An example of agro-forestry for tropical mountain areas

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Abstract

This paper gives a short survey of the Projet Agro-Pastoral in Rwanda, which in 1976 incorporated an extension programme to integrate trees in local smallholders' agriculture. The tree-integration programme of the project is regarded as an essential part of a low-input strategy for the re-establishment of self-sustaining agriculture in this severely degraded and over-populated area.

Introduction

The economy of Rwanda depends on agriculture; 95 per cent of the population earns its living from agriculture. No important industries exist, and mineral resources are limited to lime. Methane gas is present in substantial amounts in the Kivu Lake, but it has not yet been exploited. The average annual income per person is US$180. About 90 per cent of the exports are agricultural products; of US$92 million in exports in 1977, $66 million was from coffee, $9 million from tea, and $7 million from minerals, with the remaining $13 million from miscellaneous other products.

Rwanda is composed of scattered settlements of individuals whose average land holdings are about 1 ha. Hardly any land reserves are available in the country. The desperate economic and social situation finds its expression in the fact that Rwanda is among the poorest of the developing countries.

Rwandese development efforts must focus on agriculture; the lack of mineral resources and of competitive industries limits other possible paths to development. A further obstacle with strong impact on the national economy is the restricted access to international markets. Agriculture has not only to meet the growing food demands but also to serve as a driving force for the development of other sectors of the economy.

The key to progress must be through improved practices by smallholders. The basic aim is to meet the food demands on the farms and to produce a surplus to be marketed. With assistance, the agricultural sector can have a considerable impact on the development opportunities.

The prerequisite for integrated rural development is an improved farming system that will be able to capitalize on the under-exploited potential of the area. At present, land use is characterized by low productivity and rapid destruction of the natural resources. The predominant cause of degradation is soil erosion on cultivated fields and grazing land. Because of over-grazing and the lack of effective erosion control, this process has reached crisis proportions

In the last centuries Rwandese agriculture has switched from shifting cultivation to permanent land-use practices. With the growth in population the average farm size is continuously shrinking, as are the periods when the land is left fallow. Contributing to the crisis is the deforestation of the hilly countryside. The people are suffering from a lack of firewood, and the destruction of the forests is causing negative impacts on the hydrological cycle and the local climate.

Still, there are some positive aspects to be found in the traditional farming systems. The farmers generally practice multiple cropping, especially cultivation under bananas. Mulch is used on nearly every farm in the well-maintained coffee plantations Of special interest are the traditional farming methods of raised-field agriculture, which allow the use of the widespread swamps. Unfortunately, against the background of rapid ecological destruction all over Rwanda, the positive aspects of traditional agriculture are of minor significance.

The Projet Agro-Pastoral, Nyabisindu, started in 1969 with the re-organization of the collapsed Dairy of Rwanda and its milk-collecting scheme. An extension unit-the aim of which was to improve the smallholders' fodder cropping -and a veterinary service were attached to the project. From the beginning, the project constantly widened its aims and in 1981 it covered all aspects of the local farming systems and rural development, including agriculture, animal husbandry, forestry, agro-industries, rural infrastructure, and farmingsystems research.

Since 1976, the goal of the project activities has been the development of a new farming system for smallholdings, which are continuously threatened by ecological crisis in the region on account of erosion, soil degradation, deforestation, etc. The ultimate goal is to overcome the economic obstacles facing both the smallholders and the national economy. The integration of agriculture, animal husbandry, and forestry makes feasible a selfsustaining and productive farming system. Recycling and a balance of inputs and outputs are the main features of such a system, thus minimizing costly inputs such as chemical fertilizers while maintaining soil fertility.

The project region, Iying in central Rwanda, consists of seven intensively managed communes with about 43,000 holdings and a population density of 200-450 people/km². In these communes, the project oversees all activities in agriculture, animal production, and forestry. Furthermore, 14 communes have been provided with tree nurseries, multiplication centres, and demonstration plots.

The altitude of the project region varies from 1,500 m in the east to 2,000 m in the west. The climax vegetation is a transition from tree savanna to montane forests. The average annual rainfall ranges from 900 mm in the east to 1,200 mm in the west.

The high productivity of the natural ecosystem in the humid lowland tropics often misleads people into believing that the soils are fertile. High temperatures and precipitation have deeply weathered the soils and left little mineral reserves. The weathering process has resulted in a high proportion of two-layered clay minerals (kaolinite is predominant) with a cation exchange capacity (CEC) of only 3-15 meq/100 9 of soil. Under these conditions, mineral fertilizers soluble in water, which are the basis of modern agriculture, are leached from the soil and quickly become unavailable to the crops. In addition, monocropping encourages decomposition of humus, degradation of soil structure, and the spread of diseases and pests. In contrast, intercropping and relay cropping of complementary crops can help control pests and maintain soil fertility.

