile, E. angolense, Guarea cedrata, Tectona grandis, Cassia siamea, Leucaena leucocephala*... This will be taken into account in the silvicultural management of mixed crops.

TYPOLOGICAL TESTING

Mixed crops can be defined by their architecture (single-layer, two-layer), their purpose (production, protection), and their type of wood product (timber, industrial wood, fuelwood...)...

Three main major types of mixed plantations can currently be singled out :

□ **Mixed crops for timber production :** these are usually single-layer mixtures of either medium rotation (20-40 years) or long rotation (50 years or more) species. They associate species such as *Terminalia ivorensis* and *T. superba, Terminalia superba* and *Triplochiton scleroxylon, Khaya ivorensis* and *Heritiera utilis, Khaya ivorensis* and *Aucoumea klaineana, Heritiera utilis* and

Purpose, association-type and plantation density of principal mixed crops

Type of mixture	Simgle-layer	Two-layer	Two-layer
Silvicultural purpose			
Production			
* timber	**principal**	**principal**	**principal**
* usable wood	secondary	**principal**	secondary
* protection	secondary	secondary	**principal**
Type of mixture	*Khaya ivorensis* + *Heritiera utilis* *Terminalia ivorensis* + *T. superba*	*Tectona grandis* + *Cassia siamea* *Terminalia ivorensis* + *Acacia mangium*	*Khaya spp.* + *Leucaena leucocephala* *Tectona grandis* + *Acacia auriculiformis*
Planting density	700-1 100 stems/ha	1 100-1 500 stems/ha	400-1 500 stems/ha
Rate of mixture	50 % -50 %	25 % -75 %	50 %-50 %

Aucoumea klaineana, Triplochiton scleroxylon and *Gmelina arborea*... The two associated species have fairly similar rotation periods and silvicultural systems (planting density, thinning calendar).

□ **Mixed production crops (timber, usable wood and fuelwood) :** these are usually two-layer mixed crops. The principal species, which is dominant, is a medium rotation (20-40 years) species. Its purpose is to produce timber. The secondary, dominated species is for producing usable wood or fuelwood. It is usually a short or medium rotation (5-10 years) species. This type of mixture renders it simpler to make better use of the first thinnings carried out on a priority basis in the lower layers. By way of example, we can mention the following species associations : *Tectona grandis* and *Acacia mangium, Gmelina arborea* and *Acacia auriculiformis, Cedrela odorata* and *Acacia mangium*... A coppice system for the species forming the lower layer (*Cassia siamea, Acacia spp.*) makes it possible to encourage and stabilize a two-layer structure for the stand.

□ **Mixed crops combining productive and protective functions :** in these mixed crops, a timber-producing, medium or long rotation (more than 20 years) species is associated with a species whose function is that of a crop. We may mention, as examples, the following associations : *Khaya spp.* (bassam mahogany, white mahogany, bigleaf mahogany, caïlcedrat) and *Leucaena leucocephala, Entandrophragma spp.* (sipo, kosipo, tiama, sapelli...) and *Leucaena leucocephala. Tectona grandis and Acacia auriculiformis, Gmelina arborea and Acacia auriculiformis*...

In this instance, the main task of the accompanying species (*Leucaena leucocephala, Acacia auriculiformis*...) is to protect or improve soils, either by combating invasion by grasses and the development of unwanted species (*Musanga, Chromolaena, Trema, Solanum, Imperata*..), or by reducing fire risks, or by trying to limit the impact of parasitic attacks. So, essentially, this species is a cropping species. It is regularly felled when young (cutting back or coppicing, topping) so as not to compete with the timber-producing species, whose purpose is productive. The production aspect is secondary for the accompanying species, which is on a short rotation system (5 years or less). Leguminous species are often used, which have the advantage of combining good physical soil protection with a capacity to improve it in mineral elements, in particular nitrogen.

THE OUTLOOK FOR MIXED PLANTATIONS

Once those involved are familiar with the elementary rules of silviculture and the purpose earmarked for the stand chosen, it is possible to produce, to good effect, many mixed plantations in various settings. In many instances, the rehabilitation of the condition of the forest is in effect an unavoidable restriction in tropical Africa, as a result of over-logging combined with improper land clearance. In zones of tropical and rain forest, intensive reforestation operations must first and foremost deal with abandoned fallow land, that has been more or less degraded by itinerant farming and bush fires. Without considering their bio-climatic impact, reforestation plays many roles : rehabilitation and soil protection, wood production, fire protection, ex-situ safeguarding of plant matter, wildlife protection...

The association of ligneous cover species helps to ensure soil protection against atmospheric agents. By creating a sufficiently closed forest cover, these associations can limit the development of unwanted adventitious species which may encourage the spread of bush fires within plantations. The associated species may have a positive impact that is direct (leguminous species) or indirect (storage in humus) on the mineral reserves in the soil, as well as on their water balance (improvement of the physical structure). It is worth noting that the use of herbaceous cover plants such as *Pueraria phaseolides* may also offer an interesting alternative.

In the case of risks of parasite attacks on a given species, the creation of mixed stands can be envisaged, which develop along with thinnings favouring the least attacked species. This type of mixture, either tree-by-tree or in clumps, does not reduce the risk of attack, but experience shows that it limits the risks of failure, by distributing them among two or more species. This type of reasoning can be applied to other risks involving the destruction of plantations, such as bush fires. Fire resistance does in fact vary a lot from species to species.

The study of mixed species associations is invariably a comparative study of the behaviour of two species. It is a necessary complement to studies on monospecific plantations. The degree of compatibility with mixed species is a good pointer to their silvicultural flexibility and their sociability. The species in young secondary forests, called fire scar species (AUBRÉVILLE, 1947 ; GUILLAUMET & ADJANOHOUN, 1971 ; ALEXANDRE, 1979 ; TROCHAIN, BLASCO & PUIG, 1980 ; KAHN, 1982 ; FAVRICHON, 1991) such as : *Terminalia spp., Triplochiton scleroxylon, Aucoumea klaineana, Nauclea diderrichii, Funtumia spp.*, etc. show a behaviour typical of socially dominant species. When

young, these species need thinning and sufficient space. Failing this they do not manage to establish themselves, and they disappear fast. Species of old secondary or climactic forests (*Heritiera utilis, Khaya spp., Mansonia altissima, Entandrophragma spp., Chlorophora excelsa...*) have a more sociable behaviour, and may tolerate slightly stiffer competition. These species may be developed in shade when young and thus remain in the expectant phase until the arrival of light enables them to resume sustained growth.

From this viewpoint, studies of mixed plantations also become a useful complement to research projects dealing with the auto-ecology of species in natural forest area in which there is still much work to be done. In many respects, the silvicultural systems for mixed plantations appear to form a link between systems for monospecific plantations and natural forest systems. Last of all, we should point out that mixed plantations and productivity are not two incompatible concepts, provided that the species to be associated in the mixed plantation are very carefully selected. □

For bibliography, see the French version.

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