サブサハラアフリカでは何故緑の革命の実現が遅れたか？：水田仮説（１）
Why was the Green Revolution not Successful in Sub-Sahara Africa?: Sawah (Suiden) Hypothesis (1)

若月　利之　Toshiyuki Wakatsuki
近畿大学農学部教授
Professor, School of Agriculture, Kinki University

Abstract

The green revolution has yet to occur in SSA due to the lack of the necessary prerequisite conditions. The lacking of the concept and appropriate technical term, therefore lacking appropriate research and the development of “sawah” technology made confusion in the research and development of rice cultivation in SSA. Contrary to Asian farmers’ fields, farmers’ fields in SSA, and specifically their farming technologies, are not ready to accept irrigation, fertilizer and high yielding varieties (HYV). Although research and development on irrigation, fertilizers and HYV has been discussed 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. The term “sawah” refers to leveled and bunded rice fields with inlet and outlet connecting irrigation and drainage. The term originates from Malayo-Indonesian. The English term, Paddy or Paddi, also originates from the Malayo-Indonesian term, Padi, which means rice plant. In order to avoid confusion between upland paddy fields and man-made irrigated rice growing environment, lowland paddy fields, the author proposes to use the term “sawah” in West Africa.

Simply speaking, the basic infrastructures for green revolutions are lacking. The potential of sawah based rice farming is enormous in SSA, especially in West Africa. Ten to twenty million ha of sawah can produce additional food for more than 300 million people in future. The sawah based rice farming can overcome both low soil fertility and scarce water resources through the enhancement of the geological fertilization process, conserving water resources, and the high performance multi-functionality of the sawah type wetlands. 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 green revolution cannot take place.

Although the upland was the major rice ecology 15 years ago, it seems now upland is not and will not be the major rice production ecology in Sub Sahara, especially in West Africa. This is the very promising change to complete the green revolution finally in this region. Between 1984 and 1999/2003, annual paddy production dramatically increased from 3.4 to 7.7 million tones in West Africa. Major increases were from the expansion and yield increases of rainfed lowland, mainly inland valley, i.e. 0.75 to 3.4 million tones of annual paddy production during the same period. Expansion and the yield increase of irrigated lowland were the second contributors. From 1984 to 1999/2003, annual paddy production from irrigated ecologies has increased from 0.64 to 1.9 million tones. Only very minor contributions were from the rainfed upland, i.e. 1.5 million tones of paddy in 1.5 to 1.8 million tones of paddy during the same period.

These trends clearly show natural resource management technology, especially through the improvement of water control in lowland, especially rainfed lowland, also played a major role in increasing rice production last 15 years. If this good intensification trend will be enhanced properly, the green revolution will be realized in this region within next 10-20 years.

Materialization of African Rice Green Revolution by Sawah Eco-technology: Concept Paper of New Sawah Project, 2007-2011

Toshiyuki WAKATSUKI*, Moro M. BURI** and Oladimeji I. OLADELE***
*Faculty of Agriculture, Kinki University
**Soil Research Institute, Kumasi, GHANA
***Department of Agricultural Extension and Rural Development, University of Ibadan

Abstract

Even 40 years after the success in tropical Asia and Latin America, the green revolution is yet to be realized in Sub Sahara Africa (SSA). The materialization of rice green revolution is the major target of the millennium development goals of the United Nations. Although the breeding of high yielding varieties (HYV) by biotechnology was the core technology in Asian and Latin American green revolution and which the African Rice Center, WARDA, has innovated in NERICA technologies, the successful path to the green revolution in SSA is still unclear. The paper discussed the Sawah hypothesis (I) and (II). The first Sawah hypothesis (I) explains that the central to the realization of the rice green revolution in SSA is eco-technologies, which can improve farmers rice growing environment, such as lowland sawah eco-technologies. The second Sawah hypothesis (II) explains that sustainable rice productivity of lowland sawah is more than 10times than that of upland rice fields, if appropriate lowlands are selected, developed and managed. Contrary to Asian farmers' fields, the majority of farmers' rice fields in SSA are not ready to accept the three basic components of the green revolution technologies, i.e., (1) irrigation for water supply, (2) fertilizer for soil nutrient supply, and (3) high yielding varieties (HYV). Although researchers have worked seriously on the effect of irrigation, fertilizers and HYV for the last forty years, the researchers have not touched on whether the prerequisite conditions which can accommodate the three basic components of the green revolution exist or not in SSA. The concept and technologies of Sawah is such an example. The term sawah refers to leveled, bunded, and puddled rice field with water inlet and outlet to control water and manage soil fertility, which may be connecting irrigation and drainage facilities including sawah to sawah irrigation and drainage. The term 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 puddled rice fields, i.e., typically irrigated rice ecology, which is inappropriately used as lowland paddy fields, the authors propose to use the term "Sawah" in SSA. Simply speaking the basic infrastructures for the green revolution are lacking in the farmers' fields of SSA. Irrigation without farmers' sawah farming technologies has proved inefficient or even damaging because of accelerated erosion and waste of water resources in SSA. 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 can not be achieved. The potential of Sawah based rice farming is enormous in SSA, especially in West Africa. Ten to twenty million ha of sawah can produce additional food for more than 300 million people in future. The sawah based rice farming can overcome both low soil fertility and scarce water resources through the enhancement of multi-functionality of sawah type wetlands as well as geological fertilization processes in watersheds. The sawah systems can even enhance the restoration of degraded watershed through the sustainable expansion of afforestation to form a watershed agro-forestry, which will combat global warming in future.