In humid, mountainous areas, the soils often have better mineral reserves than in the lowlands; however, the soils are usually shallow and particularly susceptible to erosion. Under these conditions, the returns from modern agricultural techniques do not cover the costly inputs.

The initial search for farming systems that would be acceptable to smallholder farmers and make optimal use of the land was characterized by efforts to modernize agriculture in the project region. These efforts consisted of introducing high-yield varieties in combination with mineral fertilizers and pesticides. These first attempts were totally unsucessful, with one reason being that the project was often cut off from transport for several months and supplies could not be guaranteed. Also the costs of such imported means of production were prohibitive. Even the establishment of a credit system and the formation of co-operatives failed, as the smallholders were unable to refund the credits. Most of the yields were needed to cover their families' nutritional needs. Besides the high costs in foreign currency and the dependence on foreign inputs, this approach to agriculture did not take into account the special conditions of tropical ecosystems.

In the second phase of the search, the study of the indigenous farming systems in East Africa was of great help. The works of Ruthenberg and, especially, of K. Egger, who became consultant for the project in 1976, were the basis for the integrated concept now used in Nyabisindu.

The East African highlands are the home of many traditional farming systems producing considerable outputs with local resources on a long-term basis. One example of these forgotten African farmers who developed their farming systems without foreign help is the Wakaras, on the island of Ukara in Lake Victoria. Within a few generations the Wakaras were able to set up a self-sustaining agriculture on the granitederived, poor soils of Ukara. Their farming system sustained a modest Iiving for 500 inhabitants on a single square kilometre.

The main components of such permanent farming systems are:

- Integration of trees in agriculture (multistorey farming);
- Integration of animal husbandry (stall feeding, fodder cropping);
- Use of organic fertilizers like dung, compost, and green manures;
- Use of diverse crops and sophisticated cropping tech niques (relay cropping, mixed cropping, etc.); and
- Effective erosion control by contour planting, mulching, etc.

Observations of the traditional agriculture in Rwanda and the neighbouring regions of East Africa were the basis for the elaboration of a new farming system. In combination with the results of modern agricultural and ecological science, a development strategy that is consistent with the conditions in Nyabisindu was designed.

Low-lnput Strategy

The first step towards the development of new farming systems adapted to local conditions was the definition of realistic aims for the project. The aims were to:

- Cover subsistence needs;
- Enable a surplus to be sold at local markets (monetary income);
- Reclaim and maintain soil fertility; and
- Minimize costly external inputs.

The target group was the smallholder farmers, with special attention being given to those with submarginal holdings.

The second step was the practical evaluation of different agricultural methods and technologies which seemed to be suited to the locale. After five years of experimental work under field conditions, a survey was taken which allowed a first synthesis of a complete farming system.

To devise a complete farming system, it was necessary to determine which methods had components that met the project aims. The methods were examined according to economic factors (cost-benefit, access to means of production); ecological factors (soil conservation, external effects); and socio-economic factors (source of know-how, adaptability).

TABLE 1. Hierarchy of Methods

Methods	Techniques	Benefits
1. Vegetative Structure		
Multi-storey farming	Trees in erosion-control strips and hedges (for wood, fruit, and browse)	Integration of forest functions in agriculture (high and long-term stability)
Subdivision of plots by erosion-control strips, woodlots, permanent crops, and gardens		
	Mixtures of root, fruit, leguminous, and other crops	Bettermicro-climate, lower soil temperatures, unlocking of mineral reserves in deep soil layers, better trapping of nutrients, and water-retention capacity
	Erosion-control strips	
	Wood lots	

