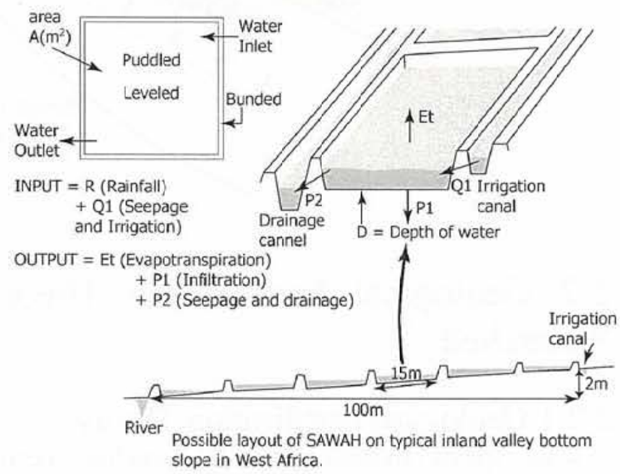
Chapter 2. Conceptual Frameworks and Methodology

2-1 The Sawah hypothesis

2-1-1 Sawah hypothesis

Why has the green revolution not yet occurred in West Africa and Ghana in spite of its success in Asia in the 1960s? The green revolution laid the foundation for the rapidly growing economies of Asia today. The layouts of groups of sawahs in the watershed were adapted to the local topography for efficient irrigation and drainage. The main cause of the present agricultural and environmental crises in West Africa is the general under development of lowland agriculture. Environmentally creative technology, such as sawah farming (Fig.2-1) in lowlands is not traditionally practiced in sub-Saharan Africa or in Ghana. Sawah is the prerequisite for realizing the green revolution as well as for preserving and even restoring ecological environments. Irrigation and drainage without sawah farming technologies has proved inefficient or even dangerous because of accelerating erosion. Thus, the development of irrigation has been slow. In the absence of water control, fertilizers cannot be used efficiently. Consequently, the high yielding varieties are useless and soil fertility cannot be sustained. Hence, the green revolution cannot take place.

Fig. 2-1. What is sawah? sawah is a leveled, bunded and puddled rice field with inlets and outlets to control water.



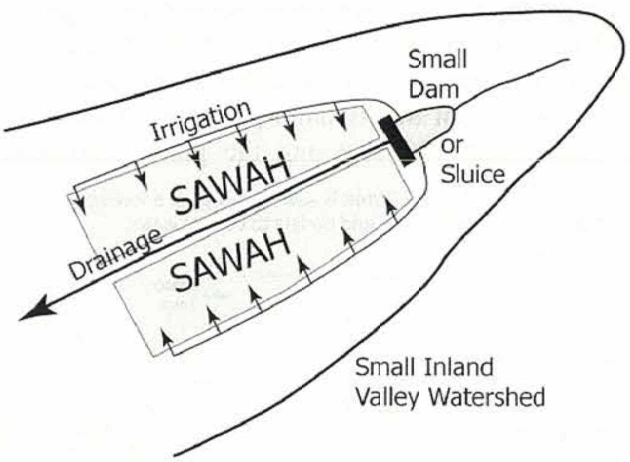
2-1-2 Sawah and Irrigation

Another frequent source of misunderstanding in West Africa is the term of irrigated rice. In Asia, the meaning of this term is clear, as the sawah is prepared first by farmers before completing the government assisted irrigation system. However, there are many irrigation systems without proper sawah preparation in West Africa.

In the past, research on water control of inland valleys concentrated on irrigation and drainage systems, such as the central-drain system, the interceptor-canal system, the head-bund system and head-dyke system. The contour-bund system is somewhat similar to the sawah in terms of bunding and leveling. The contour bund system, however, may be more difficult to construct and manage by local farmers than the sawah system. It may be difficult to share land and irrigation water fairly for local farmers by using the contour bund system, which may be more suitable for large scale irrigated rice farming such as in the United States and Australia.

Generally speaking, the construction cost of sawah is far higher than that of irrigation facilities in terms of labor and amount of soil moved. Out of the total cost, 50-70% should be allocated for sawah construction and 30-50% for irrigation and drainage. Therefore in order to achieve sustainable development, sawah systems need to be constructed with the active participation of farmers. The key element is the sawah. In the sustainable irrigation systems in inland valleys, the sawah technology should be extended to the farmers first (Fig 2-2).

Fig. 2-2. Sawah and irrigation/drainage facilities for the control of water in a watershed. Dam, sluice and irrigation/drainage canals can be effective for water control only in combination with sawah. Irrigation/drainage without sawah accelerate erosion or drought.