Introduction

The green revolution has yet taken place in West Africa and Sub Sahara Africa (SSA)(FAOSTAT 2006, Evenson and Gollin 2003). Although food crops are very diverse, per capita total production of major food crops has been stagnating between140-170kg in SSA as seen in Table 1. In tropical Asia, because of the green revolution, the figures increased from 205kg in 1961-1965 more than 280kg in 1996-2000 (Table 1). This is the foundation of high difference of economic growth between SSA and Asia at present. Now Asia is a global center of economic growth thanks to the green revolution that started in 1970s.

Due to high water content (60-70%) of root and tuber crops, such as yam and cassava, the energy per kg is one third of cereals, such as rice, wheat and maize. In addition, the protein and minerals content of yam and cassava are only one fourth to one fourteenth in comparison with cereals. Therefore, the production data of FAO are shown after division by the factor of 8 for cassava and 5 for yam. These factors of 8 or 5 are only tentative, which were used only for reach to the estimation of reasonable cereals' equivalents for comparison in the Table 1 (FAOSTAT 2006, Kiple and Ornelas 2000, Sanchez 1976). Also the following historical observation in Asia adds to the argument. Root and tuber based food had changed to cereals based food, such as rice and wheat. In future, cereals, especially rice, will be more important than now in SSA (FAOSTAT 2006). Although the cereals' equivalents are tentative values, the trend data show the difference of Asia and SSA during 1960-2003. As shown in (Fig. 7) later, mean rice yield has increased from 1.8 t/ha to 4.0 t/ha in Asia, but the yield has stagnated between 1.2 to 1.5 t/ha in SSA during 1960 - 2005.

Table 1 Five years' means of 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 & 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).

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*	169.8	167.2	159.9	147.4	139.5	154.9	157.1	157.3	151.6

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*	205.3	220.4	227.6	243.1	265.4	271.4	279.0	282.5	265.3

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*	210.7	201.6	182.2	155.5	157.3	197.3	225.3	220.1	211.3

Total*: Excluding the imports of paddy rice and wheat.

As seen in Table 1, West Africa is a core region of SSA in terms of the rice production and importation as well as rice consumption. Therefore the authors discussed mainly West Africa in this strategic paper.

As shown in Table 2, although upland was the major rice ecology 15 years ago, it is no more the largest rice production ecology in West Africa now. If this trend continues, upland rice production ecology will be very small in SSA especially in West Africa in the near future (Table 2: The data were compiled from FAOSTAT 2006, WARDA 1988, 2002, and 2004, JICA 2003). This is however very promising change to realize the green revolution finally in West Africa and SSA. Between 1984 and 1999/2003, annual paddy production increased dramatically from 3.4 to 7.7 million tones in West Africa. Major increases were from the rainfed lowland rice ecology, mainly inland valley, which expanded the area from 0.53 to 1.8 million ha and yield increased from 1.4 to 2.0 t/ha. Thus, the annual paddy production increased from 0.75 to 3.4 million tones during the same period. Irrigated lowland was the second contributor. The annual paddy production from irrigated ecologies increased from 0.64 to 1.9 million tones during the same period through the expansion of area from 0.23 to 0.56 million ha and yield increased from 2.8 to 3.4 t/ha. Only very minor contributions came from the upland rice ecology, i.e., the increase of paddy production was from 1.5 to 1.8 million tones and the increase of the cultivated area from 1.5 to 1.8 million ha, but no yield increased during the same period. Although the NERICA technology was released, the upland rice strategy of WARDA for 1993-2003 (WARDA 1988) did not contribute to the rice production during the same period in West Africa.

These trends clearly show that the improvement of the natural resource management technology, especially through the improvement of water control in rainfed lowland played a major role in increasing rice production during last 15 years. If this trend is supported by adapting the sawah eco-technology strategy proposed in this paper, the green revolution will be realized in this region by 2015.

Table 2 Estimation of rice production trends 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

Table 3 Major soil distributions in the three tropics based on the Soil Taxnomy (Hirose and Wakatsuki 2002)

	Entisol	Spodosol	Histosol	Ultisol	Inceptisol	Andisol	Oxisol	Psamment	Alfisol	Mollisol	Vertisol	Aridisol	Total (excluding no-soil surface)
Soil Characterristics	Immature parent materials	Sandy, leaching	Peat wetland	Strongly weathered, acid	Young vitality	Volcanic ash, fertile	Aging, leaching	Quartz leaching	Eutrohpic, low activity	Grasslands, dry season	Black, semi-arid	Dry, desert	
Toropical Africa	50	3	2	190	240	5	440	340	320	4	100	810	2,504
Toropical America	90	0.5	5	330	130	90	660	20	120	15	20	50	1,531
Toropical Asia	250	3	22	300	200	50	tr	tr	80	tr	100	10	1,015
Total tropics (million ha)	620	7	30	820	570	145	1,100	360	520	19	220	890	5,050
Total (ratio in %)	11.7	0.1	0.6	15.5	10.8	2.7	20.8	6.8	9.8	0.4	4.2	16.6	100
Japan (ratio in %)	4	3.5	1.0	2.5	58	16	0	tr	tr	0	0	0	100

Soil distribution characteristics of SSA and soil fertility of West African lowland in comparison with that of Tropical Asia (Wakatsuki and Masunaga 2005)

Table 3 shows the estimated area of soil order in three major tropical zones in the world, i.e., tropical Asia, Africa, and America (Sanchez 1976, Kyuma 2004, Eswaran et al 1992 and 1997, Soil Survey Staff 1998, 1999, Hirose and Wakatsuki 2002). The combined area of the nutrients depleted Oxisols and Psamments as well as water deficient Aridisols accounts for 64% of SSA. In tropical Asia, although acid Ultisols are widespread, since the geology is much younger, Oxisols, Psamments and Aridisols are minor distribution. These soils are unsuitable for agriculture. In tropical America, Oxisols have wide distribution, 43%, but few distributions of Aridisols and Psammnets. Among the soil orders in the tropics, Andisols on upland and Inceptisols as well as Entisols in lowland have good moisture and fertility in general. While intensive and relatively sustainable farming systems are practiced on Andisol areas in all of the three tropical zones, the Inceptisols and Entisols in lowlands are not very much used in both tropical Africa and America. In tropical Asia, however, the lowland Inceptisols and Entisols are utilized more intensively for sawah based rice production systems. The sawah systems, total area of about 100 million ha, are producing rice food for more than two billion people in sustainable basis (Greenland 1997, Kyuma 2004).