		Erosion control and mulching
		Habitat for pest predators
	Permanent crops (coffee, etc.)	Production of firewood, timber for construction fruits, forage, mulch, etc.
		Improved labour management and planning
2. Crop-Planning System		
High diversity of crops, products, and auxiliary plants	Multiple cropping with legumes, cereals, and tuber crops	Lessened risk with regard to pests, climate, and markets
Use of resistant and improved varieties	Relay cropping with seasonal and annual crops	Better biological control of weeds, pests, and diseases
Crop rotation with multiple and relay cropping and intensive fallows	Fallows (1-2 seasons) to regenerate soil fertility using Mucuna, Vicia, Crotalaria, Tephrosia, Cajanus, etc.	Higher degree of soil cover, preventing soil erosion, preserving humus and soil structures, and improving water-retention capacity and cation-exchange capacity
Selective weeding		Natural regeneration of soil fertility (fallow)
3. Organic Manuring		
Mulch, green manure	Mulch in gardens and permanent crops from weeds, hedges, tree leaves, fallows, and crop residues	Recycling plant nutrients
Compost		Lower leaching losses
Animal manure		Raising humus content
	Compost for use in coffee plantations, gardens, tree planting, and seasonal crops; sources: termite soil, ashes, plant matter including crop residues, etc.	Improving soil structure, water infiltration, and water-retention capacity
		Improving cation-exchange capacity
		Reducing pest and disease infections Manure of cows, sheep, goats, rabbits, etc.
4. Integration of Animal Husbandry		
Fodder crops	Production of fodder in fields, hedges, anti-erosion strips, and browse trees	Transformation of low-yielding pastures into fodder-cropping plots
Stables or pens		
Manure		Profitable use of manure (see 3 above)
		Better control by veterinary service
5. Mechanical System		
Labour saving tools	Introduction and improvement of tools and garden implements (distribution with subsidized prices)	Improved labour productivity
6. External Fertilizers		
Ground rock	Ground lava, chalk	Addition of nutrients not supplied by farm manure, compost, etc.
Rock phosphate	Phosphorus, potassium, trace elements	
Mineral fertilizers	Application in several doses	Faster recovery rates on plots that need to be reclaimed
		Minimized leaching losses
7. Plant Protection with Biocides		
	Selective application	Prevention of total crop losses
	Treatment of storage pests	Re-establishment of equilibrium
	Protection of seedlings in nurseries	

On the basis of the criteria, a hierarchy (table 1) was formed; it defined preferences in the choice of elements for the synthesis of the farming system, and it pointed to the most adaptable and cheapest combination of the different elements with respect to the specific conditions of every site. Although it did not definitively rank different methods, the hierarchy was a guideline for the extension service, and the criteria are suited to many marginal regions in Third World countries.

If farmers respect the rank of the methods, they may profitably apply costly inputs like mineral fertilizers. The elements of the farming system promote soil conservation and high humus content, and thereby create the preconditions for good fertilizer response. Thus there would not be a heavy dependence on outside inputs, and the system would not break down if the regular supply were cut off. To implement the programme, the project staff established a number of services (Appendix 1), one of which is concerned with integrating tree crops.

Integration of Trees

This paper focuses on practical experience with the integration of trees. The project is now starting a research programme that will give a solid scientific basis for its recommendations.

Interdisciplinary research in the field of agro-forestry has bean neglected in the last decades, probably partly because of the length of time required for research involving trees and partly because of the barriers between the disciplines of agriculture and forestry. Those who see the necessity for, and the promising possibilities of, agro-forestry will understand why the project in Nyabisindu did not wait for precise research results.

The tree programme of the project is based on the 170 tree nurseries that are spread throughout the project region. These decentralized tree nurseries are the key to effective extension work. In 1979, the annual capacity amounted to 5 million trees, including fruit trees (30 per cent) and coffee seedings (6 per cent). All tree seedlings are produced in plastic bags.

Afforestation, Fruit Trees, and Roadside Plantings

The overall tree programme incorporates afforestation of the denuded hilltops in areas that are not suited to agriculture or grazing; the aim is to improve the landscape and increase tree production. In 1979, 650 ha were afforested by communal work service (cost per hectare using seedlings produced in the nurseries was US$200).

The main genera used are Eucalyptus, Cupressus, and Pinus. The seriously degraded hilltops are suitable only for Eucalyptus, but, on the more fertile hillsides, a mixed stand of Grevillea robusta, Pinus patula, Cupressus sp., and Eucalyptus sp. has been planted. The Eucalyptus monoculture has turned out to be very exhausting for soils. Many of the older Eucalyptus forests are adversely affected by soil erosion because no shrubby or weedy species will grow in Eucalyptus stands.

Losses of about 40 per cent of the trees occurred, mainly because of poor planting practices by the community service. Although afforestation with paid labour is far more effective, it was rejected for psychological reasons. The self help efforts of communal services should be encouraged as long as there is no national forestry service to guarantee sustainable forests.

Another part of the overall tree integration programme is a project for the planting of fruit trees. Farmers in Rwanda have hardly ever planted fruit trees, even though the value of fruit in the human diet cannot be over-emphasized. The project made great efforts to spread fruit-tree growing in the region. About 30 per cent of the total nursery capacity has been reserved for fruit trees, with the most important being avocado, guava, papaya, and custard apple (Annona). Altogether about 5 million fruit trees have been given to the farmers in the project area as compensation for their communal work; 80 per cent of all farmers so far have planted fruit trees. This project has, therefore, touched more farmers than any other activity.