2-2 Geological Fertilization Theory for the Integration of a Watershed

2-2-1 Geological Fertilization Theory

In what type of environment do humans live? Fertile soils and ample water cycling secure an abundant food supply and rich human life on the earth. What are the factors that determine the geographical distribution of population? What causes the extremely great differences in population density in the areas around cities as shown in Figure 2-3. In this figure, the areas with a concentration of black dots are densely populated ones. It is clear from the figure that densely populated areas are restricted by precipitation (or water supply from rivers). In the temperate zones, high population densities are observed only in the areas where the yearly precipitation is 500-1,000 mm or more, and in the tropics, they exist only in the regions with an annual rainfall of 1,000-2,000 mm or more. But in the tropics having much rain, population density differs greatly from area to area.

As Figure 2-3 shows, tropical Asia has a higher density than tropical Africa on the whole but has substantial differences in population according to region. The density reaches 500 persons/km^2 or more in the delta of the Ganges and other large rivers, on such volcanic islands as Java and Bali and on basaltic lava flow plateau like the Indian Deccan highland. By contrast, Borneo's population density is as low as about 10 persons per km^2. In tropical Africa, while the Zaire basins have a low density, the Ethiopian Plateau, volcanic ash zones around Lake Victoria in East Africa, the Hausa area in northern Nigeria and the Yoruba and Ibo areas in southern Nigeria have hundreds of people or more per km^2. These densely populated areas are all those blessed with fertile soil and abundant water resources. Whether a region has a plentiful water resource or not is dependent on the distribution of rainfall and topographical features. On the other hand, the distribution of fertile soils is determined by geological fertilization, one of the workings of the earth. "Geological fertilization" is here defined as the earth's activity of supplying new starting materials to the weathering of rocks and soil formation actions, which are irreversible processes, and thus restoring (renewing) soils (Figure 2-3).

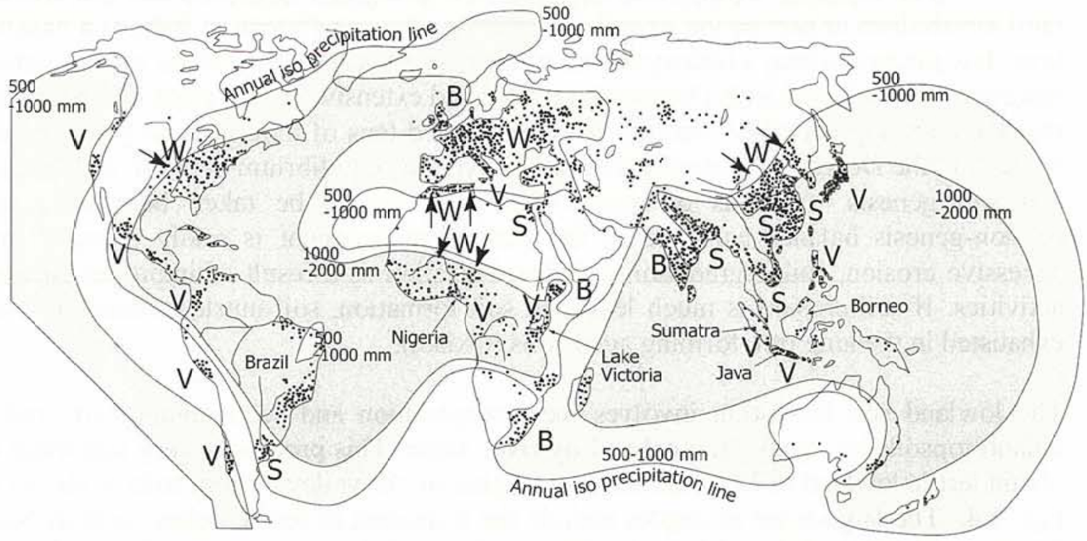


Fig. 2-3. Global distribution of geological fertilization, fertile soils and population density. Dense dots show the areas of dense population. Global distribution of fertile soils is related to four geological fertilization processes.
W: loess deposition by wind, S: sediments by river, V: volcanic ash, and B: dynamic balance between soil formation and erosion on base rich parent material.

Geological fertilization can be divided into the following four categories as shown in the Fig. 2-3:

1) S: Action of water (rivers' transporting and alluvial action): Floods occur once in several years to several decades and form fertile lowland soils (Inceptosol). In Africa, the delta of the Nile Delta is a typical example. The Nile Delta also benefits from the volcanic ash soils distributed in the Ethiopian Plateau and around Lake Victoria in the upstream sections.

2) V: Volcanic activity (supply of volcanic ash and basic lava): Supplied once in several hundred to several thousand years, volcanic ash causes catastrophic disasters in the short term but restores soils and forms fertile volcanic soils (Andisol) full of nutrition and vitality. Soil fertility is high on the Ethiopian Plateau and in the countries around or near Lake Victoria (Kenya, Uganda, Rwanda, Burundi and far eastern parts of the Democratic Republic of the Congo) because volcanic ash and basic lava provide these regions with geological fertilization.