During 1986 to 2007, the senior author conducted various surveys on the West African rice based farming systems in flood plains, inland valleys and various uplands. Those soils, mainly lowlands, were collected from most West African countries, including Senegal, Guinea, Sierra Leone, Liberia, Cote d'Ivoire, Mali, Burkina Faso, Ghana, Togo, Benin, Niger, Nigeria, and Cameroon as well as the Dem. Rep. of the Congo in central Africa. Soil fertility characteristics were evaluated and their fertility were compared with that of soils in tropical Asia and Japan. The results were summarized in Table 4 (Wakatsuki et al 1998, Issaka et al. 1997, Buri et al. 1999 and 2000, Kawaguchi and Kyuma 1977, Hirose and Wakatsuki 2002).

Total carbon and nitrogen content were low both for West Africa and tropical Asia. The mean values of available phosphorous and pH suggest that the phosphorous status of West Africa is very critical. Base status such as exchangeable calcium and potassium and effective cation exchange capacity were also very low in comparison with the tropical Asia. In addition, some micronutrients, such as sulfur and zinc are also generally very low and about 60-80% of lowland soils, both inland valleys and flood plains were in deficient level (Buri et al 2000). Comparison of soil fertility data of tropical America also revealed that the fertility of lowland soils in West Africa was the lowest among the three tropics (Hirose and Wakatsuki 2002).

Table 4 The mean values of fertility properties of inland valleys (IVS, about 200 sites) and flood plains (FLP, about 70 sites) of West Africa in comparison with lowland topsoils of tropical Asia (about 500 sites) and Japan (about 150 sites) (Hirose and Wakatsuki 2002)

Location	pH	Total C (%)	Total N (%)	Available P (ppm)**	Exchangeable Cations (cmol/kg)				Sand (%)	Clay (%)	CEC /Clay
					Ca	K	Mg	eCEC			
IVS	5.3	1.3	0.11	9	1.9	0.3	0.9	4.2	60	17	25
FLP	5.4	1.1	0.10	7	5.6	0.5	2.7	10.3	48	29	36
T. Asia*	6.0	1.4	0.13	18	10.4	0.4	5.5	17.8	34	38	47
Japan*	5.4	3.3	0.29	57	9.3	0.4	2.8	12.9	49	21	61

*Kawaguchi and Kyuma 1977, ** Bray 2

In high rainfall zones of West Africa such as equatorial forest in Liberia and Sierra Leone, Oxisols are widespread in upland areas. The typical toposequence of inland valley soils near Makeni in central Sierra Leone was Oxisols in flat upland, Oxisols/Ultisols in gentle slopes and Inceptisols in valley bottom. The eCEC of the topsoils were 1-5 cmol(+) /kg and exchange acidity percentages were 10-90% throughout the topesequnce (Smaling et al 1985 a and b, Hirose and Wakatsuki 2002). The upland soils have especially low carbon and nitrogen contents, less than 1% and 0.1% respectively. Available phosphorus (Bray II) was also lower than that of lowland soils. Exchangeable bases are also generally lower than those of soils in inland valleys and flood plains. In Savannah zones, such as Sudan and Guinea, although the upland soils are mainly Alfisols but the eCEC of these soils is also very low, normally less than 5 Cmol(+)/Kg. Low activity clay soils are predominant. In addition to the poor soil fertility, the recent shortage of rainfall also further makes it difficult to conduct sustainable upland rice cultivation.

Although organic matter management through agroforestry and cover crop systems are possible options to sustain soil fertility (Tian et al 2001), in order to overcome such difficulties and for effective and sustainable crop production in SSA, new farming systems that can restore and enrich these poor soils must be developed. In terms of sustainability, re-evaluation of traditional farming technology is important (Barrera-Bassols and Zinck, 2000). However, for the sustainable increase to cope with recent population expansion, only re-evaluation of traditional farming is not enough (Hirose and Wakatsuki 2002). As discussed in this paper, the new concept of ecological engineering technology is necessary. The African adaptive lowland sawah-based farming with adjunct small-scale irrigation scheme for the integrated watershed management will be the most promising strategy to increase sustainable and intensive food production and at the same time to restore the degraded watersheds in SSA.

Concept of sawah eco-technology

The concept and the term “sawah” refers to man-made improved rice fields with demarcated, leveled, bunded and puddled 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.1-6). Just sawah to sawah irrigation as well as drainage are possible. Rainfed sawahs without any irrigation facilities are also far better than rainfed fields for rice growth and for rice green revolution because of the improvement of water and soil management. Drainage facilities are also useful in over flooded area. The term “sawah” originates from Malayo-Indonesian. The English and French terms, Paddy or Paddi, also originated from the Malayo-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 growing environment, which is often un-appropriately used as lowland paddy fields, the authors propose to use the term “Sawah” in SSA (Wakatsuki et al 1998).