Tree integration is also aided by a government programme to plant trees along the roadsides, the trees being provided by the project nurseries. Rwanda is densely populated, and has a complex road system. The fact that the trees are always planted on farmland alongside the roads has helped accustom the farmers to tree integration in agriculture. Sideeffects are the creation of shade for the pedestrians, many of whom carry large containers on their heads. Also, the wood from these trees is to be made available to consumers in the near future. The main species used along roadsides are Grevillea robusta, Cedrela serrate, and P. patula, as they do not interfere with crops under them. In school areas, fruit trees are planted, with the fruit to be picked by the children on their way to school. Trees have already been planted alongside about 450 km of road.

In many parts of the project region the holdings include severely degraded plots which are not suitable for cultivation or grazing. To prevent further damage, and because of the limited capacity of individual communes to plant large areas, the project provides for the afforestation of these areas. Besides wood production, the trees help rehabilitate the soil and create some grazing for cattle. The main species used are G. robusta, P. patula, Cupressus spp., and Eucalyptus spp.. It is planned to integrate browse trees also. Up to now, however, farmers have been oriented to the fast-growing Eucalyptus species.

Trees in Fields

The main point of the tree integration efforts in Nyabisindu was to establish trees in the fields that protect cropping areas. Although agricultural scientists argue that shade trees reduce yields of undergrowing crops through competition for light, water, and nutrients, there are many arguments in favour of tree integration. Trees provide:

- Protection from raindrop or splash erosion;
- Fortification of anti-erosive cropping strips;
- Light shading of the soil and thus reduced soil temperatures, evaporation, and humus decomposition rates;
- Unlocking of mineral reserves in soil layers not accessible to the shallow root systems of crops;
- Formation of nutrient traps, as the tree root systems stop the loss of nutrients through leaching; and
- Production of firewood, construction material, and mulch.

Thus, tree cover plays a paramount role in soil conservation, maintenance of soil fertility, and production of urgently needed wood.

Ecological sciences emphasize all aspects of productivity rather than focusing solely on yields. Climate, soil properties, vegetation structure, and biological diversity are variables in productivity. Intelligent management of them increases productivity in terms of both biomass and useful products. A complex vegetation structure with high diversity, rapid accumulation of biomass, and strong inner recycling of nutrients contributes to the productivity of natural ecosystems. Increased biomass production (perhaps through higher turnover rates) can partially be converted into agricultural production by a wide range of cultivation methods and technological inputs. Before the nutrients leave the cropping area in the form of agricultural products, they may have been recycled in the agro-ecosystem, building the tree canopy (soil protection), serving the purposes of fallow (regeneration of fertility), etc. Agricultural production appears only as a by-product of the functioning of the whole system.

If the processes in natural ecosystems can be imitated by cultural systems, productivity may not only be raised but also stabilized in the long term. Although lower yields may be obtained from the crop understorey, these losses are compensated by the benefits created by the overstorey wood for timber and fuel, fruits, soil protection, nutrient enhancement (tree legumes, unlocking of reserves), etc. (Appendix II).

When shade trees are used in the field, the main concern of agronomists is the competition with other crops for light. This problem can be minimized if some general rules are followed, as has been shown by the practical work at Nyabisindu. Only trees that allow intercropping are used in the field. Eucalyptus spp., Cupressus spp., black wattle (Acacia mollissima), and Croton spp., which hinder intercropping because they emit substances toxic to plants or have too dense a canopy, are not used. G. robusta, Sesbania sesban, Cedrela serrate, and Leucaena leucocephala have been used with great success in Nyabisindu. Observations of the traditional agriculture of Rwanda and other countries in East Africa indicate that Albizia spp., Acrocarpus fraxinifolius, and Millettia laurentii are also promising trees. Generally one should look for species that produce little shade and high rates of litter production.

In hedges, the choice of species is greater than for open fields. The following species have been shown suitable: Psidium guajava L., Morus alba, Cassia spectabilis, Entada abyssinica, Croton macrostachys, Marcamia lutea, Erythrina abyssinica, etc.

In Nyabisindu, trees for anti-erosive purposes are generally planted 3.5-4.5 m apart. On the basis of a 10-m distance between strips and taking into account the outside hedges, the number of trees is between 250 and 350 per hectare, that is, about 10 per cent of the density of normal afforestation. Grevillea is planned to be cut on an eight-year rotation, allowing the yield of 30-43 trees per year.

If the trees create too much shade, they should be cut or the branches pruned regularly. Trees tolerate the loss of up to 60 per cent of their branches without suffering reduced growth. The branches can be used for firewood or mulch. In Nyabisindu, early figures for production from G. robusta in the field and in the forest have been encouraging (table 2). These indicate that trees interplanted in cultivated plots produced 3.4 times the stemwood of trees grown in plantations. Wood production of branches was 4.4 times that of trees in the neighbouring plantation. The weight of leaves produced (litterfall) was about three times that of the forest trees (18 kg versus 6.3 kg per tree).