3) W: Action of winds (supply of loess): Natural deserts are needed to the formation of fertile soils. Harmattan dust from the Sahara is rich in bases and fertile. Northern Nigeria has Harmattan winds from the Sahara in December and January in the dry season every year, which bring a large quantity of loess. In Lagos facing the Gulf of Guinea, too, harmattan dust sometimes intercepts sunlight, which temporarily lowers temperatures and makes the weather much milder. Loess-derived soils are widely

distributed in the granaries of Western countries, too. The eastern parts of China enjoy the benefit of dust from the Gobi Desert, loess plateaus, etc. Though the quantity is small, yellow sands from China are considered to be helpful in the maintenance of soil fertility in Japan, too. Dust from deserts also possibly helps prevent global warming by supplying iron to the ocean, which in turn promotes CO_2 absorption by algae.

4) B: Dynamic equilibrium between weathering/soil formation and soil erosion (soil metabolism or prevention of soil ageing): The Deccan Plateau in India is a basaltic lava flow plateau having a history of tens of millions of years. Using these soils as parent materials, fertile Regul soils (Vertisol) were formed extensively. But since it is estimated that the maturing period of Vertisol does not exceed tens of thousands of years, 8) the Vertisol in the Deccan Plateau clearly keeps a dynamic equilibrium between soil erosion and soil genesis. But as discussed later, care should be taken because a soil erosion-genesis balance achieved in the natural environment is easily changed into excessive erosion, soil degradation and desertification as a result of improper farming activities. If soil erosion is much less than soil formation, soil nutrients leach and are exhausted in the long run, forming aged soils (Oxisol).

The lowland soil formation involves the transportation and sedimentation of eroded upland topsoils by surface run off and by river water. This process is very important to obtain fertile lowland soils. Small-scale examples are the valley bottom soils as shown in Fig. 2-4. The large-scale examples include the formation of fertile deltas, such as Nile, Ganges and many Asian deltas. In the sawah based farming system this geological fertilization process can be enhanced. The long term of sustainability of sawah farming can be attributed to this process.

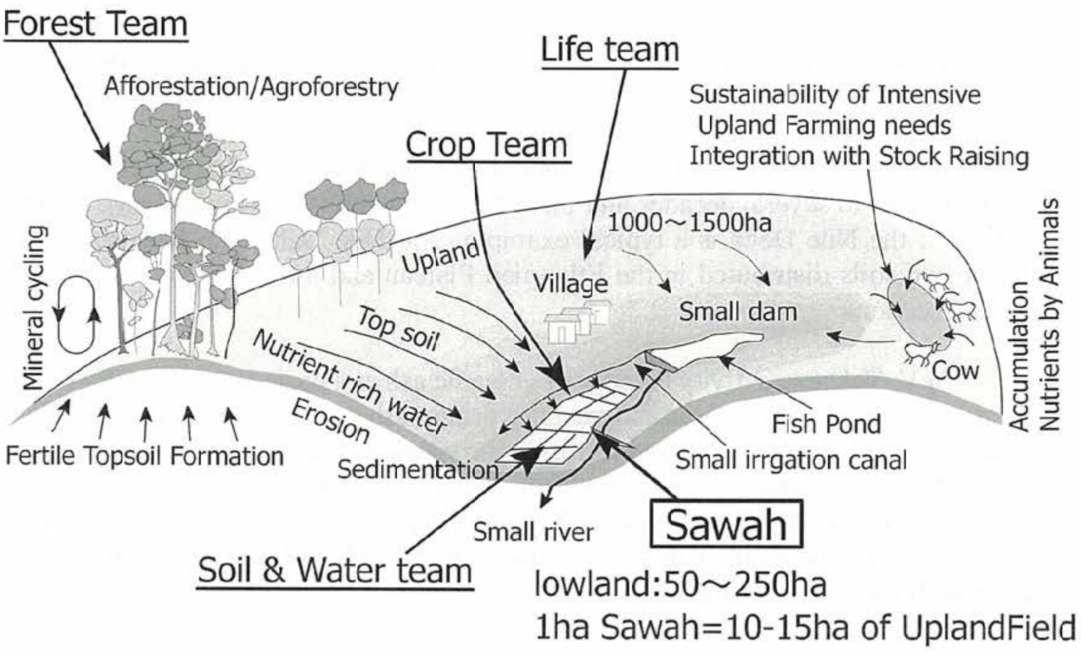


Fig. 2-4. Integrated Watershed Management Based on Sawah Eco-technology: Sustainable farming system in inland valley watersheds in west Africa: integration of forrest and agroforestry / animal / lowland sawah / fish farming.