For the sustainable increase of rice yield and production, farmers have to control water on rice fields. If the degree of water control improves, sustainable rice yields will increase (Hiose and Wakatsuki 2002, Table 5 by Ofori et al 2005). In order to control water, sawah system has to be developed, improved and managed (Fig. 1). Taiwan team has played a pioneering role in technical cooperation for the introduction of the sawah based rice cultivation in Africa during 1965 to 1975 (Hsieh 2003). However as this technical cooperation continued only for some 10 years because of political reason, confusion and stagnation occurred on the technology transfer of the sawah based rice framings in the 1980s (Buddenhagen and Persley 1978 and IITA 1989/1990).

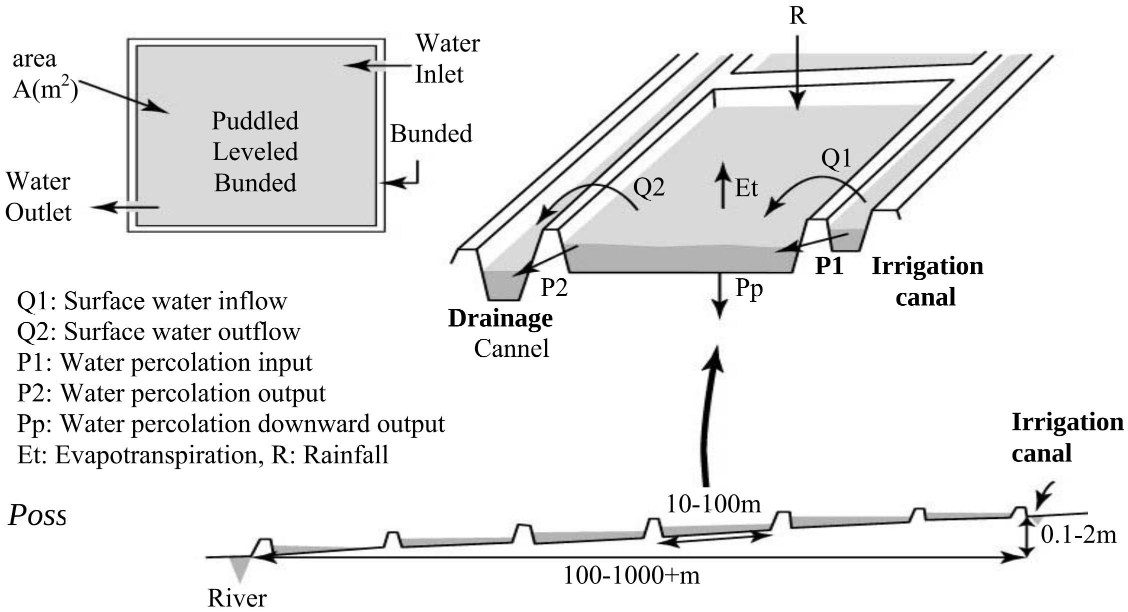


Fig. 1 What is "Sawah"?
"Sawah" is leveled, bunded and puddled rice field with inlets and outlets to control water.

Table 5 Mean gain yield of 23 rice cultivars in lowland 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 IMPROVEMENT	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 various costs of green revolution technology, the yields must be higher than 4 t/ha for sustainably adopting green revolution technologies.

It is now very difficult to build new irrigation project through the conventional ways of Official Development Assistance (ODA) because of the high cost of irrigation and its apparent low return in SSA. Especially, the large-scale irrigation projects are very costly. Even in the small irrigation schemes, the construction cost becomes comparable to large schemes as far as their development depends mainly on engineering works by construction companies. Although the total sale of produce is between 1,000 –2,000 dollars per ha, the running cost including maintenance of such systems, machinery for operation, agrochemicals become very high. Due to the high construction cost, the economic return has been negligible or rather negative for a long period of time, 20-30 years.

However, the most impressive achievements observed by the senior author in the past 15 years were that inland valley development for improving water control of the rice-growing environment through bunding and leveling, which are ongoing in West Africa despite the major negligence of the research in this area and scarce official funding (Table 2). These are based mainly on farmers' self-support efforts. Decreasing trend of rainfall in recent years might persuade farmers to shift partly from upland to lowland. The senior author observed that there were many upland rice fields around Bouake in 1987. In 2002, however, almost no upland rice fields were observed around the Bouake area.

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 some Francophone SSA, or "contour bund system". Although the quality of these systems is quite diverse, these are all covered by the "sawah concept and sawah

In addition to the construction cost of irrigation schemes, the management of the schemes has been a problem in SSA. Water use efficiency was very low because of the confusion between irrigation scheme and the sawah systems in SSA. The irrigation schemes are constructed and managed by government and/or communities, but the water condition in each irrigated rice field, i.e., sawah, has to be managed by each rice farmers. Actually water use efficiency in the whole irrigation schemes is dependent on the management skill of sawah fields of each rice farmer. The lack of eco-technologies of sawah in SSA, majority of irrigation schemes have never been sustainable for the last four decades. Therefore the official development of irrigation schemes, large and small, by governments is very slow.

technology and development" (Wakatsuki et al 1998). Some rice farmers as well as some West African and donor countries have realized the importance of soil and water management, especially the water management, through various sawah based rice cultivation technologies are not defined clearly (Figs. 1 and Table 2). WARDA's inland valley consortium (IVC) also contributed to encourage these developments partly. A USD$ 23 million inland valley rice development project (IVRDP, 2004-2009) is based on the sawah approach in Ghana financed by African Development Bank, is a good example, if it becomes successful (Wakatsuki et al 2001, Hirose and Wakatsuki 2002, Ministry of Food and Agriculture, Ghana, 2007 a and b). Massive irrigation scheme by office du Niger in Mali has been performing and now to reach the level of green revolution, 4-5ton/ha, in their full scheme of 50,000ha in last ten years after thirty years of very poor performance during 1960-1990 (JICA 2003).