TABLE 2. Wood Production in Integrated Tree Plantations. The production of stemwood, branches, and leaves of Grevillea robusta planted in November 1976 was measured in March 1981. Results were compared to trees of the same age planted in "classical" reafforestation under similar soil conditions.

	Age (years)	Height (m)	Stemwood (m^3)	Volume of branches (m^3)	Leaves (kg)
A	4.25	8.32	0.048	0.025	18.5
B	4.25	6.60	0.014	0.005	6.3

A - trees in cultivated plots
B - trees in classical afforestation

By planting about 350 trees per ha in an eight-year rotation in an agro-forestry system, the average farmer could harvest 43 trees per year. His annual wood harvest would be roughly 7 m^3, whereas the annual wood production of a comparable "classical" afforestation at 350 stems/ha would be only 1.5 m^3. In other words, the need for fuelwood, given in Rwanda as 1 m^3 per person per year, and presuming an average family of five to six persons, could be met at 148 per cent or 123 per cent, respectively. The differences in heating value between Eucalyptus and Grevillea, however, have not been taken into account.

A special question is the arrangement of the crop understorey. In Nyabisindu, mixed cropping is practiced, with the crop distribution patterns depending upon their shade tolerance. Light-consuming crops like maize and sorghum are placed away from the trees while crops like beans, cocoyam, and sweet potatoes are planted in the shade of the trees.

Research

Still the question of what is the best mix of the crops is far from answered. An important task for researchers is to test the different crops and varieties for their tolerance of shade and also to search for tree species that are suitable for integration. The ease with which trees are multiplied differs from species to species, and this should be a consideration in the identification of suitable species. Where farmers reject tree planting in the fields, the integration of bananas or plantains is recommended for the initial phase in order to accustom them to multistorey cropping. Also fruit trees, like papaya and Prunus salicina, which produce little shade but profitable returns, are appropriate.

Appendix 1. Services Provided by the Project

Plant Production

- Installation and maintenance of 170 tree nurseries in 23 communes with a total capacity of 5 million trees per year. About 30 per cent of the total capacity is dedicated to the production of fruit trees;
- Multiplication of fodder plants, anti-erosive plants, cash crops, vegetables, fruits, and spices (Tripsacum, Pennisetum, Setaria, Mucuna, Desmodium, Vicia, bananas, Capsicum annurum, etc.) in 116 multiplication centres on 96 ha of communal land; and
- Establishment of demonstration farms in each commune, also used for multiplication purposes.

Animal Production

- Mobile veterinary service held periodically at 19 centres (9,500 treatments annually);
- Stationary veterinary service with dispensaries (9,000 treatments annually);
- Provision of emergency veterinary service on weekends (800 emergencies annually);
- Introduction of tick control with seven to ten dips- altogether 510,000 treatments annually;
- Testing of immunization against east coast fever;
- Reinstallation and running of a 33 ha state cattle farm;
- Improvement of breeding in farmers' areas with 12 bull centres with selected local and crossbred bulls; and
- Construction of improved slaughter houses (two completed, one under construction).

Processing and Marketing

- Revival of Dairy Nyabisindu, with milk collection in 1969 of 156,700 litres and in 1977 of 1,076,100 litres;
- Construction of milk sales centre in Kigali and Butare and a new factory and offices for the main dairy;
- Construction of a soybean processing plant in 1979 with a daily capacity of 500 kg beans (55 litres oil, 350 kg flour);
- Introduction of sugar cane (including processing). The first pilot plant was constructed in 1976, with three further plants built since 1980. The sugar-cane plantation amounts to more than 20 ha; and
- Development of 16 communal and co-operative warehouses to date.

Other Services

Two forms of extension are under way-individual and group. In the individual extension work, more than 4,000 farmers have been approached, and 700 farmers have adopted important elements of the extension programme.

The group extension work is based on the communal labour service. Every person over 16 enters this service, thereby participating in the nurseries, multiplication centres, and demonstration farms of the project. Thus, the population is directly involved in the project. Regular meetings are held, with the participation of all farmers to discuss the project activities.

In connection with the re-organization of the milk-collecttion scheme, about 70 bridges and 20 km of new roads were built.

In 1980, the project established a small research unit to carry out a partial analysis of the farming systems and to generate further development. Three scientists (a forester, an agriculturist, and an economist) are employed. A small laboratory is under construction.