2-2-2 Sawah system in inland valley watershed

As shown in Figure 2-4, the soils formed in uplands and the nutrients released during weathering and soil forming process in upland are accumulated in lowlands. If sawah system exists in lowlands, it can store and effectively use these nutrient rich water and fertile topsoils. This is an eco-environmental basis for long-term sustainability of high productivity of Sawah based rice farming. But while relatively many data are available as to the functions of irrigation water, there are only a little quantitative data concerning the rate of soil formation, erosion and sedimentation.

A sustainable watershed should exhibit a dynamic equilibrium between soil formation and erosion. If the rate of soil formation far exceeds those of soil erosion, old leached soils like Oxisols may develop, and if erosion can not be compensated for by soil formation, soil degradation and eventually desertification will occur. The earth's mean rate of soil formation was estimated at 0.7 t/ha/y. Cool temperate granitic watersheds showed a rate of 0.02 t/ha/y. Andesitic watersheds in West Sumatra, Indonesia showed a rate of 1.8 t/ha/y.

Suppose the soil formation rate in uplands, which make up 95% of the total area in the example of a watershed shown in Figure 2-4, to be 1 t/ha/y. In a stable ecosystem in a watershed, the rate of soil formation and erosion should be well balanced; therefore, the topsoils formed in uplands--which account for 95%--and the nutrients produced in the process will be concentrated in lowlands, which make up 5% of the area. Thus the soil formation rate in the lowlands equals to 20 t/ha/y. Though it will be impossible to use all of the rich soils and nutrient rich water from the uplands effectively, sawah will be the best system for making an effective use of them. A sawah system in lowlands is, as it were, the one for effectively using the interest accrued from the huge stocks named "uplands." This farming system could artificially reinforce 1) and 4) of the geological fertilization processes.

2-2-3 Integrated Watershed Approach

The sustainable productivity of sawahs is more than 10 times greater than that of upland rice fields. Because of these geological fertilization processes and well-known bio-physico-chemical processes of inundated sawah soils as described by Kyuma and Wakatsuki (1995), sustainable productivity of 1 ha of Sawah may be equivalent to more than 10 ha of upland fields. This value was estimated by assuming that the mean yield of upland rice without fertilizer application is 1 t/ha and the mean yield of sawah rice without fertilizer application is about 2 - 2.5 t/ha. To sustain the yield, upland fields have to lie fallow (3-year cultivation and 12-year fallow, for example). On the other hand the lowland sawah rice can be cultivated continuously for more than thousand years. Thus sustainable productivity of sawah is 10-12.5 times higher than that of upland rice field, i.e., 12.5 = (2-2.5/1) x (15/3).

As Figure 2-4 clearly shows, the forest ecosystem, if it is combined with a sawah system, puts down deep roots into the ground and forms fertile topsoils and further strengthens the water holding capacity and sustainable productivity of the entire watershed. Such a combination of forests and sawah in a watershed is a sort of traditional agroforestry technique. It is an excellent ecotechnology for sustainable food production that has been developed by traditional agriculture in Japan and Asia, and is an environment-friendly system using the functions of forests and sawah system. What the present proposal attempts to achieve is to make the most of this ecological engineering technology of forests and sawah systems to restore deteriorated uplands and lowlands in West Africa.

2-2-4 Restoration of low fertility soils of inland valleys in West Africa

Issaka and Wakatsuki (1997) and Buri and Wakatsuki (1996) showed the general fertility and geographical distribution of soils of inland valleys and flood plains in West Africa (Fig.2-5). The general fertility was compared to those of Tropical Asia (Kawaguchi and Kyuma 1977) and Tropical America (Tanaka et al 1986). The results were summarized in Table 2-1. The total carbon and nitrogen content were low for West Africa and Tropical Asia. The mean values of available phosphorus suggest that the phosphorus status of West Africa is very low throughout the region. Base status such as exchangeable calcium and potassium and effective cation exchange capacity were particularly low. The study revealed that the soils of inland valleys of West Africa are characteristically low in majority of plant nutrients. In addition, some micro nutrients, such as Sulfur and Zinc also, are generally very low and about 60-80 % of lowland soils, both inland valleys and flood plains, are in deficient level, as shown in Fig.2-6. For effective and sustainable crop production, new farming systems that are both soil restoring and enriching must be developed. As discussed above, the African adaptive sawah-based farming systems by small-scale irrigation scheme is one of the most promising systems, which the project will examine and evaluate.