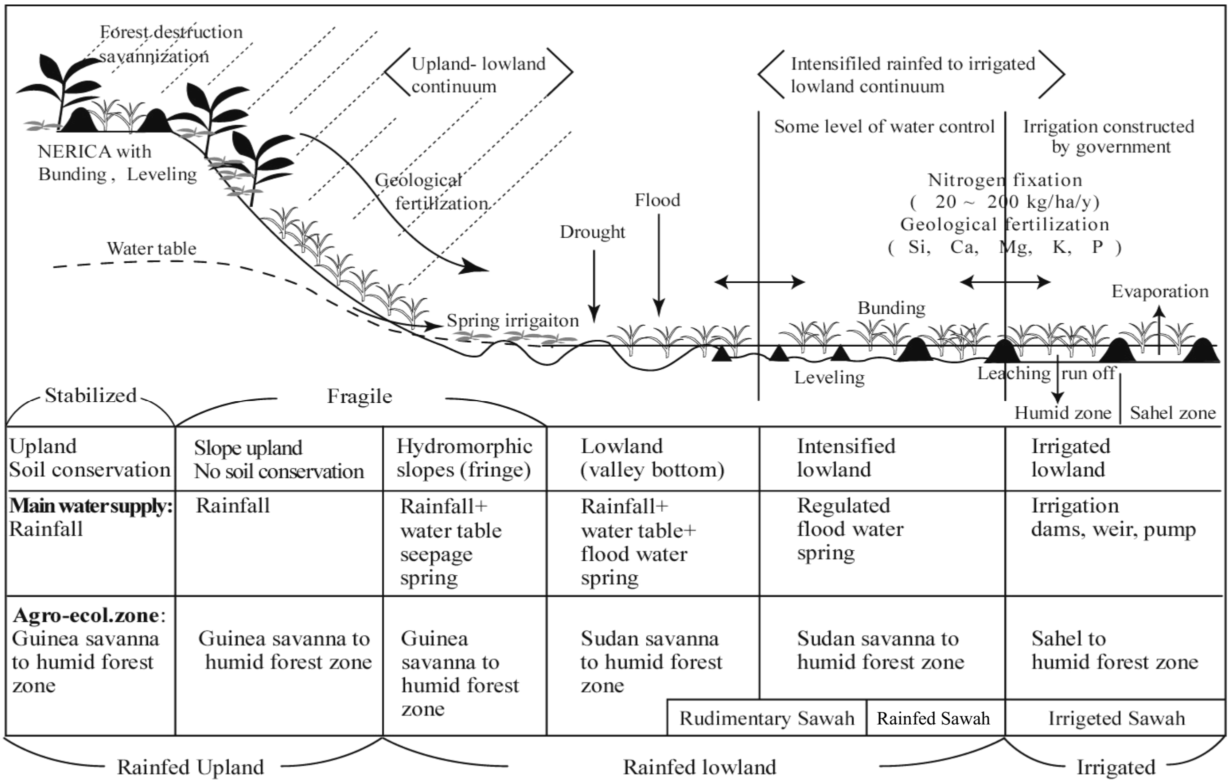
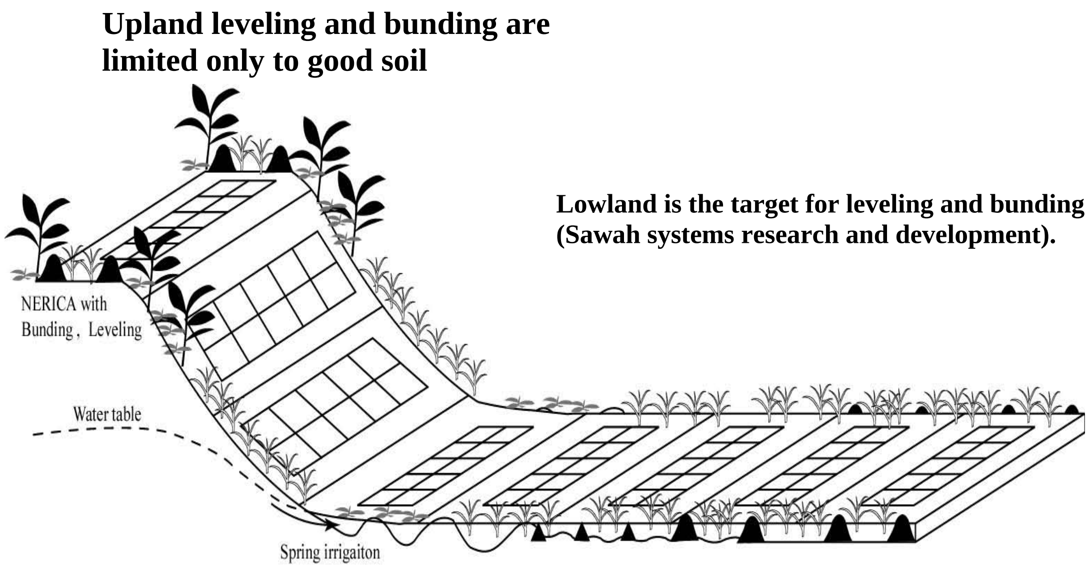
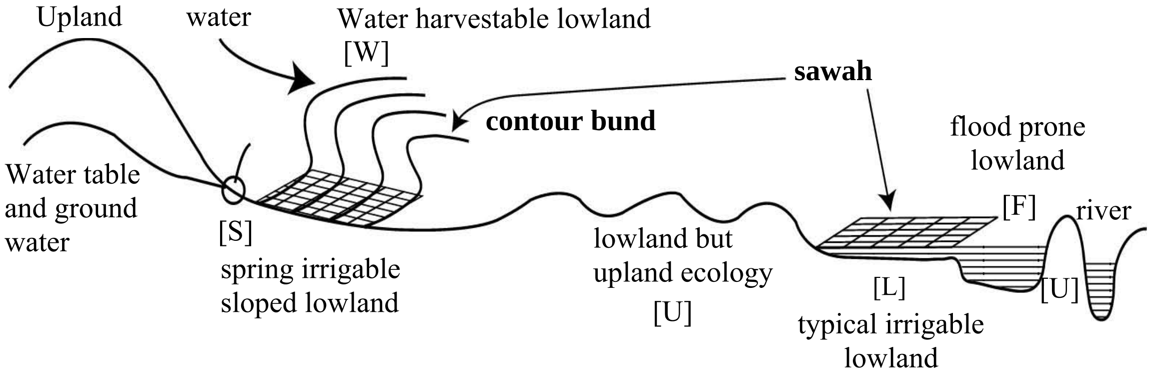