Appendix 11. Recommended Tree Species in the Project Region

Species	Forest	Roadsides	Hedge	Field integration	Fruit	Mulch	Browse
Eucalyptus gummifera		-	-	-	-	-	-
E. resinifera		-	-	-	-	-	-
E. saligna		-	-	-	-	-	-
E. camaldulensis		-	-	-	-	-	-
E. cloeziana		-	-	-	-	-	-
E. grandis		-	-	-	-	-	-
E. microcorys		-	-	-	-	-	-
E. maidenii		-	-	-	-	-	-
E. robusta		-	-	-	-	-	-
Cupressus lusitanica			-	-	-	-	-
C. benthamli			-	-	-	-	-
C. torulosa			-	-	-	-	-
Grevillea robusta					-		-
G. banksii					-		-
Pinus patula					-		-
P. caribaea				-	-		-
P. radiate				-	-		-
Cassia spectabilis				-	-		
C. siamea					-		
C. fistula					-		-
Maesopsis eminii					-		-
Albizia gummifera				-	-		-
Acrocarpus fraxinifolius					-		-
Cedrela serrate					-		-
Croton megalocarpus					-		-
C. marcrostachys				-	-		-
Casuarina equisetifolia				-	-		-
Entada abyssinica					-		-
Millettia laurentli					-		-
M. aura					-		
Acacia sp.				-	-		
Podocarpus milanjianus				-	-		-
P. usambarensis				-	-		-
Jacaranda sp.	-			-	-		-

Erythrina abyssinica					-		-
Leucaena leucocephala					-		
Sesbania sesban		-			-		-
Macadamia ternifolia	-						-
Morus alba	-	-					
M. nigra	-	-	-				
Carica papaya	-			-			-
Passiflora edulis	-	-					-
Psidium guajava	-						-
Annona cherimola	-	-					-
A. reticulate	-			-			-
Persea americana	-			-			-
Cyphomandra betacea	-	-	-				-

Dash indicates tree was not used for that purpose.

Intercropping tree and field crops

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Abstract

This paper describes an experiment started in 1978 in the humid forest belt of Ghana that attempted to demonstrate to farmers how they can establish plantations of economic tree species and, at the same time, produce food crops by means of judicious intercropping. A population density of 625 plants/ha of a fast-growing tree species, Gmelina arborea, was established at four different spatial arrangements. The stands were interplanted with an important West African food crop, plantain (Muse cultivar), at various spacings (densities ranging from 536 to 1,588 plants/ha). The minimum plant-toplant distance was 2.0 m, and the maximum was 2.8 m. Both species are being assessed periodically by standard forestry and agricultural methods. The implications of the results so far are discussed along with the objectives of the experiment and projected future experiments.

Introduction

One of the problems facing manufacturing industries that have been set up in developing countries has been the difficulty of obtaining raw materials and, quite often, the inadequacy of these raw materials. If the pulp and paper industry in Ghana is not to be bedeviled by this sort of problem, then attempts must be made to ensure sustained supplies, in requisite quantities, of tree species suitable for the industry, and local farmers must be encouraged to supplement the production from factory-owned plantations. In this regard, estimates of farmers' production must be reliable, based on an accurate enumeration by region or district of not only the farmers engaged in forest tree cropping but also the stands their farms carry.

Gmelina arborea is a medium to large fast-growing deciduous tree, capable of growing successfully in mixed forests of moist regions, such as the humid forest belt of Ghana. Usually grown in plantations at spacings of 2.0 x 2.0 m (Streets 1962), it is one of the species recommended for a proposed pulp and paper industry in Ghana.

The establishment by farmers of forest tree crops, although known in Ghana, has not been very popular, mainly because of the long time it takes for the farmers to realize any income from the operations. However, if this desirable practice were somehow combined properly with food cropping, it would probably gain popularity as a prospect for almost immediate and sustained income or savings on food costs.

On account of its ease of establishment, mode of growth, and time of maturity, as well as the demand for it as a staple item in local diets (Purseglove 1972), plantain (Muse cultivar) was selected as the food intercrop for the initial experiments with G. arborea.

The two species can be planted at a minimum distance of 2.0 m (1: 1 rectangularity). When interplanted, the rapid growth and development of effective canopies and roots, yield of leaf litter, and the number of suckers that plantain develops as it grows were all considered to be favourable for the maintenance of soil fertility (even if not its build-up), and for early protection against soil erosion, particularly that caused by splash and runoff.

It was the objective of the experiment described in this paper to establish 625 trees/ha of G. arborea. Plantain was interplanted at various spacings so that the minimum distance between and within rows (Gmelina-Gmelina; Gmelina-plantain; plantain-plantain) was 2.0 m, and the maximum distance was 2.8 m, distances at which either species can be planted in a 1:1 arrangement. In the first two years, maize (Zea mays) and cocoyam (Xanthosoma sagittifolium) were planted in the spaces between the young plants of Gmelina and plantain. Although they were not included in the study, they could provide additional sources of income and food for the farmers.

