Watershed Ecological Engineering for Sustainable Intensive Rice Production and Restoration of Degraded Environment

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1. Introduction

Among the three major cereals, rice has the highest nutritional value. Relative quality of its protein in comparison with egg protein is 66%, while wheat is 53% and Maize is 49% respectively (Juliano 1985). According to FAO (FAOSTAT 2006), during past 40 years, world population increased 34bilion (1961-70mean) to 62billion (2001-2003 mean), i.e., 184% increase. During the same period, world rice production increased 264 to 586 million ton per year (221% increase), while wheat production was increased from 278 to 574 million ton per year (206% increase). Although the increase of maize production was the highest, 238 to 619 million ton (260% increase) during the period, percentage of feed for domestic animal was about 70%. Therefore rice is the most important cereal as a direct human food.

Total population of Sub Sahara Africa was 640million at 2003, of which 30%, about 200million were malnourished. Sub Sahara Africa is the only region where hunger prevalence is over 30%, and the absolute numbers of malnourished people are increasing last 20 years (Sanchez and Swaminathan 2005, FAO 2006). The West Africa is a core region of Sub Sahara Africa. Food and environmental crises are increasingly serious. Thus the deteriorating environment is threatening the human survival. Apart from natural environmental reasons, the background for this cause can be found in the tragedies many years ago. The slave trade by European countries for as long as 400 years, 16th to 19th centuries, destroyed African communities. Subsequent colonization continued for additional 150 years until 1960. These are probably the main reason for the continuing poverty and crises facing many parts of this continent (Hirose and Wakatsuki 2002). To present the strategy and tactics to realize the green revolution in Sub Sahara Africa through the international collaboration, particularly Asia and Africa is one topic of this paper.

Thanks to the success in the green revolution, most of the Asian countries achieved food self-sufficiency and their crops production exceeded the pace of population growth. This is generally considered to be a basic condition that has brought rapidly expanding economy in Asia now. During the 1960 to 2003, per capita crop production has increased 30% in tropical Asia but decreased 10% in Sub Sahara Africa. To present the management strategy for the long-term sustainability of the green revolution in the Asian countries is the main topics of this paper in relation to the watershed ecological engineering, or ecotechnology.

2. What is the ecological engineering or ecotechnology ?

Definition of Ecological Engineering or Ecotechnology

The term, Ecological Engineering Technology (Eco-Technology), is defined here as an ecology-based sustainable farming technology viable to local socio-cultural systems, which can increase farming productivity and improve the environment. The ecotechnology 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 another examples of the ecotechnology. 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 1).

Ecological Engineering Technologies (Eco-Technologies) are the key 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.

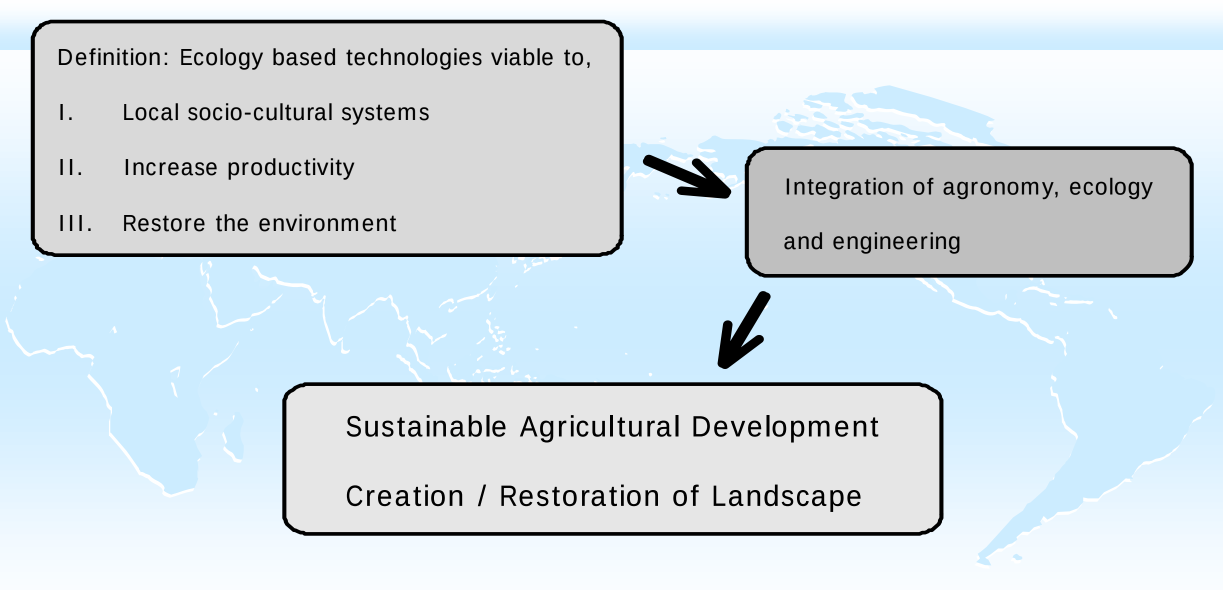


Fig. 1 Ecological Engineering or Ecotechnology

3. Global geographical population distribution, carrying capacity and geological fertilization

<u>(1) Global Geographical Population Distribution</u>

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. 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.

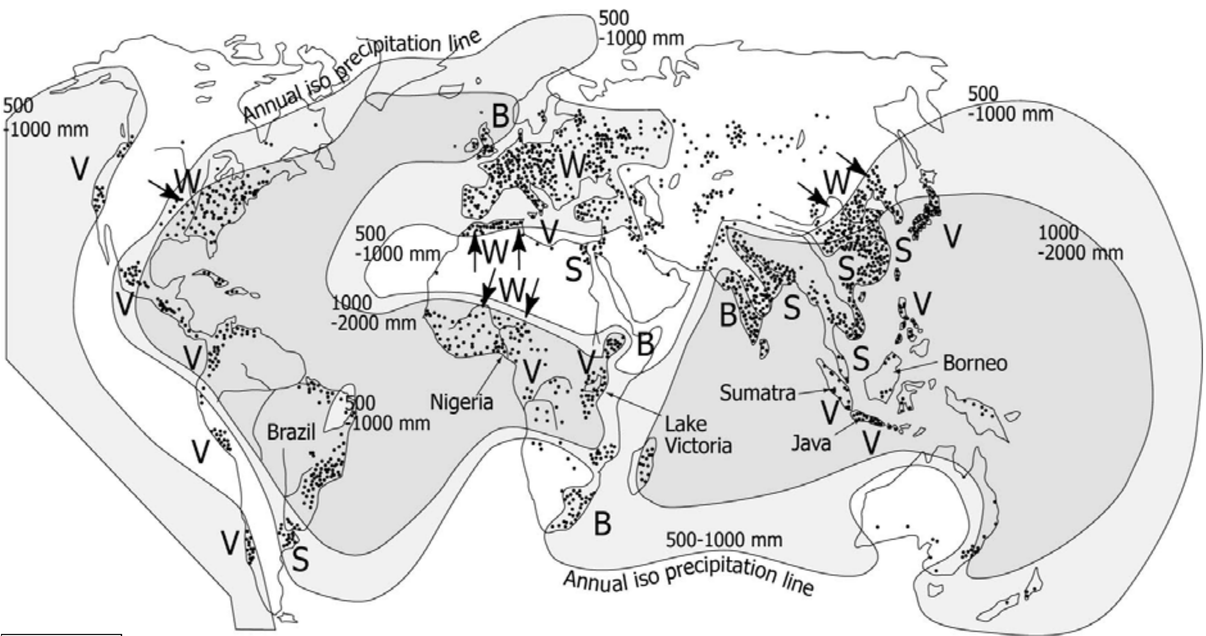


Fig.2 Global distribution of geological fertilization, fertile soils and population density. Dense dots show the areas of dense population. Global distribution of fertile soils is related to four geological fertilization processes.
W: loess deposition by wind, S: sediments by river, V: volcanic ash,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

As Figure 2 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).

(2) Geological Fertilization Processes

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

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. 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.

3. Successful Asian Green Revolution and Unsuccessful African Green Revolution

As shown in Fig.3, the green revolution has yet taken place in West Africa and Sub Sahara Africa (SSA). Although major cereals are very diverse, per capita production has been stagnating between150-200kg in SSA and West Africa during last 40 years. While the figures increased from 200kg to more than 250kg in Asia (Table 1). Because of water content of Yam and Cassava are high (60-70%) and therefore energy per kg is one third of cereals. Protein and minerals contents are one fourth to one fourteenth in comparison with cereals, the production data of FAO were divided by 8 for cassava and 5 for yam to estimate reasonable cereals equivalent in the table (FAOSTAT 2006, Kiple and Ornelas 2000, Sanchez 1976). This makes the present big difference of economic growth between Africa and Asia. Now Asia is a global center of economic growth thanks to the green revolution started in 1970s. Although SSA is extremely diverse, West Africa is a core region in terms of the rice production and importation in SSA (Table 1).

Table 1. Five years' means of population, major cereals' production and importation per person last 40 years in Asia and Sub Sahara Africa (FAO STAT 2006). Note: because of water content of Cassava and Yam are high (60-70%) and low mineral and protein content in comparison with the other cereals, the production data of FAO were divided by 8 for Cassava and 5 for Yam to estimate cereals equivalent (Sanchez 1976, Kiple and Ornelas 2000).

Population (FAOSTAT 2004) Unit: 1,000

Year	1961-1970	1971-1980	1981-1990	1991-2000	2001-2003
Ghana	7,849	9,970 (127)	13,380 (170)	17,689 (225)	20,474 (261)
Nigeria	42,957	56,198 (131)	75,560 (176)	101,388 (236)	120,914 (281)
West Africa	95,749	124,204 (130)	165,990 (173)	220,738 (231)	261,861 (273)
Africa South of Sahara (SSA)	234,782	307,466 (131)	411,559 (175)	544,361 (232)	640,376 (273)
Thailand	31,771	41,818 (132)	50,941 (160)	58,088 (183)	62,194 (196)
Indonesia	108,324	136,182 (126)	167,800 (155)	198,562 (183)	217,123 (200)
Bangladesh	59,400	76,251 (128)	98,036 (165)	124,921 (210)	143,808 (242)
Asia Developing	1,786,958	2,251,298 (126)	2,732,350 (153)	3,252,342 (182)	3,568,256 (200)
Japan	99,469	111,749 (112)	120,936 (122)	125,593 (126)	127,468 (128)
World	3,376,145	4,102,728 (122)	4,879,539 (145)	5,712,586 (169)	6,224,835 (184)

＊ figures in parenthesis are relative percentages when 1961-1970 adjust to 100

Africa South of Sahara- food production (kg/person)

Year	1961-1965	1966-1970	1971-1975	1976-1980	1981-1985	1986-1990	1991-1995	1996-2000	2001-2003
Rice, Paddy	16.3	17.5	18.2	17.6	17.3	19.2	19.2	19.9	18.1
Wheat	8.1	8.4	7.7	6.8	6.7	6.8	6.2	6.3	6.2
Maize	42.5	44.3	45.0	43.4	40.3	50.6	46.6	46.2	42.2
Cassava (1/8)	18.8	18.6	18.4	18.1	17.6	18.0	20.2	19.5	19.7
Yams (1/5)	7.8	10.8	8.8	6.6	5.6	6.6	11.5	11.9	11.6
Sorghum	44.7	38.3	34.0	31.5	31.1	30.8	31.2	31.3	31.9
Millet	31.7	29.3	27.8	23.3	21.2	23.0	22.1	22.3	21.8
Paddy Rice-Import	3.8	3.8	4.3	7.7	10.3	8.8	9.0	8.3	9.9
Wheat-Import	4.5	6.0	7.4	9.7	11.8	10.2	11.2	13.1	15.7
Total	178.1	177.0	171.6	164.8	161.9	173.9	177.3	178.7	177.2