Fig. 3 Rice ecologies along upland-lowland continuum in West Africa (JICA 2003, WARDA 2004)



Water table and water management continuum (WARDA 2004).

Fig. 4 Rice farmer’s field demarcation based on soil, water and topography, such as sawah development, are the starting point for scientific observation, technology generation and application



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. 5　Strategy for 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 agro-ecological zone.

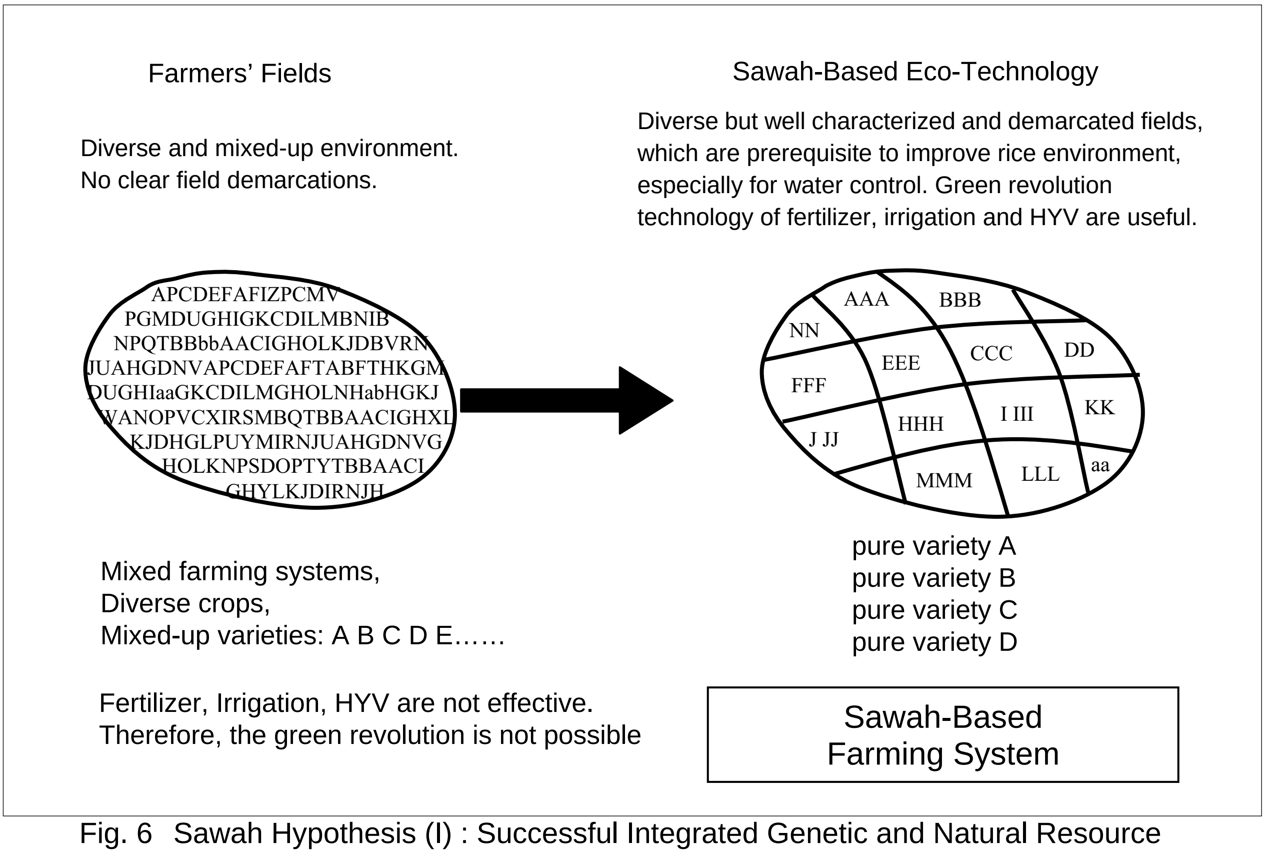


Fig. 6　Sawah Hypothesis (I) : Successful Integrated Genetic and Natural Resource Management (IGNRM) needs classified and demarcated land eco-technology.