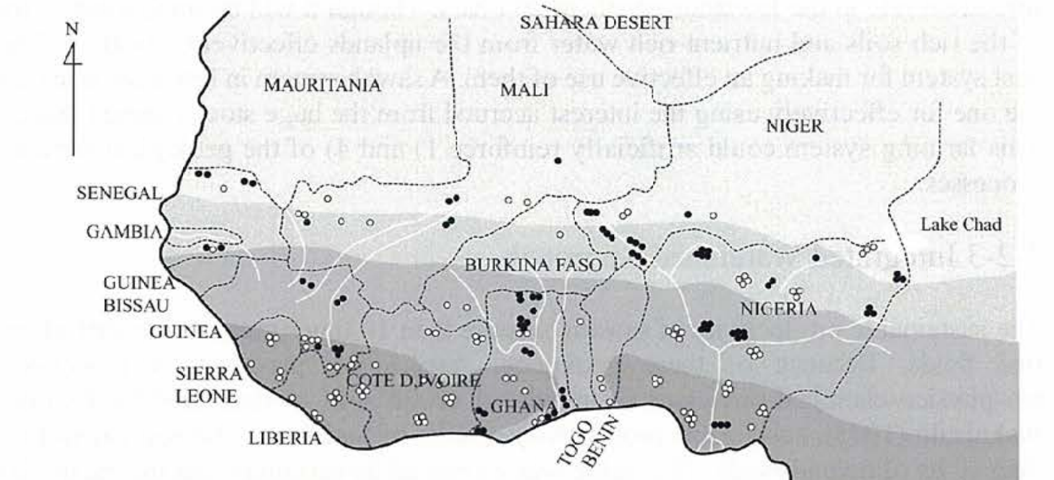


Fig. 2-5. West Africa map showing selected sampling sites. (Buri et al., 2000)

Table. 2-1. Mean values of soil fertility properties of inland valleys (IVS) and floodplains (FLP) of West Africa in comparison with lowland topsoils of tropical Asia and Japan (Hirose and Wakatsuki 1997)

Location	Total C (%)	Total N (%)	Available P (ppm)	Exchangeable Cation (cmol/kg) Ca	K	Mg	ECEC	Sand (%)	Silt (%)	Clay (%)	CEC Clay
IVS	1.3	0.11	8.7	1.89	0.25	0.88	4.20	60	23	17	25
FLP	1.1	0.10	7.3	5.61	0.49	2.69	10.31	48	23	29	36
T. Asia*	1.4	0.13	18	10.4	0.4	5.5	17.8	34	28	38	47
Japan*	3.3	0.29	57	9.3	0.4	2.8	12.9	49	30	21	61

*Kawaguchi and Kyuma (1977)

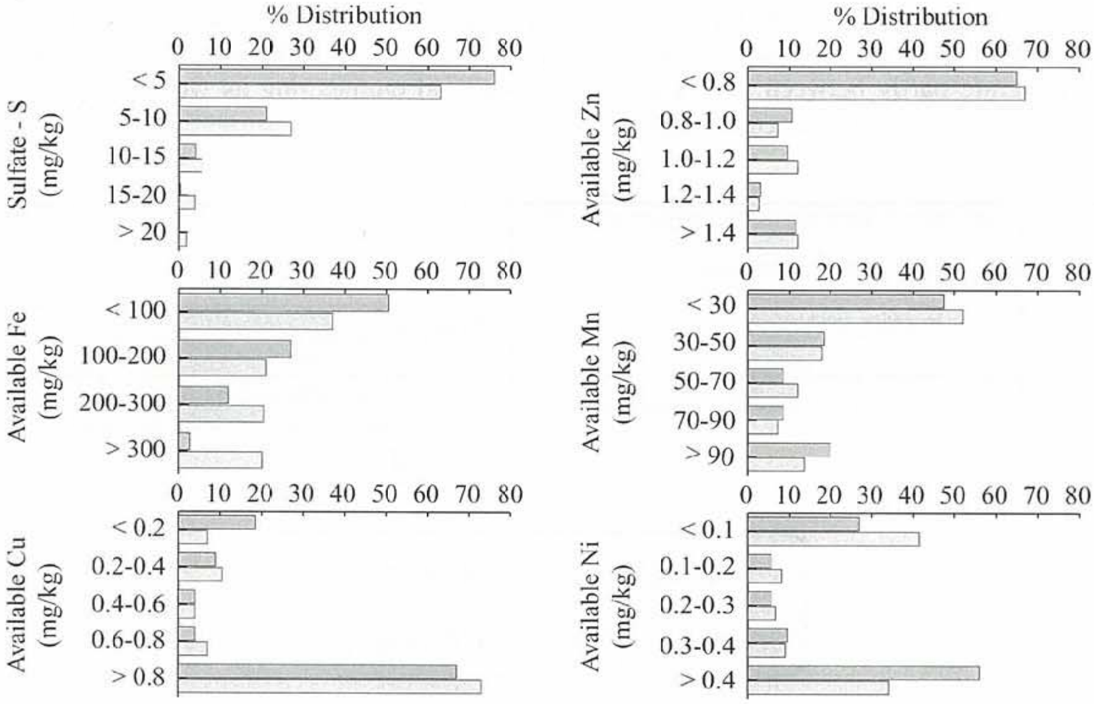


Fig. 2-6. Frequency distribution of topsoil (0-15) cm available nutrients within West Africa lowlands.