Asia- food production (kg/person)

Year	1961-1965	1966-1970	1971-1975	1976-1980	1981-1985	1986-1990	1991-1995	1996-2000	2001-2003
Rice, Paddy	124.5	131.8	134.2	137.4	148.8	149.8	147.1	149.8	141.1
Wheat	41.6	44.2	49.6	57.6	67.0	70.6	79.0	78.4	72.2
Maize	19.6	23.9	26.1	31.3	34.0	38.0	41.8	45.0	43.3
Cassava (1/8)	1.4	1.4	1.5	2.1	2.2	2.1	1.9	1.7	1.8
Yams (1/5)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sorghum	9.6	9.7	8.3	8.2	7.1	5.9	5.0	3.8	3.0
Millet	8.6	9.5	7.8	6.6	6.3	4.9	4.2	3.8	3.6
Paddy Rice-Import	3.7	3.4	3.1	3.0	2.4	2.2	2.3	3.9	3.7
Wheat-Import	10.7	11.4	11.7	12.0	13.7	14.6	15.0	13.5	11.7
Total	219.7	235.2	242.4	258.1	281.5	288.2	296.3	299.9	280.3

West Africa- food production (kg/person)

Year	1961-1965	1966-1970	1971-1975	1976-1980	1981-1985	1986-1990	1991-1995	1996-2000	2001-2003
Rice, Paddy	18.4	21.1	21.9	22.1	23.8	27.4	29.3	31.4	28.2
Wheat	0.3	0.3	0.2	0.2	0.4	0.6	0.3	0.4	0.3
Maize	27.1	27.2	23.5	18.6	21.9	42.6	48.7	41.4	38.6
Cassava (1/8)	16.6	17.3	16.4	16.7	14.8	16.8	25.3	25.3	24.7
Yams (1/5)	17.8	25.0	20.5	15.2	12.8	15.4	27.4	28.3	27.6
Sorghum	70.6	56.7	47.0	40.3	42.1	46.5	48.6	47.9	47.2
Millet	59.8	54.0	52.7	42.4	41.6	48.0	45.7	45.4	44.6
Paddy Rice-Import	5.3	5.8	6.2	13.2	17.4	15.3	16.7	15.7	19.1
Wheat-Import	4.0	5.8	8.0	13.3	14.3	9.6	11.4	13.8	16.7
Total	220.0	213.2	196.4	182.0	189.0	222.2	253.4	249.6	247.1

Per Capita Rice Paddy Production + Per Capita Import as Paddy Equivalent (FAOSTAT 2006) Unit: kg

Year	1961-1970	1971-1980	1981-1990	1991-2000	2001-2003
Ghana	5.5+6.9	7.9+4.8 (143+70)	5.4+6.5 (97+94)	10.6+10.2 (191+148)	14.2+15.2 (256+220)
Nigeria	6.1+0.02	9.5+2.8 (154+100**)	23.3+5.0 (378+182)	30.7+5.9 (500+215)	30.0+15.2 (489+553)
West Africa	19.9+5.8	22.0+10.3 (111+178)	25.8+16.7 (130+289)	30.4+16.6 (153+289)	29.5+17.6 (148+306)
Africa South of Sahara (SSA)	17.0+3.9	17.9+6.1 (105+157)	18.3+9.8 (108+250)	19.6+8.9 (115+228)	18.7+9.4 (110+240)
Thailand	379.9+0.0	357.1+0.0 (94+ -)	374.4+0.0 (99+ -)	380.9+0.0 (100+ -)	426.5+0.0 (112+ -)
Indonesia	132.3+10.4	172.0+15.6 (130+150)	232.5+2.8 (176+27)	246.8+8.4 (186+81)	236.5+5.0 (179+48)
Bangladesh	266.0+8.8	236.8+6.6 (89+75)	235.8+4.5 (89+51)	233.1+5.8 (88+66)	260.0+8.3 (98+94)
Asia Developing	126.2+3.5	136.1+3.0 (108+86)	151.4+2.3 (120+64)	153.4+3.1 (121+86)	145.9+3.4 (116+96)
Japan	172.0+0.0	137.5+0.0 (80+ -)	111.1+0.0 (65+ -)	98.3+0.0 (57+ -)	84.1+0.0 (49+ -)
World	78.4+2.9	85.9+2.9 (110+103)	95.5+3.1 (122+107)	98.0+3.9 (125+134)	94.1+4.3 (120+149)

＊figures in parenthesis are relative percentages when 1961-1970 adjust to 100, **Paddy import in Nigeria, 1971-1980 adjust to 100

Per capita paddy consumption (FAOSTAT 2004, Ito 2005, USDA PS & D View 2004) Unit: kg

Year	1961-1970	1971-1980	1981-1990	1991-2000	2001-2003
Ghana	14	14 (101)	11 (82)	23 (167)	38 (278)
Nigeria	9	15 (171)	30 (329)	37 (412)	48 (530)
West Africa	28	33 (118)	41 (145)	44 (159)	56 (201)
Africa South of Sahara (SSA)	21	24 (112)	27 (126)	27 (129)	32 (153)
Thailand	292	288 (98)	253 (87)	230 (79)	234 (80)
Indonesia	161	195 (121)	248 (154)	260 (162)	257 (160)
Bangladesh	282	248 (88)	247 (88)	248 (88)	279 (99)
Asia Developing	129	139 (108)	151 (117)	155 (120)	154 (119)
Japan	181	149 (82)	128 (71)	113 (63)	104 (58)
World	81	89 (110)	97 (120)	100 (124)	101 (125)

＊figures in parenthesis are relative percentages when 1961-1970 adjust to 100

Paddy yield (FAOSTAT 2004) Unit: kg/ha

Year	1961-1970	1971-1980	1981-1990	1991-2000	2001-2003
Ghana	1,114	915 (82)	1,109 (100)	1,866 (168)	2,135 (192)
Nigeria	1,255	1,690 (135)	2,080 (166)	1,686 (134)	1,094 (87)
West Africa	1,074	1,209 (113)	1,469 (137)	1,665 (155)	1,348 (126)
Africa South of Sahara (SSA)	1,294	1,357 (105)	1,508 (117)	1,646 (127)	1,482 (115)
Thailand	1,811	1,845 (102)	2,026 (112)	2,366 (131)	2,561 (141)
Indonesia	1,910	2,745 (144)	3,961 (207)	4,346 (227)	4,465 (234)
Bangladesh	1,685	1,813 (108)	2,234 (133)	2,839 (169)	3,418 (203)
Asia Developing	2,016	2,478 (123)	3,250 (161)	3,779 (187)	3,928 (195)
Japan	5,280	5,811 (110)	6,055 (115)	6,212 (118)	6,356 (120)
World	2,106	2,516 (119)	3,221 (153)	3,738 (178)	3,880 (184)

＊figures in parenthesis are relative percentages when 1961-1970 adjust to 100

Based on the data of FAOSTAT (2006), Ito (2005), and USDA PS & D View (2005), rice production and importation trends were reviewed in the world, Japan, tropical Asia, Bangladesh, Indonesia, Thailand, Sub Sahara Africa, West Africa, Nigeria and Ghana during 1961 to 2003(Table 1, Fig 3 and 4). In those tables and figures, the conversion ratio between paddy and milled rice was used 1:0.65. Some Asian countries, especially Japan, decreased per capita rice production and consumption during the same period because of their change on dietary taste from rice to diverse cereals.

According to Ito (2005) and FAOSTAT (2006), relative percentages of Japanese rice, wheat and maize consumptions were 65, 23 and 12% respectively in 1961. In 2003 these percentages were changed to 29, 19, and 52% respectively, in which maize was used mainly for animal feed. Although per capita rice production in Thailand kept constant, 400kg in paddy, per capita paddy consumptions decreased 292kg in 1960s to 234kg in 2003, the amount of rice export increased 1.3 to 5.8million tons during the same period. Bangladesh showed slightly decreasing trend in per capita rice production. As a result because of population increase, Bangladesh had to import 1.5million tons of milled rice and 1million tons of wheat in recent years. On the contrary although per capita paddy production in Indonesia increased 120 to 235kg, the consumption also increased 145 to 250, the amounts of annual milled rice importation were increased 1million in 1960s to 3-6mllion tons in 1997-2000 (Ito 2005). Indonesia imported the highest amount of rice in the world in 1997. During 1961 and 2003, per capita paddy production and consumptions also increased 130 to 154kg in Asia developing and 81 to 101kg in the world.

As shown in the Tables 1, during 1961 and 2003, the most dramatic increases of paddy production, consumption and importation were appeared in Ghana, Nigeria, and West Africa. During the same period, although per capita paddy production increased 5.5 to 14kg in Ghana, 6 to 30kg in Nigeria, 20 to 30kg in West Africa, and 17 to 19 kg in Sub Sahara Africa, since per capita paddy consumption also increased 14 to 38 in Ghana, 9 to48 in Nigeria, 26 to 56 in West Africa, and 21 to 32 kg in Sub Sahara Africa, the importation of rice, paddy equivalent, increased 0.05 to 0.3 in Ghana, trace to 1.5 in Nigeria, 0.5 to 4.5 in West Africa and 0.7 to 6.5million tons in Sub Sahara Africa.

Production trend (kg/person) of diversified African crops in comparison with Asia

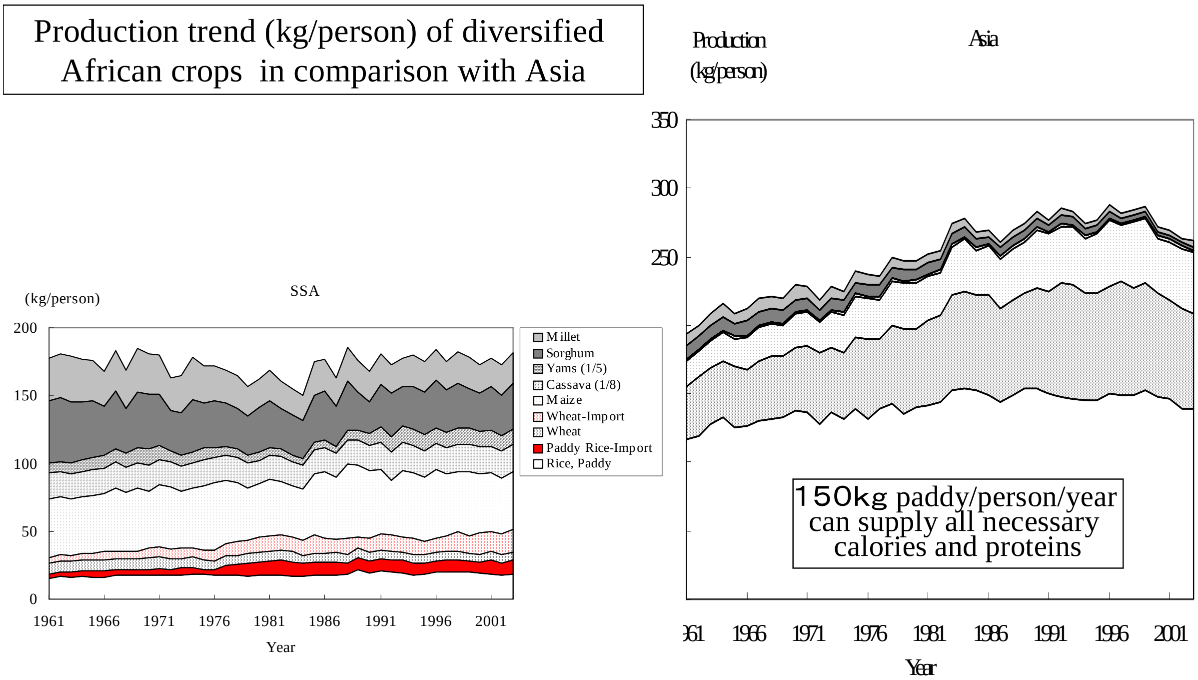


Fig.3 African crops are diverse, even production potential of rice is higher than demand, rice is importing. Wheat has not enough production Potential in majority of SSA countries. Rice is also the highest quality cereals in terms of egg protein equivalent among the other 6 crops