Balanced approach between biotechnology and eco-technology

In order to strengthen these trend, the way for rapid expansion of eco-technology based low cost and self-support sawah fields have to be researched and developed in the rainfed lowland, especially in inland valleys (Wakatsuki et al 1998, 2001, Hirose and Wakatsuki 2002). SSA needs eco-technologies that can improve farmers' rice fields similar to the biotechnologies that can improve rice varieties (Fig. 2, Table 5 by Ofori et al 2005). Table 5 clearly shows that eco-technological improvement of farmers rice fields are critical compared to the biotechnological variety improvement in SSA. The technologies of genetic improvement of rice (variety) and the rice growing environment (sawah) must be researched and developed in good balance for integrated genetic and natural resources management (IGNRM) (Fig. 2 and Fig. 8). Because of the success story of the green revolution by HYV in Asia and Latin America by CG centers, our research activities have been too much one-sided focusing on HYV only for the last forty years in SSA.

Table 6 summarized the possible eco-technology options to improve rice yields in comparison with biotechnology options. The table shows that sawah eco-technology can give wide range of the improvement of rice yield, rice quality and ecological environment including carbon sequestration (Darmawan et al 2006a and b) through the improvement of water shortage, poor nutrient conditions, acidity, alkalinity, weed control, pest and diseases control, and food quality (Hirose and Wakatsuki 2002, Kyuma 2004). Therefore, in addition to the improvement of variety through biotechnology, the improvement of rice growing environment has to be done through eco-technology. Balanced research and technology development of biotechnology and eco-technology is very important.

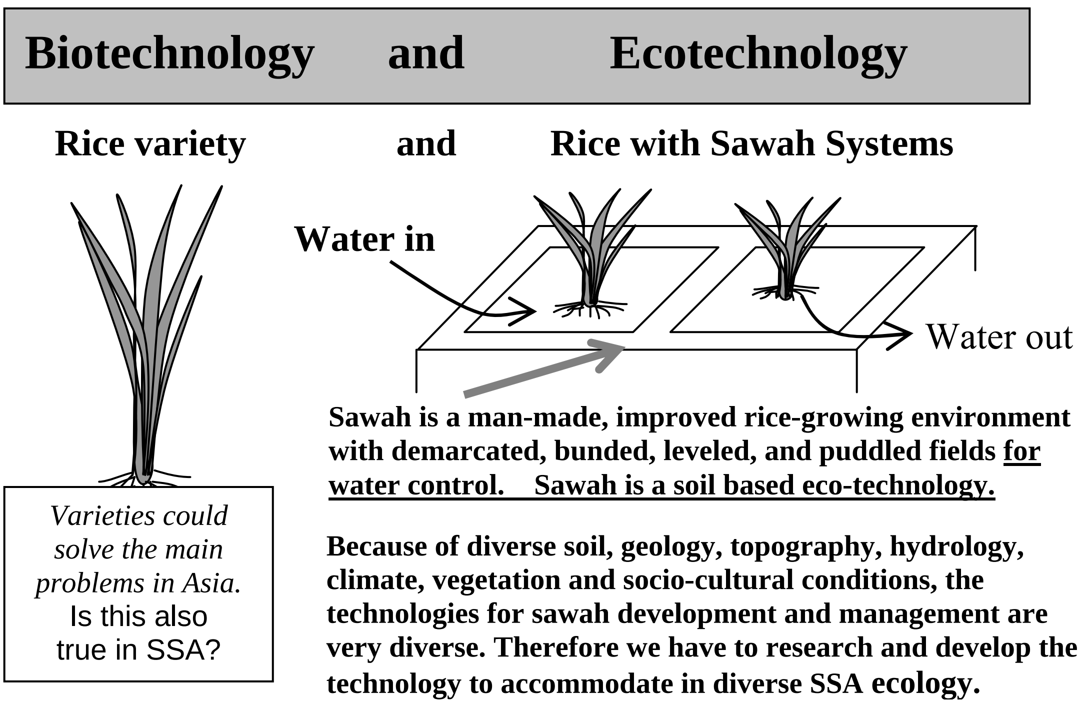


Fig. 2 Rice (variety) and environment (Sawah) improvement.
Both bio- & eco-technologies must be developed in balance

Rice growing ecologies are extremely diverse in West Africa and SSA (Fig.3, 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 inland valleys and on the targeting farming systems. Because of obvious benefits of geological fertilizations (Fig. 11) as described later, lowland is the priority target for sawah development (Fig.4). Water harvesting and various simple irrigation technologies have to be integrated with the various sawah developments in diverse characteristics of the valley bottoms (Fig.5). Small machinery, such as power tiller, has to be examined to accelerate the sawah development. Tropical Asian experiments in collaboration for sawah development and for animal traction and power tiller operation for sawah based rice farming will be very useful (Fashola et al 2007 a and b, Hsieh 2003).

Sawah Hypothesis (I) For the 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 and managing 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 publicity of NERICA by WARDA, a clear concept and key technical term are very important for integrated genetic and natural resource management (IGNRM). As discussed already, 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 (IPM), and high yielding varieties (HYV) (Fig. 6 and 7). Rice farmers’ field demarcation based on topography, hydrology and soil is the starting point for scientific observation, technology generation and application, including the green revolution technologies (Fig.6). For efficient uses of fertilizers and irrigation water, rice farmers’ fields have to be demarcated based on topography, hydrology and soils (Fig. 5 and 6). Although there have been discussions on researches and developments on irrigation, fertilizers and HYV for the last forty years, the discussions have not touched on whether the prerequisite conditions are lacking in SSA (Fig.6 and 7). The concept and technologies of Sawah is such an example. Simply speaking, the basic infrastructures for the green revolution, such as sawah, are lacking in SSA (Fig. 1, 2, 6, and 7). 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 cannot take place. These are the Sawah hypothesis (I).