2-3 Sawah and Forestry Ecotechnology Development

2-3-1 Definition of Ecotechnology

The focus of research activities is to develop suitable Ecological Engineering Technologies (Eco-Technologies) for integrated watershed/rural development through increasing sustainable productivity and at the same time through improving the total water cycling in a given watershed. Eco-technologies should be adaptive to Indigenous Farming Systems and rural village society. Various area of benchmark watersheds, from 100 to 10000 ha, which is located 40-50km northwest from Kumasi, has been selected for basic agroecological survey. Among and surrounding watersheds, various sized watersheds including Adujama, Potrikrom, Biemtetrete, and Biemso No.1 and No.2 villages were selected for detailed survey and intensive field testing.

The term, Ecological Engineering Technology (Eco-Technology), is defined here as an ecology-based sustainable farming technology viable to local socio-cultural systems to increase farming productivity and to improve the environment. The ecotechnology developed in this project should be able to use by local farmers to control water and to conserve water and soil. Leveling, bunding, and construction of canal and head dyke are the example of such ecotechnologies, which can be practiced as an extension of agronomic practices using locally available tools and materials. Forestry technology, such as nursery preparation and management, contour bunding planting of the useful trees, regeneration of the water and soil conservation forest, and to establish carbon sequestration against global warming are the examples of the ecotechnology which this project are going to develop. The ecotechnology will be the key technology to attract local farmers' active participation for the improvement of basic agricultural infrastructure, such as irrigation and soil conservation measure. The ecotechnology will be able to integrate partly between agronomy and agricultural engineering as well as ecological sciences and various engineering (Fig 2-7).

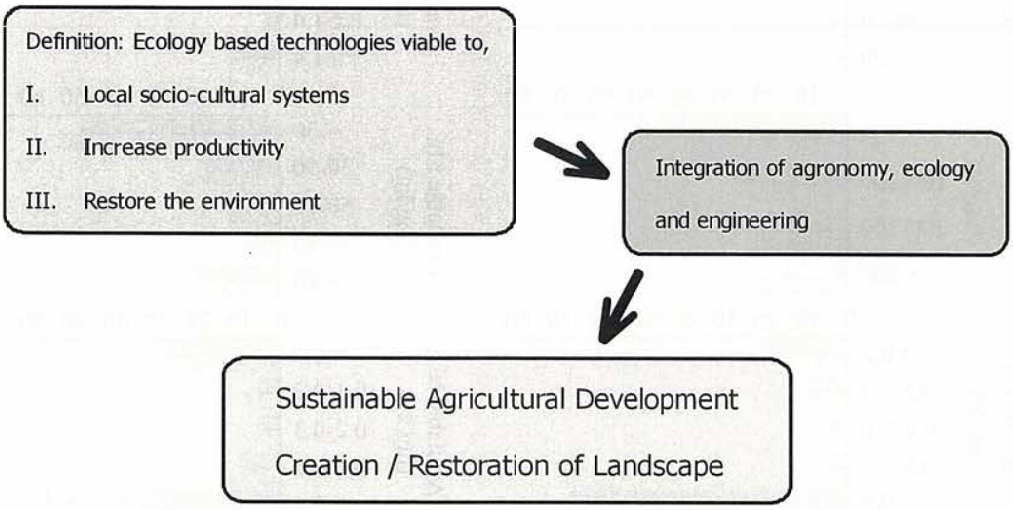


Fig. 2-7. Key concept 3: Ecotechnology

2-3-2 Regeneration of Africa and the earth through the sawah and the forest based ecotechnology in 21st century

In tropical environment and ecology, (only ?) sawah based farming systems have fully proved long term intensive sustainability. Since sustainable productivity of 1 ha of Sawah is equivalent to more than 10 ha of upland fields, development of 1ha of sawah opens the field for the afforestation in the degraded upland field in Africa. The total potential area for new sawah development in Africa is estimated to 20 million ha. Thus if we can develop 20 million ha of sawah in the next 50-100 years, we can open the afforestation area of 200 million ha. If we can plant the trees of net primary productivity of 5 ton-C/ha/year in 200 million ha, the forest can fixed the carbon dioxide one billion ton annually in next 50-100 years which is roughly equivalent to reduce 10% of the present global carbon emission. Since it is estimated that such carbon fixation can sell no less than 100 dollars per ton in quite near future, global market price will be no less than 100 billion dollars annually in next 50-100 years.