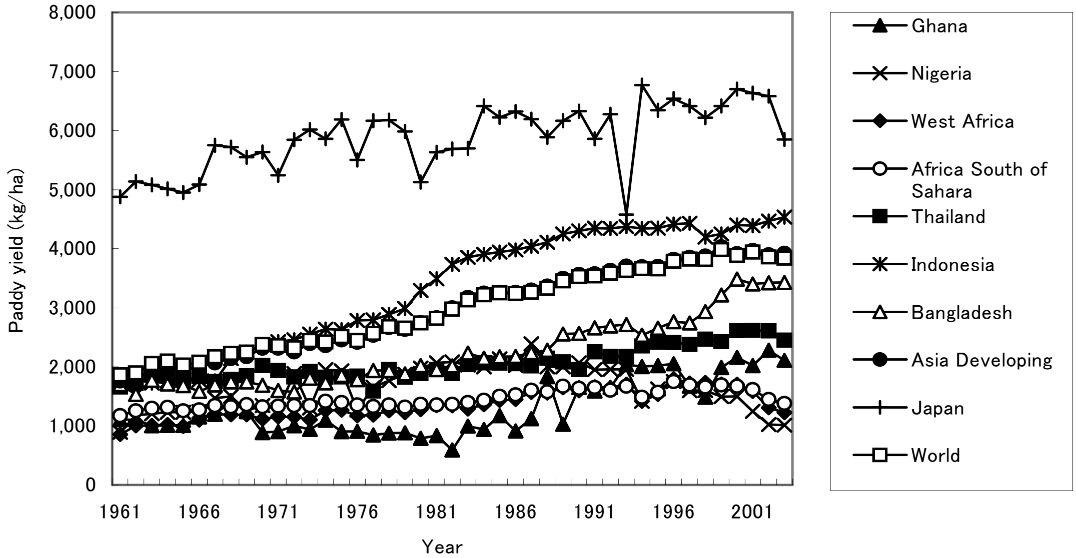


Fig. 4 Paddy yield (FAOSTAT 2006)

Figs 3 and 4 show per capita major food crops production trends comparatively in Sub Sahara, West Africa and developing countries of Asia (FAOSTAT 2006). Since the nutritional values of cassava and yam are quite low in terms of protein and mineral contents (Kiple and Ornelas 2000, Sanchez 1976), cereal equivalents of cassava and yam were calculated by dividing 8 and 5 respectively in those figures. Clear contrast is divers food crops consumption in Sub Sahara Africa and rice domination in Asia developing. The most important contrast is, however, the decreasing trend in Sub Sahara Africa while increasing trend in Asia developing. In 1960s per capita cereals production was about the same 150 kg both in Asia developing and Sub Sahara Africa, but less than 150 kg in Sub Sahara Africa and more than 200kg in Asia developing in 2000s. Although Sorghum and millet showed decreasing trend in the regions, West Africa showed somewhat more positive trends than whole Sub Sahara Africa, especially after 1990s. Both per capita maize and rice production showed clear increase in West Africa, mainly through the contribution by Ghana and Nigeria.

The historical trends of paddy yields were shown in Fig. 5. In Japanese rice history there were four major technological innovation stages to increase rice yield. The first step was the development of small-scale irrigated sawah systems, Jouri and other systems in Japanese, during 7 to 16s centuries. The second stage was the development of large-scale irrigated sawah systems based on the development of civil engineering technologies during 16 to 19 centuries. These technologies were developed and derived from technologies for fighting during the Warring State Period, Sengoku Jidai during 1467 to 1616. Paddy yield up to 2.5t/ha can be reached by these irrigated sawah systems (Tabuchi and Hasegawa 1995). The third step was based on the integration between scientific breeding and farmers varietal selection coupling with newly introduced fertilizer technologies originated from Europe and USA. The integration of technical innovations and introduction was accelerated since Meizi Restoration in 1868. Japanese farmers bred and selected varieties with semi-dwarf gene both in rice and wheat. The semi-dwarf gene, named sd1, is known common in all high yielding varieties, HYV, in rice, wheat and maize (Sakamoto et al 2004). The sd1 gene in semi-dwarf wheat, Nourin 10, was bred by Dr. Gonjiro Inazuka, which was collected at 1946 by Dr. S.C. Salmon, technical advisor of US army of Japanese occupation (Peitz and Salmon 1968). The Nourin 10 was the gene source for the Green Revolution initiated by Dr. Norman Borlaug.

The fourth stage was structural reform, reclamation and land consolidation of sawah systems for mechanization as well as lowland rice and upland crop rotations (Takase 2003).

As shown in Fig.4, using the green revolution technology, majority of Asian countries, except for Thailand, increased rice yield rapidly since. These increases are started during 1960-80s and still ongoing. These recent yield increases in Asian countries can be compared to the achievement in Japanese rice history last 500 years as shown in Fig.7. We have to examine this kind of very rapid yield increases are sustainable or not in long-term. As seen in Fig.5, the rapid yield increase started at Stage 3, 1880, in Japan and although very gradual the increasing trend is still continuing during 1960-2003 in Japan as seen in Fig.4, we may foresee some more yield increase continues in Asia developing in future. Yield stagnation and decline in IRRI's rice field reported recently have to make clear (Olk et al 2004). Thailand shows very stable but gradual increase of rice yield. On the other hand, Sub Sahara Africa, West Africa, and Nigeria have no clear trend of yield increase during the last 40 years. Although Ghana showed some indication of yield increase, green revolution technologies have not yet reach to this region.

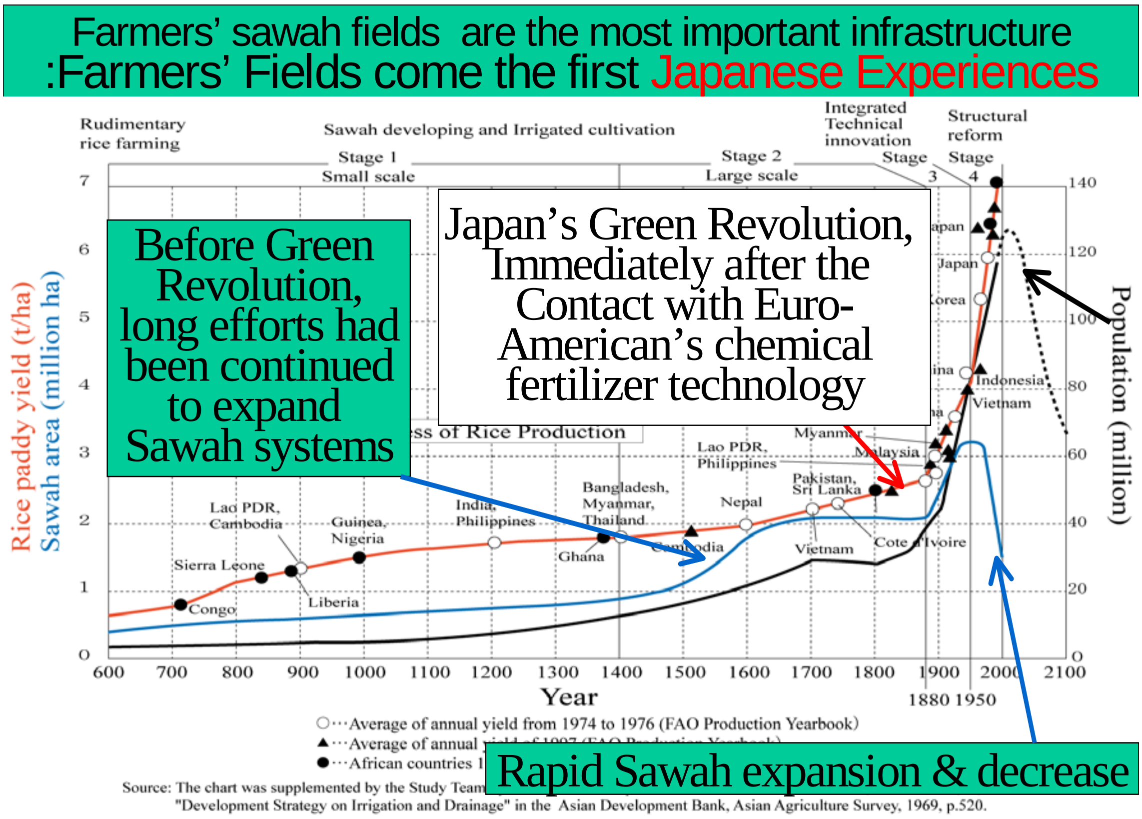


Fig. 5. Population, Rice yields & Sawah area of historical path in Japan in comparison with Asia & Africa Takase & Kano,1969, modified

4. Long Term Soil fertility change after the green revolution in Bangladesh and Indonesia

Table 2 shows regional soil fertility data as well as some historical changes of soil fertility of lowland rice soils in West Africa, tropical Asia, Japan, and some Mediterranean countries. These fertility evaluations were made based on the extensive soils samplings to reach general characteristics in each country or region (Buri et al 1999, 2000, Issaka et al

11996, 1997, Kyuma 2004, Hirose and Wakatsuki 2002, Obara and Nakai 2003, 2004, Mohsin et al 1997a, 1997b, 1998, 2003a, 2003b, Darmawan 2006).

As seen in the Table 2, rice soil fertility in Japan is in good condition and has no indication of decline in terms of soil organic matter status, exchangeable potassium and other bases, and available phosphorous. However, Japanese rice faming is under crises. Total areas of Sawah for rice cultivation decreased 3.4 to 1.7million ha during the last 40years. Because of ample food importation there are no short-term food crises in Japan. The most serious problems related to the decline rice cultivation are related the loss of multi-functionalities of sawah systems, such as (1) water and soil pollution, (2) landscape deterioration, especially in rural watersheds, Sato-Yama in Japanese, and (3) the deterioration of traditional Japanese community. Controlled release fertilizer (Saigusa 2004) is the promising technology to reduce nitrate pollution. Although cadmium contamination of Japanese sawah soils can be restore by new remediation technology (Ishikawa 2004), general imbalance of nutrients in many watersheds in Japan, deficient of Si to N and P in irrigation water, river, lake, and sea, is now basic ecological problems. Hydrological changes by dam constructions and eutrophication during 1960-2000 may be major reason such imbalance of Si to N and P (Harashima 2003).