This experiment therefore served as both a quantitative scientific study, and a demonstration to farmers of the advantages of intercropping trees with food crops, both of which would have ready markets.

Materials and Methods

The South Fomangsu Forest Reserve was chosen for the study, and the research site, which is about 80 kilometres from Kumasi on the Kumasi-Nkawkaw road, is at the western end of the reserve. The land was cleared and burned during the 1977-1978 dry season, and it was ready for planting by April 1978. Meanwhile, seedlings of G. arborea had been raised for the experiment by early 1978, and bigfruited (Apantu) plantain suckers had been purchased from February to April.

A Gmelina tree population of 625/ha was maintained, and the spacings used in the four different treatments were 4.0 x 4.0m (1:1); 5.7 x 2.8m (2:1); 6.9 x 2.3m (3:1); and 8.0 x2.0 m (4:1).

Where the between-row or within-row distance from one Gmelina plant to the next was 4.0 m or more, a plantain sucker was planted so that the distance from any one plant (Gmelina or plantain) to the next measured at least 2.0 m but not more than 2.8 m. Thus, for every four Gmelina plants in the 4.0 x 4.0 m spacings, there were five plantain plants; for every four Gmelina plants at 5.7 x 2.8 m spacings, there were only two plantain plants; for every four Gmelina plants at 6.9 x 2.3 m spacings, there were also four plantain plants; and for every four Gmelina plants at 8.0 x 2.0 m, there were six plantain plants. Planting started in May 1978 and continued for about one month.

The layout for each treatment was as follows: (1) each plot measured 32.0 x 28.0 m, with nine rows of Gmelina plants along the 32.0 m axis and eight Gmelina plants within each row, interplanted with plantain so that there were nine rows of Gmelina/plantain alternating with eight rows of plantain, each only 2.0 m from the next; plantain plants numbered 183; (2) each plot was adjusted to 34.2 x 28.0 m, with seven rows of Gmelina plants along the longer axis, each with 11 plants, alternating with six rows of plantain, 2.8 m apart with 11 plants apiece (total 66 plantain plants); (3) each plot was adjusted slightly to measure 34.5 x 27.6 m, with six rows of Gmelina plants along the longer axis, each with 13 plants; in between every set of two adjacent rows of Gmelina were two rows of plantain plants, 2.3 m apart (i.e., ten rows of plantain plants, each with 13 plants); and (4) each plot measured exactly 32.0 x 28.0 m, with five rows of Gmelina along the longer axis, each with a population of 15 plants; between the two adjacent rows of Gmelina were three rows of plantain plants, a total of twelve such rows, 2.0 m apart, each with 15 plants.

Thus, for a Gmelina population of 75±3 trees per plot, the plantain population varied from a low of 66 in the second spacing to a high of 183 plants in the first spacing. The four treatments were replicated six times in a randomized complete block design, with 24 plots in all. Any plants that died in the first few months were replaced; weeding and removal of fallen branches were carried out regularly.

Data collected for assessment of the Gmelina at the end of the first year (1979) and in 1980 were from 25 plants chosen from the middle of each plot in order to avoid border effects. The data collected were:

- Height from the soil surface to the terminal bud;
- Girth at breast height;
- Height to the main fork where applicable;
- Approximate length of the first major branch as an index of the size of the branch, with qualification as to where it was small, medium, or large;
- Size of the crown (depth and diameter);
- Crown exposure scoring from l to 5, with 1 being for the lower understorey, in which the plant is completely suppressed, with no direct light from above or from the sides; 2 for upper understorey, in which the plant is exposed to some direct light from the sides but not from above; 3 for lower canopy, in which the plant receives direct light from above but light from the sides is impeded; 4 for upper canopy, in which the plant receives much light from above and direct side light is only slightIy impeded; and 5 for emergent, with the crown completely exposed to light from all angles; and
- Canopy-forming agents (whether shading of plants is caused by Gmelina, plantain, or weeds, a term used to describe any plant, e.g., oil palm, other than the two species being studied).

TABLE 1. Assessment of Gmelins arborea in the Mixed Cropping (Gmelia and Plantain) Experiment South Fomangsu Forest Reserve, Ghana