2-4 Participatory Approach for Ecotechnology Research, Development and Extension

2-4-1 Fieldwork, Ecotechnology Research and Development: Field work should come the first.

Farmers field and forest are our place where major research activities for ecotechnology development and extension are done. This is the important character of this joint study project. Although the result of experimental fields and laboratory works at the research institutes will be applied, field work should comes the first and field confirmation is the most important evaluation criterion.

2-4-2 Participatory approach and the ecotechnology development and extension: Ecotechnology comes the first, then participatory approach.

Various water management ecotechnologies will be researched and developed in collaboration with farmers, designed based on the local ecological and socio-economic conditions, constructed or practiced with the farmers' participation, and tested by ecological and socio-economic view points. In this joint study project, researchers should propose the possible various ecotechnology options to farmers. This is especially necessary for our two main target fields, Sawah based ecotechnology in lowland and Forestry based ecotechnology on the upland. Field ecotechnology development comes the first, and then participatory approach comes. The participatory approach in this joint study project should apply in this principle. Farmers' participation at various steps of the ecotechnology research, development, design, construction and practices, testing and evaluation is essential. Therefore the farmers participated in this project are not only beneficiaries but also the partners. At the same time the farmers participated will be trained on the job, OJT, for further extension.

2-5 Methodology and Study Frameworks

2-5-1 Soil and water team

This team conducted investigations on, among others, water balance and rainfall runoff in the benchmark watershed, existing soil and water control techniques and soils in the entire benchmark areas, especially the distribution and fertility characteristics of lowland soils in the watershed of different sizes in the benchmark sites. It also carried out fundamental research on, for example, the development potential of various sawah systems in the watershed.

The team's main role was to plan, design, develop and evaluate various sawah systems making the most of the data obtained by the above investigations. The team was making different types of sawah systems in lowland watershed of all sizes in cooperation with farmers and conducting cultivation experiments.

The ultimate goal of the soil and water team can be summarized as follows. 1) to analyze the climate, hydrology, topography, soils and water resources as well as the distribution of lowlands suited for paddy fields in the watershed of all sizes in the benchmark sites and to evaluate quantitatively the development potential of different types of demonstrative sawah fields (rain-fed, spring water-irrigated, river water-irrigated, dike-irrigated, pump-irrigated, combinations of these, etc.) in and around these areas; 2) to compile manuals and draw up development guidelines concerning the selection of sawah field sites, surveying, designing, participatory development, extension and management for each sawah field type; and 3) to define the soil and water conditions of sustainable land use systems harmonious with the ecology of all sizes of watershed.

2-5-2 Crops team

The tasks of the crop team included the selection experiments of rice varieties suitable for developed sawah fields, selection of the varieties from which local farmers could get a 4 t/ha yield level sustainably and selection tests of varieties of dry-season crops for the fields, such as cowpea. The team also developed a highly sustainable rice farming system suited for the sawah fields opened, studies various cropping patterns and examined the effect of different organic and inorganic fertilizers for rice growing. Comparing the effect of sawah field systems with the traditional system in the project site (Ashanti district) was this team's role, too.

The crop team's final goals were, 1) to investigate the comparative advantages of different types of demonstrative sawah fields over the traditional farming system in the Ashanti district so that by the end of the project, the general comparative advantage of sawah field systems might be proved and that rice farmers in the district would willing to introduce sawah based agriculture technology and 2) to compile manuals of sustainable planting and management systems of both rice and dry-season crops for each type of demonstrative sawah fields.

2-5-3 Forestry team

The forestry team had collected socio-ecological information concerning afforestation and forest management, especially data on afforested areas and tree nursery development. What is noteworthy is that local farmers showed interest not in tree planting in general but only in the planting of multipurpose trees (MPTs) that they could sell or would be useful, such as cacao, oil palm, orange and teak. As shown in the Chapter 5, this team constructed tree nurseries in three villages in cooperation with farmers and conducted demonstrative experiments on seed storage, increased seedling production, grafting, management, selling of seedlings and distribution of profits. In these activities, socioeconomic sides, including a fair management of earnings, were as important as technical problems.