Table 2 Regional and some historical changes of soil fertility of lowland rice soils in West Africa, Tropical Asia, Japan and Mediterrenian countries

Location	pH	Total C (%)	Total N (%)	Available Si (ppm)	Available P (ppm) *	Exchangeable Cation (cmol/kg)					Sand (%)	Clay (%)	CEC /Clay
						Ca	K	Na	Mg	eCEC			
IVS-WA 1980s (1)	5.3	1.3	0.11	-	9	1.9	0.3	0.2	0.9	4.2	60	17	25
FLPWA 1980s (1)	5.4	1.1	0.10	-	7	5.6	0.5	0.8	2.7	10.3	48	29	36
T. Asia 1970s (2)	5.6	2.1	0.17	111	13	10.4	0.4	1.5	5.5	17.8	23	41	43
Japan1970s (2)	5.4	3.3	0.29	91	57	9.3	0.4	0.4	2.8	12.9	49	21	61
Japan1979 (3)	5.7	2.5	0.22	--	11**	8.7	0.5	---	2.4	---	--	--	--
Japan1997 (3)	5.6	2.3	0.21	--	14**	8.9	0.6	---	2.2	---	--	--	--
Thailand 1970s(2)	5.2	1.1	0.09	57	6	7.2	0.3	1.4	4.3	13.2	38	37	36
Bangladesh 1967(2,4)	6.1	1.2	0.13	60	17	7.8	0.3	0.9	2.7	12.1	28	30	40
Bangladesh 1995(4)	5.9	1.1	0.09	---	15	6.9	0.2	0.9	2.5	11.1	---	---	---
Indonesia 1970(2)	6.6	1.4	0.13	294	11	17.8	0.4	1.5	6.3	26.0	23	51	51
Indonesia 2000s(5)	5.6	1.6	0.16	241	19	21.3	0.2	0.5	7.1	29.1	---	---	---
Mediterinian 1970s(2, 6)	6.8	1.8	0.16	112	32	15.9	0.6	1.0	4.6	22.1	---	---	---

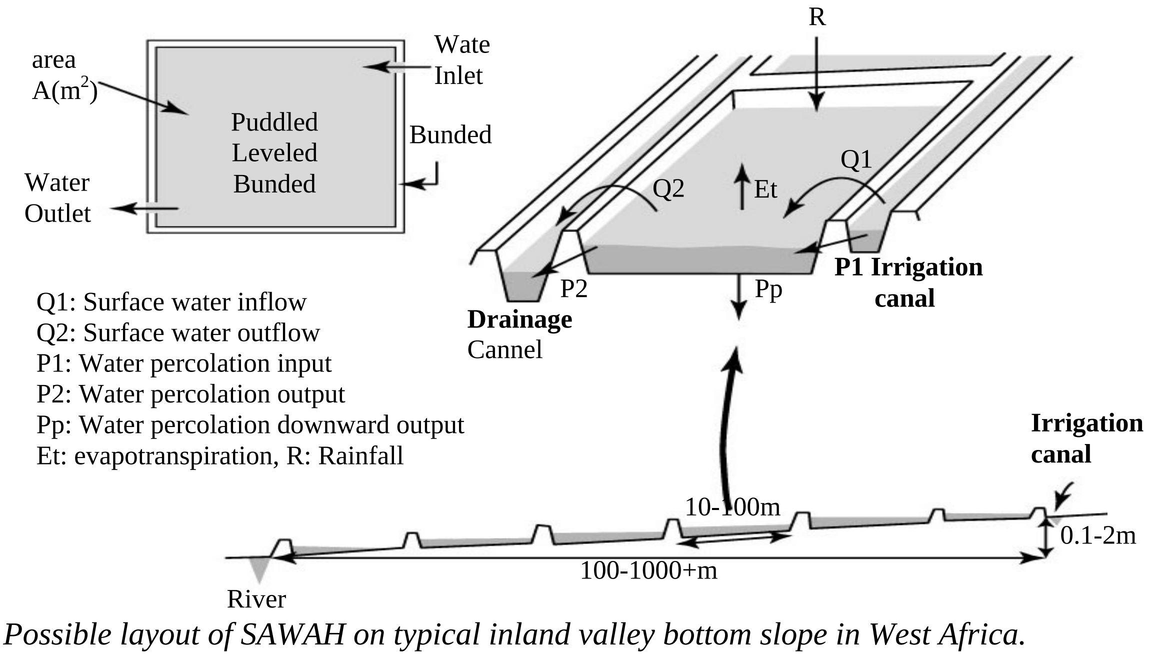
* Bray 2, **Truog, (1) IVS-WA, means of 185 sites of Inland valley soils, FLP-WA, means of 62 sites of flood plain soils in West Africa by Hirose and Wakatsuki 2002, (2) means of 529 sites of lowland rice soils in tropical Asian countries by Kyuma 2004, (3) means of 8706 sites of lowland rice soils in Japan collected at the same sites in both 1979 and 1997 by Obara and Nakai 2003, Nakai and Obara 2004, (4) means of 53 sites of lowland rice soils collected at the same sites in both 1967 and 1995 by Mohsin et al 1997a, 1997b, 1998, (5) means of 46 sites collected at the same sites in both 1970 and 2003 by Darmawan 2006, (6) means of 62 sites of lowland rice soils in 1973 from Portugal, Spain and Italy by Kyuma 2004

Indonesian rice soil fertility may be one of the highest in Asia developing. Although rice yield increased dramatically last 20 years by green revolution (Fig.4), there are no indication of decline of soil fertility as seen in Table 5(Kyuma 200 and Darmawn 2004). Phosphorus fertilizer increased available phosphorous level considerably. However long term soil fertility monitoring will be important to sustain multi-functionality of beautiful sawah based rice cultivation in Java(Indonesian Soil Research Institute 2004). Rice yield of Bangladesh increased last ten years followed by Indonesia as seen in Fig.4. Although soil fertility decline is not clear, organic matter contents and base status showed some indication of decline. Arsenic pollution due to heavy utilization of ground water and possible relation to nitrogen fertilizer is very serious problem under expanding (Ahmed et al 2004). At the moment rice soil contamination is not so clear (Mohsin 2003 a and b).

Although soil fertility of Thailand is not so high, especially available phosphorous was low in 1970s as seen in Table 2. However as seen in the case of Indonesia, phosphorous fertilization might increase the available phosphorous level, as seen the steady increase of rice yield. Thailand has diverse rice farming systems in terms of irrigation and soil fertility management (Tabuchi and Hasegwa 1995). Since agroecology of north-eastern Thailand, so called Isan region, has quite similar agro-ecology settings in majority of West Africa, experiences in sawah development and rice farming in the Isan area will be very useful for the sustainable development sawah based rice farming in West Africa which as the most sever agroecology for rice cultivation in terms of soil fertility and hydrological condition. However the benefit by geological fertilization and multi-functionality of the sawah system can overcome these constrains in West Africa. Asian African collaboration with the interfaces of Europe and USA for sustainable sawah development will be key (Hirose and Wakatsuki 2002).

5. Watershed Agroforestry for sustainable intensive rice based farming system and the restoration of degraded environment

5-1 What is "sawah" or paddy systems?



Possible layout of SAWAH on typical inland valley bottom slope in West Africa.

Fig. 6. What is a sawah? A sawah is a leveled, bunded and puddled rice field with inlets and outlets to control water.

New Concept of Sawah Ecotechnology for Green Revolution

For the sustainable increase of rice yield and production, sufficient areas of sustainable sawah fields (Fig.6), leveled, bunded, and puddle fields have to be developed. The sawah development should be viable for diverse lowland ecologies and soci-economic, especially land ownership conditions in tropical Asia and SSA. Apart from the conventional and costly expansion of irrigated area, the way for rapid expansion of ecotechnology based low cost and self-support sawah fields have to be researched and developed in the rainfed lowland, especially in inland valleys, in case of SSA (Wakatsuki et al 1998, 2005, Hirose and Wakatsuki 2002). Taiwan team has played a pioneering role in technical cooperation for sawah based rice cultivation in Africa during 1965 to 1975. However as this technical cooperation only continued fro some 10 years, confusion and stagnation occurred in the 1980s (Buddenhagen, I.W. and Persley, G.J. 1978 and IITA 1989/1990).

Although the development of irrigation schemes, large and small, is ongoing steadily even not rapidly, the most impressive efforts observed by the author in the past 20 years were that inland valley development for improving water conditions of the rice-growing environment through bunding and leveling, which are rapidly ongoing in West Africa despite scarce funding (Table 3). This is thanks to the efforts of these countries and based mainly farmers's self-support efforts. Decreasing trend of rainfall in recent years might enforce farmers to shift partly from upland to lowland. Various donor countries and WARDA's inland valley consortium (IVC) also contributed to encourage these developments. A USD$ 23 million inland valley rice development project based on the sawah approach in Ghana, which is financed by African Development Bank, is a good example (Wakatsuki et al 2001, Hirose and Wakatsuki 2002).

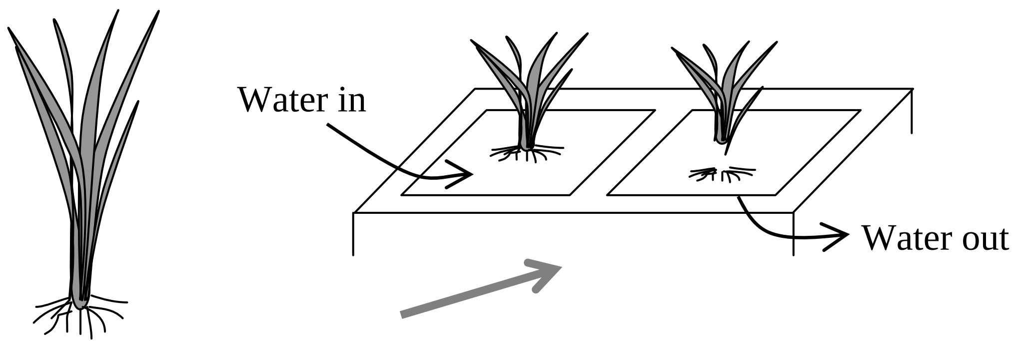
Table 3. Estimation of rice production trend by rice ecology in West Africa during 1984-1999/2003 and 2015 estimation by the author (JICA 2003, WARDA 1988, 2002, 2004, FAOSTAT 2006)

	Area (million ha)			Production (million ton/y)			Yield (t/ha)		
	1984	1999/03	2015	1984	1999/03	2015	1984	1999/03	2015
Upland	1.5	1.8	2.0	1.5	1.8	2.0	1.0	1.0	1.0
Contribution (%)	57%	40%	30%	42%	23%	13%	No yield increase		
Rainfed lowland	0.53	1.8	3.0	0.75	3.4	7.0	1.4	2.0	2.4
Irrigated lowland	0.23	0.56	0.80	0.64	1.9	3.0	2.8	3.4	3.8
Total	2.6	4.7	6.0	3.4	7.7	14	1.3	1.6	2.4

These lowland development activities are called "intensified lowland", "partial water control", just "lowland development", "amenagement or System du Chinois after the activities by Taiwan team" in French, or "contour bund system". These are all covered by the "sawah concept and sawah technology and development" (Wakatsuki et al 1998). Rice farmers, West African countries themselves, and donor countries have accelerated the trend towards various sawah based rice cultivation with various levels of soil and water management technologies even well not defined clearly. SSA and still some areas of Asian countries needs eco-technologies that can improve farmers' rice fields similar to the biotechnologies that can improve rice varieties (Fig. 7, Table 4: Ofori et al 2005). What critical now for the green revolution in SSA is the eco-technology rather than biotechnology. Rice growing ecologies are extremely diverse in West Africa, SSA and some areas of Asian countries (Fig.8, JICA 2003, WARDA 2004). The appropriate bund layout, bunding and leveling quality, and size and shapes of sawah as well as appropriate site selection are different depending on the characteristics of targeted valley bottom nature of inland valleys and on the targeting farming systems Because of obvious benefits of geological fertilizations as described later, lowland is the priority target for sawah development. Water harvesting and various simple irrigation technologies have to be integrated with the various sawah development in diverse valley bottom characteristics (Fig.9). Small machinery, such as power tiller, has to be examined to accelerate the sawah development (Fashola et. al 2006). Tropical Asian experiments and collaboration for sawah development and for animal traction and power tiller operation for sawah based rice farming will be very useful (Hsieh 2003). growing environment, i.e., lowland paddy fields, the author proposes to use the term "Sawah" in SSA (Wakatsuki et al 1998).