	Treatment 1 (4 x 4 m)				Treatment 2 (5.7 x 2.8 m)				Treatment 3 (6.9 x 2.3 m)				Treatment 4 (8 x 2 m)			
	Mean height to terminal bud (m)	Mean girth at breast height (cm)	Mean depth of crown (m)	Mean diameter (horizontal) of crown (m)	Mean height to terminal bud (m)	Mean girth at breast height (cm)	Mean depth of crown (m)	Mean diameter (horizontal) of crown (m)	Mean height to terminal bud (m)	Mean girth at breast height (cm)	Mean depth of crown (m) of crown (m)	Mean diameter (horizontal)	Mean heighan to terminal bud (m)	Mean girth at breast height (cm)	Mean depth of crow (m)	Mean diameter (horizontal) of crown (m)
Block I	10.00	44.1	4.80	5.16	7.04	39.2	3.12	4.46	10.12	42.4	3.77	5.0	7.64	30.8	4.07	5.45
Block II	9 09	44.7	4 09	5.22	8.70	45.0	4.23	5.36	8.99	36.5	5.47	6.36	9.37	39 4	4 47	5.16
Block III	754	41.5	3.50	5.29	9.85	40.8	6.11	6.92	6.35	34.8	3.22	4.88	9.70	41.3	3.93	5.0
Block IV	8.98	33.7	4.20	4.59	9.38	42.5	4.17	5.44	8.25	38.0	2.73	4.14	6.88	32.8	2.66	3.94
Block V	10.69	42.8	5.16	4.50	4.88	25.6	1.92	3.84	8.68	39 6	4.92	5.20	10.27	42.3	4.52	5.44
Block VI	5.74	29.6	3.03	3.97	7.92	38.6	5.08	5.08	10.76	42 1	5.14	4.79	10.14	39 3	4.90	4.15

Means	8.67	39.4	4.13	4.78	7.96	38.6	4.10	5 03	8.86	38.9	4.20	5.06	9.00	37.6	4.09	4.85

Assessment of the plantains (all the plants except those in the outer rows) involved height measurements; grouping of plants into small, medium, and large; enumeration of the number of functional leaves per plant; determination of the lengths and the widest breadths of the oldest functional and newest (but completely unrolled) leaves; enumeration of the number of suckers produced per plant; and yield and components,-i.e., mean number of hands per bunch, mean number of fingers per hand, and mean weight of individual fingers.

Results and Discussion

The first and second years' assessment data of G. arborea are available, but only those for the second year, taken at the end of 1980, are presented in table 1. Although the data have not been statistically analysed, to date there is little evidence that one treatment is markedly superior to another in the parameters evaluated. It is possible that two years of growth is too short a period for treatment differences to be shown. Streets (1962), in fact, suggests that a minimum of four years is required for the manifestation of differences as a result of interference between trees and crops. Even if no differences are detected in the near future, this work will have shown the ability of Gmelina trees to successfully withstand competition from other trees and plantain plants at the spacings used.

Because the trees are destined for the paper and pulp industry, an important consideration is the production of those parts useful as raw material under the conditions of the experiment. Also, the claim of plentiful natural regeneration is to be carefully examined from about the fifth or sixth year onwards.

In May 1979, when the Gmelina and plantain were assessed, only a few of the plantains in each plot had produced mature bunches. Four plants per plot were harvestable so their yields were determined.

An analysis of variance of the bunch yield did not show any significant treatment effects on yield. Yet, when the yields were resolved into their components-the mean number of hands per bunch, the mean number of fingers per hand, and the mean individual finger weight-it was found that the block effect on the mean individual finger weight was significant ($P = 0.05$). Thus, the consistently higher yields obtained in one block can only be due to this higher component. This point has been stressed because the mean weight per finger is an important component of yield in plantains and must be studied in future data analysis. Mean weight per finger is dependent on the number and size of functional leaves and their exposure to sunlight during the period of fruit filling (Osafo, unpublished).

At this early stage and on the basis of only four plantains per plot, not much can be expected with respect to treatment differences. However, within a year of the planting date, some food was obtained from the operation as well as sizeable quantities of maize and cocoyams, and this fact can be used by extensionists to canvass farmers. If, as indicated by the preliminary yield data for 1980, nearly all the plantain stands have produced mature bunches after a year, then farmers may be convinced to take up this sort of agro-forestry practice.

It is thought that, after four years or so, plantain suckers will be produced in abundance, the Gmelina trees will be producing seeds, and natural regeneration will be noticeable. Then it may be necessary to thin the plantain stands to promote both growth and yield. This possibility assumes that under the conditions of the experiment, the Gmelina trees will grow to heights of 15 m or more and form dense canopies that will interfere with light interception by the plantains. The competitive effects would need careful assessment on the basis of crown exposure scoring and enumeration of canopyforming agents.

To date, it has not been possible to follow up the soil aspects of this study because of financial difficulties and scarcity of competent technical staff. However, the plans to assess soil effects have not been abandoned.

The final choice of an agro-forestry system should be made by the farmer, and this will depend on what combination of trees and crops leads to the most enduring benefits in terms of food production, wood output, and maintenance of soil fertility. Answers with regard to combinations of Gmelina arborea with plaintain may not be forthcoming until the experiment has run, and been assessed yearly, for a minimum of eight years.

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