To promote forestry and protect the environment, especially to investigate the CO_2-fixing capacity of forests, an experimental plot for CO_2 sequestration was established in the lowlands in Biemso where sawah fields were opened. Eleven tree species listed in Table 2-2 were planted in this plot and studies were conducted to find effective ways to manage forests, including manure and fertilizer application methods. In addition, various experimental plots were built in natural forests, secondary forests, cacao bushes, land in fallow, mixed-crop land, traditional rice growing land, sawah, etc. in the benchmark watershed to study material cycling and nutrient movement. The nutrient movement (geological fertilization) from upland forests and fields to lowland sawah was also quantitatively evaluated. Figure 2-8 shows an outline of land use in and around the benchmark sites. While all of the natural vegetation shown in these figures was considered to be forests, the ratio of forests (secondary forests plus cacao bushes and other shrubs) was now only about 20% at present as evident from the figures. Therefore, if sawah and other intensive lowland use increase, it would be possible to extend forest areas.

Table 2-2. Eleven tree species planted on the upland fringe at Biemso No.1 site.

Timber tree species	Boot and Ship building	Cabinet works	Construction (heavy / general)	Decorative veneer or plywood face	Doors	Firewood	Flooring (heavy / general)	Furniture (high class, other grades)	Poles, Posts, Piles
Acacia mangium									
Albizia ferrugenia									
Cedrela odorata									
Eucalyptus camoldulensis									
Guibauatia ehie									
Khaya ivorensis									
Pericapsis elata									
Piptadeniastrum africanum									
Senme siamea									
Tectona grandis									
Triplochiton scleroxylon									

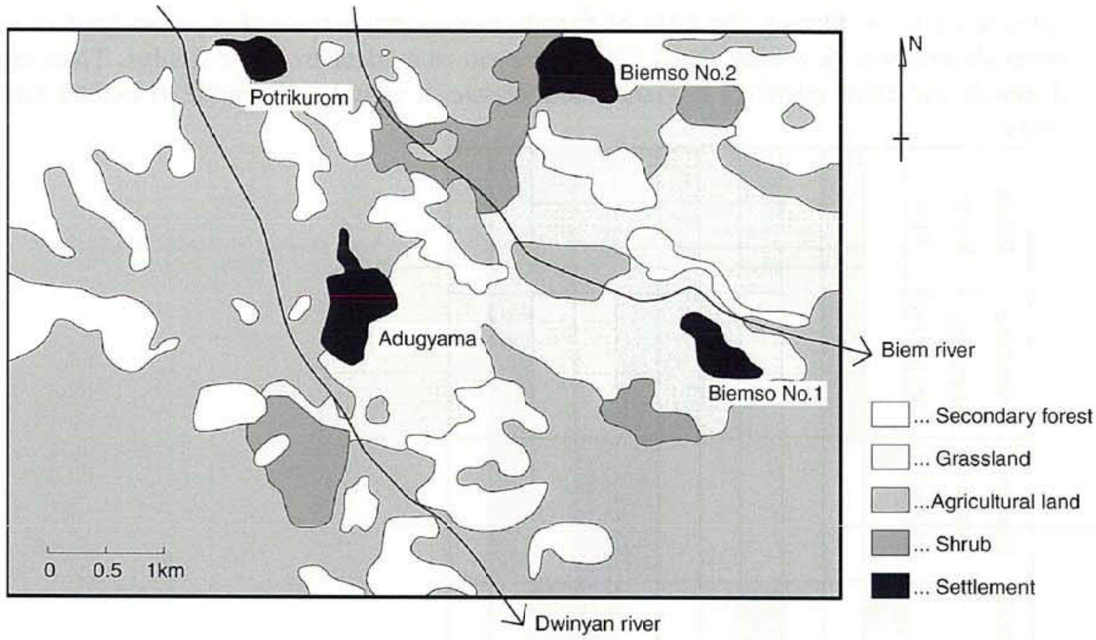


Fig. 2-8. Vegetation patterns in project area.

The goals of the forestry team were: 1) to identify a sustainable land use layout and distribution harmonious with the ecosystem of watershed (primary and secondary forests, cacao bushes, other trees, fallow, upland cropping, lowland paddy agriculture, etc.); 2) to draw up guidelines for the design of the techniques for using tree nurseries/agroforestry/tree use and participatory development management in and around the benchmark watershed; and 3) to make quantitative analysis of nutrient movement and material cycling in forests and tree-using ecosystems in the watershed and to study what implications forests and trees have in upland farming and lowland sawah systems.

2-5-4 Life team

The role of the life team was to support from socioeconomic sides the above-mentioned demonstrative studies on ecotechnology-based sawah development by the soil and water team, on sawah based agriculture by the crop team and on forestry promotion by the forestry team. Its ultimate goals were, 1) to study the present situation and problems of the existing land ownership and land use system and agriculture/forestry system in the project sites; and 2) to draw up, based on the knowledge of the existing land ownership and land use system, guidelines for encouraging local farmers to take part in sawah filed (and forestry) development and to discover a socio-economically suitable development process.