Biotechnology and Ecotechnology

Rice variety and Rice with Sawah Systems



Sawah is a man-made, improved rice-growing environment with demarcated, bunded, leveled, and puddled fields, <u>for water control. Sawah is soil based eco-technology</u>

Varieties could solve the main problems in Asia Is this also applicable to SSA?

Because of diverse soil, geology, topography, hydrology, climate, vegetation and socio-cultural conditions, the technologies for sawah development and management are very diverse. Therefore we have to research and develop the technology to accommodate in diverse SSA ecology.

Fig. 7. Rice (variety) and environment (Sawah) improvement Both Bio & Eco-technologies must be developed in balance

The concept and the term "sawah" refers to man-made improved rice fields with demarcated, leveled, bunded and puddle rice fields with water inlet and water outlet, which, if possible, can be connecting various irrigation facilities, such as irrigation canals, pond, spring, pump, water harvesting, and flooded sawah etc (Fig.9). Rainfed sawahs without any irrigation facilities are also far better than rainfed fields for rice growth and of cause for rice green revolution. Drainage facilities are also useful. The term “sawah” originates from Malayo-Indonesian. The English and French terms, Paddy or Paddi, also originated from the Malyo-Indonesian term, Padi, which means rice plant. In order to avoid confusion between upland paddy fields and man-made leveled, bunded and puddle rice fields, i.e., typically irrigated rice

Table 3. Mean gain yield of 23 rice cultivars in low land ecologies at low (LIL) and high input levels (HIL), Ashanti, Ghana (Ofori et al 2005)

Entry No. Cultivar			ECOTECHNOLOGICAL YIELD IMPROVEMENT					
			Irrigated Sawah		Rainfed sawah		Upland like fields	
			HIL	LIL	HIL	LIL	HIL	LIL
			(t/ha)		(t/ha)		(t/ha)	
BIOTECHNOLOGICAL	1	WAB	4.6	2.9	2.8	1.6	2.1	0.6
	2	EMOK	4.0	2.8	2.9	1.3	1.4	0.5
	3	PSBRC34	7.7	3.5	3.0	2.1	2.0	0.4
	4	PSBRC54	8.0	3.7	3.8	2.1	1.7	0.4
	5	PSBRC66	5.7	3.3	3.8	2.0	1.8	0.4
	6	BOAK189	7.0	3.8	3.7	2.0	1.4	0.3
	7	WITA 8	7.8	4.2	4.4	2.1	1.8	0.5
	8	Tox3108	7.1	4.1	4.0	2.3	2.3	0.6
	9	IR5558	7.9	4.0	3.8	2.0	1.8	0.5
	10	IR58088	7.7	4.0	3.7	1.8	1.4	0.3
	11	IR54742	7.7	4.3	4.0	2.2	1.9	0.4
	12	C123CU	6.9	4.1	4.2	1.9	2.0	0.4
	13	CT9737	6.5	4.0	4.0	1.7	1.9	0.6
	14	CT8003	7.3	3.8	3.8	1.7	2.0	0.5
	15	CT9737-P	8.2	4.0	4.3	1.8	1.2	0.5
	16	WITA1	7.6	3.6	3.3	1.8	0.9	0.3
	17	WITA3	7.6	3.5	4.1	2.0	1.3	0.5
	18	WITA4	8.0	4.1	3.7	2.1	1.5	0.3
	19	WITA6	8.0	3.5	4.0	2.3	1.4	0.3
	20	WITA7	7.3	3.7	3.8	2.2	2.0	0.4
	21	WITA9	7.6	4.4	4.5	2.8	2.0	0.6
	22	WITA12	7.6	4.0	3.8	1.9	1.8	0.4
	23	GK88	7.5	3.8	3.5	2.0	1.8	0.5
Mean (n=23)			7.2	3.8	3.8	2.0	1.7	0.4
Range			(4.0-8.2)	(2.8-4.4)	(2.8-4.5)	(1.3-2.8)	(0.9-2.3)	(0.3-0.6)
SD			1.51	0.81	0.81	0.45	0.44	0.12

Because of cost of green revolution technology, yield must be higher than 4t/ha

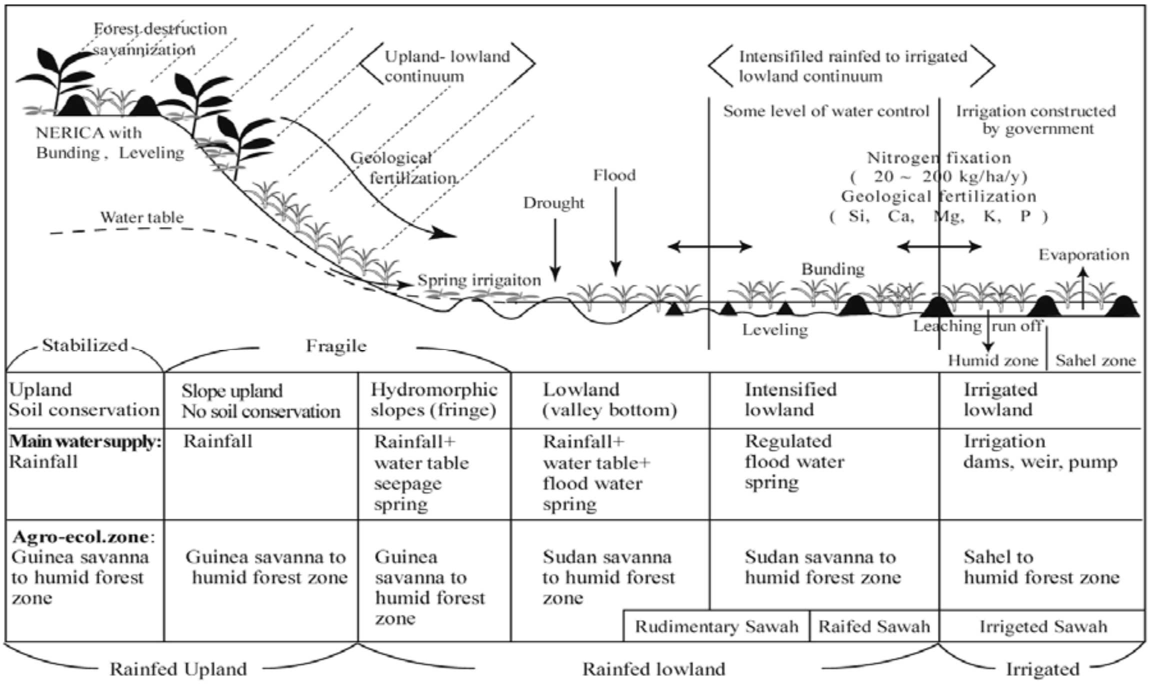
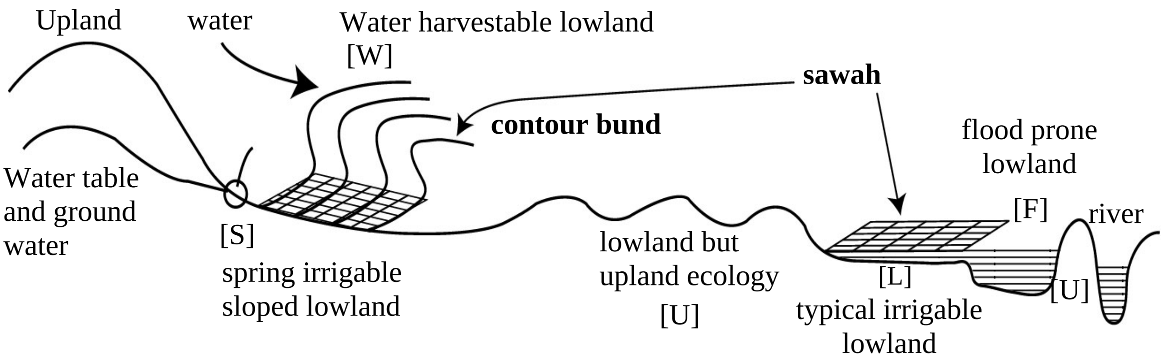


Fig. 8. Rice ecologies along upland-lowland continuum in West Africa (JICA 2003, WARDA 2004)



Irrigation options: Sawah to sawah/ contour bund water harvesting, spring, dyke,
river, point, peripheral canal
Interceptor canal, tank, pump

Lowland sawah development priority
[S] > [L] > [F] > [W] > [U]

Fig. 9. Strategy fro sawah and irrigation development: Various sawah (bunded, leveled, puddled rice land) development with various Irrigation Options depending on the Characteristics of Valley Bottom Diversity in each agroecological zone.

5-2 Sawah hypothesis(I) for successful green revolution

On December 26, 2004, the concept of and the term “TSUNAMI” were lacking in the vocabulary of people in Indian Ocean locations such as Sumatra, Indonesia, Sri Lanka, India and Thailand. This seriously exaggerated the tsunami disaster. The lack of the concept and appropriate technical term for improving the rice growth environment, such as “sawah” creates confusion in the research and sustainable development of rice cultivation in West Africa. As seen from the success of NERICA, a clear concept and key technical term are very important for integrated genetic and natural resource management (IGNRM). Unlike in Asian rice farmers’ fields, Sub Sahara African farmers’ fields, and therefore the farming technologies, are not ready to accept various IGNRM technologies, such as irrigation, fertilizers, integrated pest management IIPM), and high yielding varieties (HYV). Rice farmers’ field demarcation based on topography, hydrology and soil is the starting point for scientific observation, technology generation and application (Fig.10). Although we has been discussed researches and developments on irrigation, fertilizers and HYV for the last thirty years, the discussions have not touched on whether the prerequisite conditions are lacking in SSA. The concept and technologies of Sawah is such an example. Simply speaking the basic infrastructures for the green revolution, such as sawahs, are lacking (Fig. 6, 7, 9). Irrigation without farmers’ sawah farming technologies has proved inefficient or even damaging because of accelerated erosion and waste of water resources. In the absence of water control, fertilizers cannot be used efficiently. Consequently, the high yielding varieties perform poorly and soil fertility cannot be sustained hence the green revolution could not take place (Sawah hypothesis I).

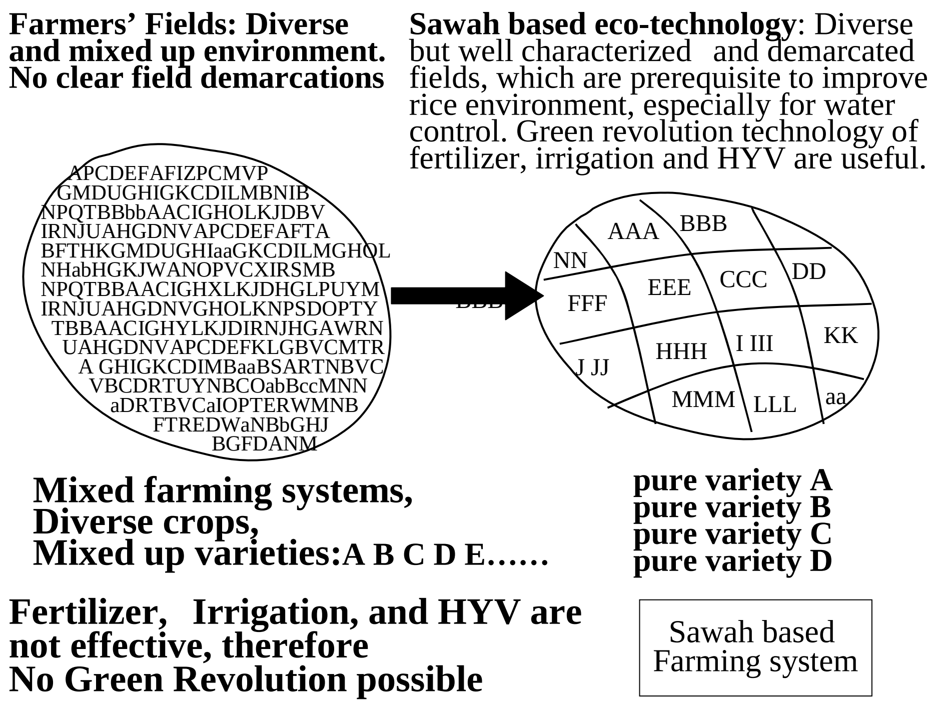


Fig. 10. Successful Integrated Genetic and Natural Resource Management (IGNRM) Needs Classified Demarcated Land Eco-technologically

Historical and Geographical Consideration for Sawah Development

Undoubtedly natural environmental conditions, such as hot temperature and enough water during rice growing season and lowland soil sedimentation are the important factors for sustainable development of sawah system. As seen in Fig. 11 (Walling 1983), soil erosion and hence lowland soil formation in West Africa are very low in comparison with Asian watersheds. High rates of soil erosion and lowland sawah soil formation can be compensated by high rate of soil formation in Asia because of active geological formation and ample monsoon rainfall. Paradoxically, extreme diversity of lowland in West Africa (Fig. 8) may relate to the low rate of soil erosion and weak lowland soil formation.

Apart from the above natural geographical reasons, the background of the cause of lack of the prerequisite for the green revolution can be found in the tragedies many years ago. The slave trade by European countries for as long as 400 years, 16th to 19th centuries, destroyed African communities. Young Africans had to work for the nation building of the new worlds not for SSA. Subsequent colonization continued for additional 150 years until 1960. These are probably the main reasons why the basic nation building is still stagnating and farmers' fields are lacking basic infrastructures for the green revolution in SSA (Wakatsuki 2002).

As shown in Fig. 8, before green revolution, there were long continued efforts to expand lowland sawah systems in the history of Japanese rice cultivation. The Fig.5 shows the trends of rice yields, sawah area, and population of historical path in Japan in comparison with rice yields in major Asian and African countries. Because of farmers' sawah fields had been developed and sawah based technology were traditional beforehand, Japan's green revolution was realized immediately after the introduction of Euro-American's fertilizer technology at the end of 19th century. The green revolution in turn encouraged the rapid expansion of sawah area more than one million ha within 50 years at the population of less than 60 million (Fig.5). Although after world war the II, because of the expansion of the economy and industrialization the sawah area had decreased rapidly, more than 1.5 million ha within 40 years, 1960 to 2000. The Japanese population is estimated to decrease almost 50% during 21st century. These are the crises in current Japan and near future.

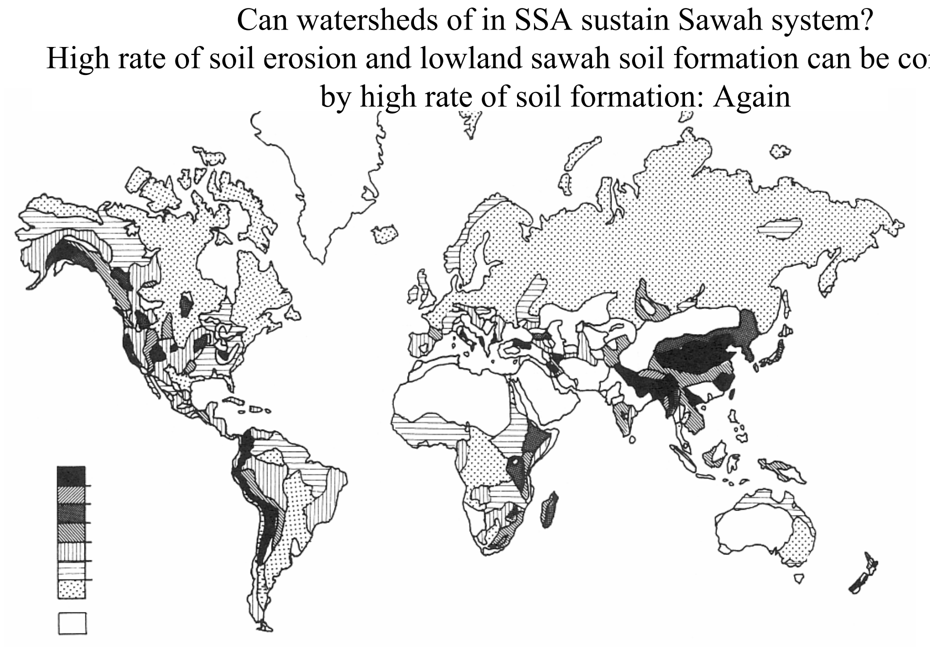


Fig. 11. Rates of Soil Erosion in the Worlds (Walling 1983)

Balanced Approach between Biotechnology and Ecotecnology

The technologies of genetic improvement of rice (variety) and the rice growing environment (sawah) must be researched and developed in good balance for IGNRM (Fig. 12). For efficient uses of fertilizers and irrigation water, rice farmers' fields have to be demarcated based on topography, hydrology and soils (Fig. 9 and 10). The sawah system development and management are the technologies that should transfer to farmers. Since bunding, leveling and puddling need very hard and skilled works as well as obvious additional benefits of geological fertilization, rainfed lowland will be the primary target for sawah development (Fig. 8 and 9). The ecology of the majority of rice farmers' fields is extremely diverse in naturally and farming systematically, therefore even the good quality of pure seeds cannot be evaluated properly (Fig.10). Sawah is also a means by which such ecologically diversified rice fields bringing into relatively homogenous and classified fields to evaluate appropriate variety. The successful IGNRM needs classified demarcated lands such as sawahs. The technology of rice variety improvement and dissemination has a clear concept and target such as high yield, pest, draught and poor nutrient tolerant, and high eating quality varieties. The remarkable achievement of the breeding program at WARDA is clear. However there were no such clear concepts and targets in the researches of natural resource management in West Africa. The missing link for the green revolution is a sawah concept and technology targeting the expansion of high quality but with low cost. The basic infrastructure for the green revolution is bunded, leveled, and puddled fields with good layout of terraced sawahs in watersheds (Fig.6-10). If sawah systems are successfully introduced to farmers' rice fields, the integrated genetic and natural resources management (IGNRM) technology generations to deal with water, soil, and fertilizer management, low P availability problem, weed and striga management, IPM, control of CH_4 emission and carbon sequestration, animal traction and small machinery operation, fish and rice, vegetable after rice, and so on, will have clear target fields to apply and will therefore be accelerated (Fig.12). Sawah based farming can also encourage diversification of rice farming systems in SSA. Long term experiments on the effect of cropping system researches such as legume, biological nitrogen fertilizer (BNF) and organic manure will be possible. Iron toxicity has been often cited in West Africa that can be tackled only properly in sawah based IGNRM. Some pest and disease such as African rice gall midge (AfRGM) and rice yellow mottle virus (RYMV) problems may even be partly mitigated through enhancing the health growth of rice. Above all sawah systems supply the rice fields that can apply scientific technologies (Fig. 7 and 9).

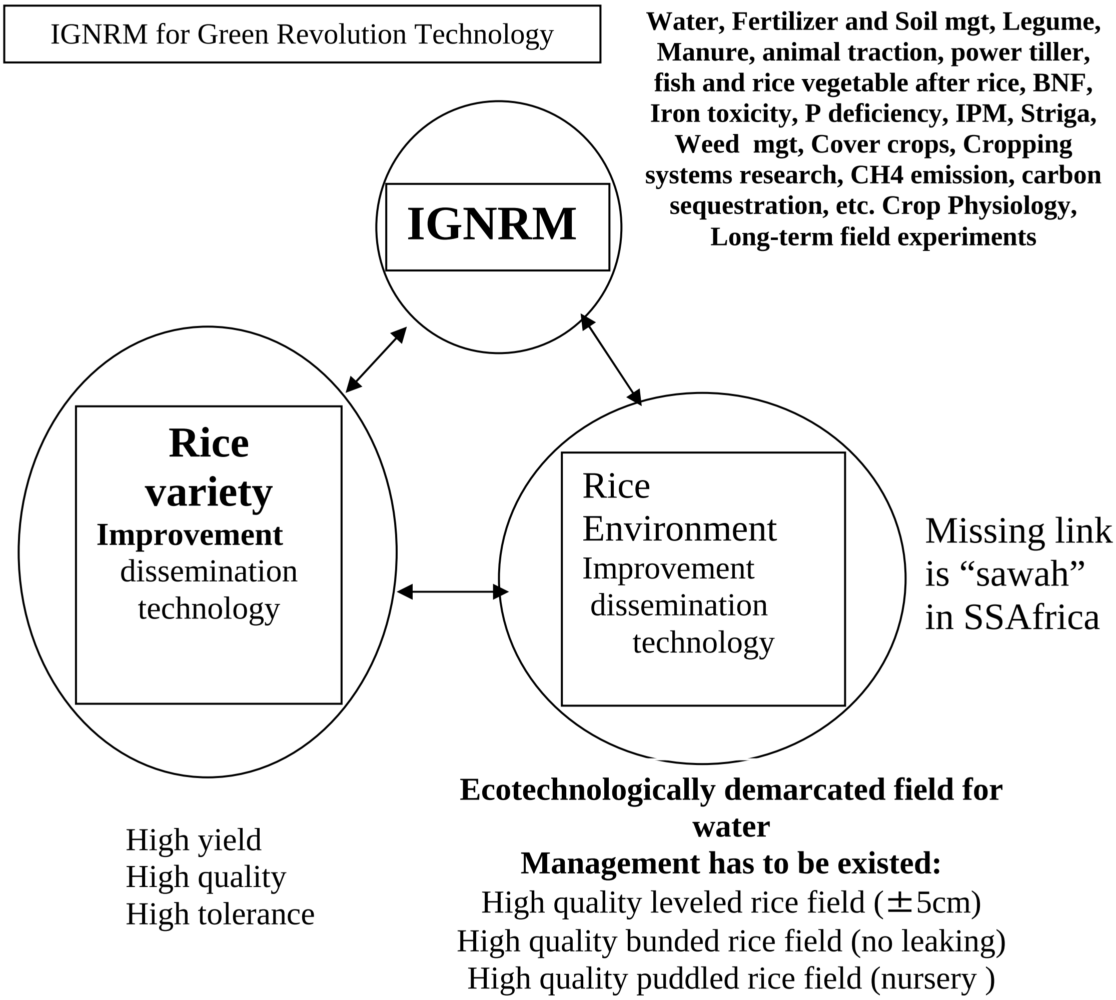


Fig. 12. Concept of Integrated Genetic and Natural Resources Management (IGNRM) for green revolution technology: Missing link is Sawah which is lacking in majority of famers' fields

5-3 Sawah hypothesis(II) for intensive sustainability

Sustainable yield of lowland system is very high. Although we know this through the long history and experiences (not experiments) of sawah based rice farming in Asia, there is no scientific quantitative confirmation yet. Lowland sawah can produce about 2t/ha without any chemical fertilizer application (Fig. 8). In addition lowland sawah based farming can crop rice continuously decades or more without any fallow. However sustainable upland slush and burn rice yield without fertilizer never exceed 1t/ha. I addition to the lower yield, the upland rice fields need a fallow period to restore soil fertility, such as two years of upland cultivation and eight years of fallow. This means 1 ha of sustainable upland rice cultivation need 5 ha of additional land. Therefore sustainable upland rice yield is actually not 1t/ha but 0.2t/ha. Therefore sustainable productivity of sawah based rice farming is about ten times higher than that of the upland slush and burn rice farming (Sawah Hypothesis II). This hypothesis II has to be examined quantitatively under SSA conditions. This is a reason why the upland rice cultivation destroys forest and degrades the land in SSA. Accordingly, the development of 1 ha of lowland sawah field enables the conservation or regeneration of 10 ha of forest area. Sawah fields can, therefore contribute to not only increase food production but also to conserve forest, which in turn enhances sustainability of an intensive lowland sawah systems. Furthermore, they can contribute to the alleviation of global warming problems through the fixation of carbon to forests and soils (Wakatsuki and Masunaga 2005).

5-4 Waterhsed Agroforestry and Multi-functional Wetlands of Sawah

Comparison of historical forest cover changes in Europe, USA and Japan

As Fig.13 shown, major forest covers in EU and USA disappeared by early 1900s. Forest cover of EU and USA were only 25% and 23% in 1995, respectively. The forest covers of UK, the Netherlands, and Spain are only 9.9%, 9.8%, and 16.8% respectively in 1995. Although Germany and France have more forest cover but have 30.7% and 27.5% respectively (World Resources 1998-2000). This is not so strange, since for European styles of upland farming their forests have long been natural enemy. Their farming needs to cut the forest to develop the agricultural land. Thus the globalization of the European Civilization and population explosion have been destroyed world forests (Darby 1956, Goudie 1981, Y. Yasuda 1996).

On the contrary, Japan's forest cover survived even after the period of major population explosion and industrialization. Japan's forest cover is still 67% even in 1998. These characteristics of Japanese civilization as a parts of Orient Civilization will be important for the contribution to solve the present global environmental issues (Umehara T. 1996). There are two reasons why Japan's forest covers are so high even now. (1) As we explained in this book, lowland sawah and rice based farming systems are not necessary consume upland forest. Carefully managed upland forests are rather useful for the lowland sawah because of water conservation and supply of fertile topsoil to lowland sawah (Sawah hypothesis and Geological fertilization theory in the subsections of 6-2 and 6-3 of this chapter). (2) Among the 25 million ha of Japanese forest, 11million ha of forests are afforested by the long continued efforts starting 17 centuries to 1970s. About 50% of Japanese forests are man made (C. Totman, 1989).

Afforestation is negligible, less than 1%, in Africa and South America. Although Asia has relatively wide area of afforestation, 10% of his forest land, still absolute area is very small comparing to their huge population. The per capita afforested area of Japan is 0.089ha, whereas Asia is only 0.013ha, about one seventh. Both West and whole Africa as well as South America have actually no man made forest, less than one percent. This is the very important fact that Japanese culture can contribute to solve the present global environmental problems. The motive of this paper is also depends partly on this historical consideration of Sawah and forest based Japanese culture which can contribute the food and environmental issues in Africa.

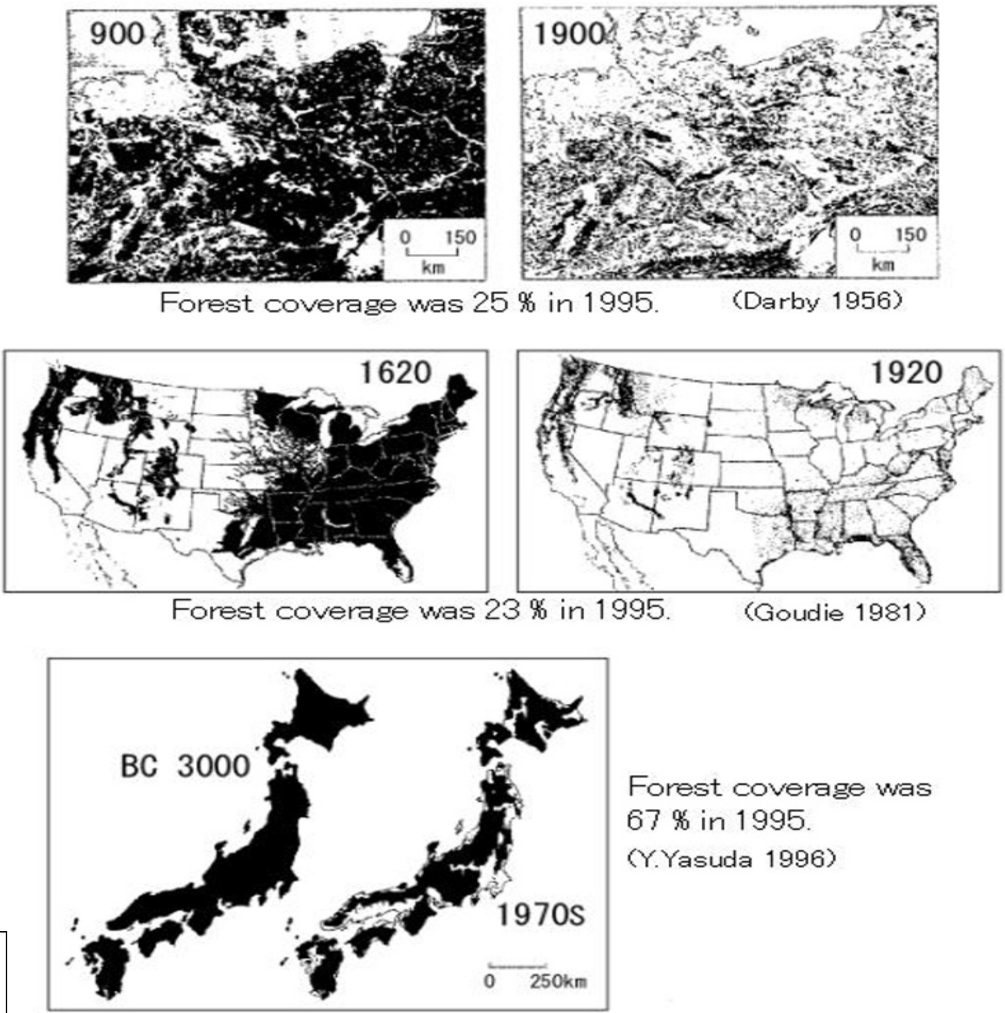


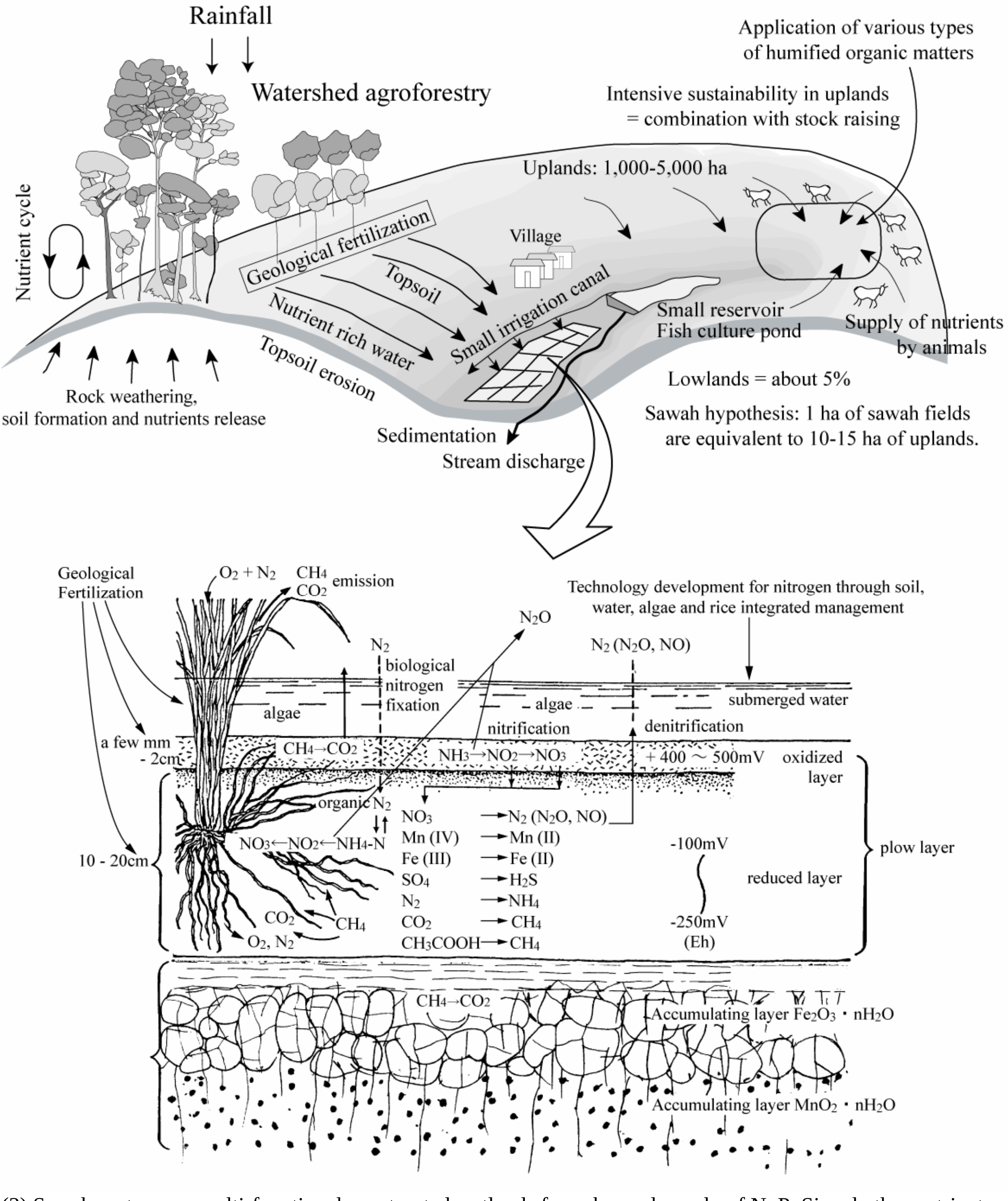
Fig.13 Historical change of forest cover in Europe, USA and Japan

Mechanisms of Intensive Sustainability of Lowland Sawah Systems

(1) Geological Fertilization Theory

The upper part of Fig. 10 explains what is the geological fertilization. Although this is a kind of axiom process, quantitative confirmation data are lacking. West African conditions are quite different to Asia. Watershed characterization in terms of upland and lowland connected sequences is important in relation to the geological fertilization as shown in Fig.2. The upper part of Fig. 10 shows a concept of macro-scale ecological engineering, i.e., watershed ecological engineering and watershed agroforestry. The soils formed and nutrients released

(1) Concept of "Watershed Ecological Engineering" and "Watershed Agroforestry" :
The optimum landuse pattern and landscape management practices optimize the geological fertilization through the control of optimum hydrology in watershed. Because of geological fertilization, lowland can receive water, nutirents, and fertile topsoils from upland. Sawah system enhances to utilize such geological fertilization flows.



(2) Sawah systems as multi-functional constructed wetlands for enhanced supply of N, P, Si and other nutrients. Technology development for enhance the multi-functionality of wetland sawah in diverse SSA agro-ecologies is a key in IGNRM.

Fig. 14. (1) Macro- and (2) micro-scale ecological mechanisms of intensive sustainability of lowland sawah systems

during rock weathering and soil formation processes in upland are accumulated at least partly in lowland through geological fertilization processes, such as soil erosion and sedimentation as well as surface and ground water movements or colluvial processes. The sustainable integration of upland forestry, upland farmings and lowland sawah systems in a watershed composed a watershed agroforestry, which can be a typical model of watershed ecological engineering. The optimum land use pattern and landscape management practices optimize the geological fertilization processes through the control of optimum hydrology. Irrigation water also contribute the increase of the supply nutrients, such as Si, Ca, Mg and K as well as sulfate. This is an eco-environmental basis for long-term intensive sustainability of sawah-based rice farming in Asia.

World scale sediment delivery data from various river basins in tones per ha per year were reported by Walling (1983). The Asian monsoon area, which has the major distribution of sawah based rice farming, has the highest delivery of sediments by soil erosion as shown in Fig.7. For upland based farming, such soil erosion destroys biological productivity. For sawah-based rice farming, however, such eroded topsoil from upland is a source for fertile parent materials of lowland sawah fields. The soil erosion is compensated by new soil formation in healthy sustainable ecosystem in a watershed. Major problem in terms of sustainability of the sawah systems in West Africa may be very limited rates of soil formation and erosion in comparison with Asian watersheds (Fig. 7, Wakatsuki 2002). The rates of both soil erosion and soil formation in West Africa may be one fifth to one tenth of those of Asia watersheds. There is, however, no simple appropriate scientific method to evaluate such geological nutrients flows in a given watershed (Wakatsuki et al 1992, 1993, Rasyidin et al 1994). Ecological engineering researches to evaluate the geological fertilization processes and to develop the technology for enhance and control the processes are important in future.

(2) Multi-functionality of Sawah systems as Constructed Wetland

The lower half of the Fig. 10 shows the micro scale mechanisms of the intensive sustainability of the sawah system. The sawah system can be managed as multi-functional constructed wetland. Submerged water can control weeds. Under submerged conditions, because of reduction of ferric iron to ferrous iron, phosphorous availability is increased and both acid as well as alkaline soil pH is neutralized. Hence, micronutrients availability is also increased. These mechanisms encourage not only the growth of rice plant but also the growth of various aquatic algae and other aerobic as well as anaerobic microbes, which make increase nitrogen fixation in the sawah system. The quantitative evaluation of the nitrogen fixation in sawah including the role of algae will be important future research topics too. Although the amounts of nitrogen fixation under the submerged sawah systems are not well evaluated, the amounts could be 20-100kg/ha/year in Japan and 20-200kg/ha/y in tropics depending on the level of soil fertility and water management (De Datta and Buresh 1986, Kyuma 2004, Greenland 1997). Because of general very poor fertility of lowland soils in West Africa (Abe et al 2006, Buri et al 1999, 2000, Issaka et al 1997, Kyuma et al 1986), these various multi-functional mechanisms to enhance nutrient availability of lowland sawah systems are particularly important for intensive sustainability. The sawah systems are the field laboratory for research and technology generation and the factory for dissemination the technology developed. Rice green revolution will only be realized in the farmers' sawah fields.

6. Asian and African collaboration for future global food security and the restoration of the environment

African Lowlands Characterization in Comparison with Asian Lowlands in Watersheds

Because of diverse soils, hydrology, climate, vegetation, topography, and geology as well as socio economic and cultural and historical conditions, the technologies for sawah development and management must fit such diverse conditions. This is an important research and development target for sustainable rice production (Fig. 4-10). There is information on the potential area of lowland sawah development, such as 330,000 ha in Benin, 230,000 ha in Burkina Faso, 200,000 ha in Togo, one million ha in Ghana, and so on. This area estimation is, however, still at the preliminary stage. Details survey and characterization targeting sawah type lowland development are necessary (Table 4, Fig. 4-10).

As shown in Table 4, the lowland area in SSA is enormous (Windmaijer and Andriesse 1993), but because of characteristics of natural environment, particularly scarce water resources, the potential area for sustainable sawah development cannot cover all the lowland of SSA. Lowland soil formation in SSA is smaller than in tropical Asia (Waling 1983, Wakatsuki 2002). This will be a basic ecological limiting factor to develop sawah systems in SSA. One of the reasons why the ecology of inland valleys in West Africa is so diverse (Jamin and Windmeijer 1995) can be explained from this (Fig.5, 6, 7). Inland valleys have various micro-topographies as shown in Fig. 5, of which spring irrigable sloped land and typical irrigable lowland that can be easily irrigated using pump, weir and dyke have the highest priority for sawah development in SSA. We do not know the relative distribution of these kinds of lowlands in various inland valleys. Flood prone areas need the control measures. Many areas of inland valley bottoms that have upland hydrology have the lowest priority for sawah development. However upland NERICA may fit such upland like ecology in lowland. Water harvestable lowland along the foot slopes can be developed as contour-bunded sawah systems with partially water controllable rice fields as seen in northern Ghana and Burkina Faso. The cost-effective technology to develop these systems has to be researched based on the field trials and errors approach. The lowland demarcation and area estimation can be done with help of geographical information system (GIS) technology.

Table 4. Distribution of lowlands in Sub Sahara Africa

Windmeijer and Andriesse (1993); Sawah area estimation by Wakatsuki (2002)

Classification	Area (million ha)		Percentage (%)	
Coastal swamps	16.5	(5?)	7	(15?)
Inland basins	107.5	(4?)	45	(12?)
Flood plains	30.0	(10?)	12	(29?)
Inland valleys	85.0	(15?)	36	(44?)

↑

Figures in parentheses are the potential area of sawah development (million ha): *Maximum total area in SSA may be 20 million ha. This estimation is based on the data that the relative amount of rain fall in Asia Pacific monsoon is five times bigger than that of SSA and sawah area in Asia is 100 million ha currently*

Asian region has about 60-75% of global monsoon rainfall, while SSA has about 10-15%, about one fifth of Asia (Trenberth et al 2000, Qian et al 2001, Levinson 2004). Based on the amount of water cycling in the monsoon climate in comparison with Asia where has about 100 million ha of irrigated sawah, total potential irrigated sawah may be about 20 million ha (Table 4). However more appropriate estimation has to be researched in detail coupling with real development through the field trials and errors approach in each agro-ecology.

Green Revolution: Strategy to Double the Rice Production in SSA by 2015 through the Balanced Approach of Integrated Genetic and Natural Resource Management

We need clear target for research, technology development and dissemination. In order to disseminate lowland NERICA in 0.5 million ha and other HYVs in two million ha to make 2.5 million ha in total for example, improved rice growth environment, such as sawahs have to be developed based on field action research trials. At the same time, the sawah technologies for development and management have to be disseminated to farmers, especially in rainfed lowland such as inland valleys, if we are targeting a two-fold increase of rice production in West Africa by 2015. Then we will be able to declare the success of the green revolution. The past 15 years of the achievements in rice production in West Africa is supporting the reality of the target, if WARDA, West African governments and donor countries have enhanced balanced approach between genetic improvement and natural resource management, especially sawah system (Table 3: Ofori et al 2005).

Asian African collaboration and Japanese Role

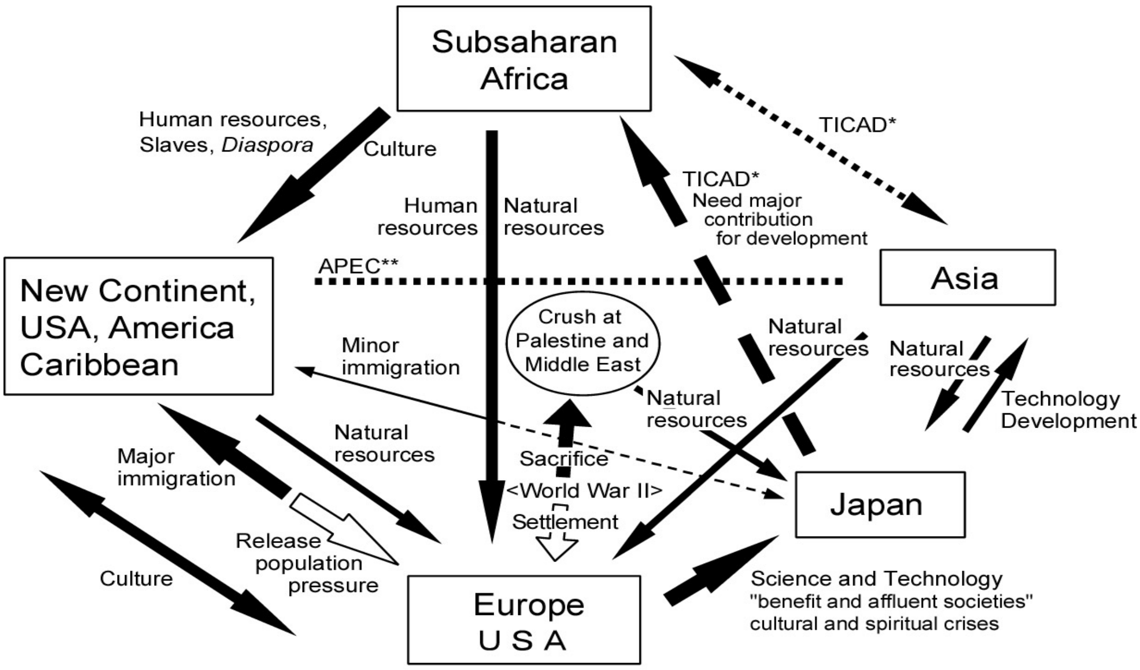


Fig.15 Histrical outlook of globalization
(modified based on T. Wakatsuki, 2000 and K. Takase, 1999)
*TICAD: Tokyo International Conference for African Develoment
**APEC: Asia-Pacific Economic Cooperation

Figure 15 summarizes a historical outlook of the globalization mentioned above (Wakatsuki T., 2000, Takase 1999). Africa's long-term "contact" with the West caused serious distortions of the ecological environment as well as its community, which include intense ethnic opposition and corruption of leaders. A community that suffered slave trade and colonial rule for more than 500 continuous years had no great possibility of turning out those leaders who would fight for a just cause. The fact that Christian justice accompanied this slave trade and colonization was a tragedy of global history. On the other hand, the 500 years when Africa was victimized continuously allowed the West to globalize itself and accumulate wealth, which then brought the development of Western science and technology. The globalization of European and the development of the new continent, US, created science and technology based "affluent societies" in developed countries by the sacrifices of African people and global environment. Although Japan has been benefited directly from Euro-American science and technology since the Meiji Restoration in 1868, as shown in Fig.1-4, the Sub-Sahara Africa contributed indirectly in deep sense for the present NO.2 economic power and the present "affluent society" of Japan.

If we understand this, we need to consider that Africa, the continent victimized by the West, is the "main battlefield" of global environmental issues. If we are to overcome the negative effects of Western modern civilization and science and build a new global community that could solve environmental and North-South problems, it is considered that Japan should based itself on Asia but should also involve itself positively in Africa rather than concentrating on Asia only. Past 10 years the amount of Japanese Official Development Assistance for the developing countries was the top among the OECD countries. Nevertheless, Japanese ODA hasn't yet clear strategy and philosophy so far. The above historical overview of present globalization and global environmental issues clearly claims Japanese major contribution for the development of Sub-Saharan Africa and the restoration of her environment. This, the author hopes, in turn may vitalize the sprit and culture of Japan in the new globalization century of the 21st.

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