As shown in Fig.7, the majority of Asian rice farmers’ fields were already quality sawah fields in 1960s when the green revolution technologies were introduced. Therefore the three major components of the green revolution technologies were quickly adapted. However, the majority of rice farmers’ fields of SSA are lacking such sawah fields, therefore the three green revolution technologies have not been effective for the last forty years. The HYVs have never been performed successfully without sawah fields. Irrigation and other agronomic technologies also never performed well without sawah fields. But if the sawah eco-technolgy is adapted to the majority of rice farmers in SSA, the green revolution will be realized quickly as in the case of Asia. Contrary to Asian farmers’ fields, the farmers’ rice fields in SSA are not ready to accept the three basic components of the green revolution technologies, i.e., (1) irrigation for water supply, (2) fertilizer for soil nutrient supply, and (3) high yielding varieties (HYV).

As described as “African Statistical Error” in the yield trend of Sub Sahara Africa during 1960-2005 in Fig. 7, agricultural statistics are also not so reliable in SSA. There are many reasons, but lack of sawah as demarcated rice fields makes it difficult to estimate the yield too. Without reliable statistical data, appropriate rice development policy can not be established.

The sawah system development and management are the technologies that should be transferred to farmers. Since bunding, leveling and puddling need very hard, skilled and careful works as well as obvious additional benefits of geological fertilization, rainfed lowland will be the primary target for sawah development (Fig. 4 and 11). The ecology of the majority of rice farmers' fields is extremely diverse in naturally and farming systematically (Fig. 3), therefore even the good quality seeds cannot be evaluated properly without sawah systems (Fig.6). 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 nutritive and 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 for the last 20 years.

The missing link for the green revolution is a sawah concept and technology, targeting the expansion of high quality but with low cost. 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.7 and 8). Long term experiments on the effect of cropping system investigations 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 healthy growth of rice through the sawah type eco-technology. Water saving aerobic rice cultivation and Systems Rice Intensification (SRI) methods become only possible on sawah fields (Fig. 6 and 8).

African lowlands characterization in comparison with that of Asian lowlands in watersheds

Because of diversity in soils, hydrology, climate, vegetation, topography, and geology as well as socio economic, 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. 4-8). 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, 20 million ha in whole SSA (Hirose and Wakatsuki 2002) 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 7, Fig. 3-5).

As shown in Table 7, 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 much smaller than in tropical Asia (Fig 9 by Walling 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 partly from this (Fig.3, 5 and 9). 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, simple weir and dyke have the highest priority for sawah development in SSA. The relative area distribution of these kinds of lowlands in various inland valleys is yet to be determined. 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 into 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 low cost 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.

Asian region has about 60-75% of global monsoon rainfall, while SSA has about 10-15%, which is about one fifth of Asia (Trenberth et al 2000, Qian et al 2001, Levinson 2004). Based on this amount of water cycling in the monsoon climate in comparison with Asia where it has about 100 million ha of irrigated sawah, the total potential irrigated sawah may be about 20 million ha in SSA (Table 7). Immediate target will be 10 million ha in SSA by 2050 (Fig. 7). However, more appropriate estimation has to be researched in detail coupled with real development through field trials-and-errors approach in each agro-ecology.

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. 9 (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 (Hirose and Wakatsuki 2002). Paradoxically, extreme diversity of lowland in West Africa (Fig. 5) may relate to the low rate of soil erosion and weak lowland soil formation.

As shown in Fig. 10, before the green revolution, there were long continued efforts to expand lowland sawah systems in the history of Japanese rice cultivation during the 6th to 20th centuries. The Fig.10 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 eco-technology was traditional, Japan's green revolution happened immediately after the introduction of Euro-American's fertilizer technology at the end of the 19th century. The green revolution in turn encouraged the rapid expansion of sawah area more than one million ha within 50 years when population was less than 60 million (Fig.10). Although after the World War II, because of the expansion of the economy, industrialization, and urbanization, 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. On the other hand, SSA and the world are expecting rapid population explosion during the 21st century, the green revolution and the expansion of sawah area are necessary to cope with the forthcoming peak population.

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, the 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, i.e., typically the farmers' fields, is still stagnating. Thus the farmers' fields lack basic infrastructures to accept the green revolution technologies in SSA (Wakatsuki 2002).

Sawah Hypothesis (II) for intensive sustainability

Sustainable yield of lowland sawah system is very high. Although this is based on the long history and experience (not experiments) of sawah based rice farming in Asia, there is no scientific quantitative confirmation yet. Lowland sawah can produce about 2 t/ha without any chemical fertilizer application (Fig. 10 and Table 8). In addition the lowland sawah based farming can support rice cultivation continuously for decades or more without any fallow. However sustainable upland slush-and-burn rice yield without fertilizer never exceeds 1 t/ha. In 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, sometime more than 15 years, of fallow. This means 1 ha of sustainable upland rice cultivation need at least 5 ha of additional land. Therefore sustainable upland rice yield is actually not 1 t/ha but less than 0.2 t/ha. Therefore as shown in the Table 8, sustainable productivity of sawah based rice farming is more than 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 the 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 more than 10 ha of forest area. Sawah fields can, therefore contribute to not only increased food production but also to conserving the forest, which in turn enhances sustainability of intensive lowland sawah systems through nutrient cycling and geological fertilization processes. Furthermore, they can contribute to the alleviation of global warming problems through the fixation of carbon in forest trees and sawah soils (Wakatsuki and Masunaga 2005, Darmawan 2006a).

Mechanisms of intensive sustainability of lowland sawah systems

(1) Geological fertilization theory

The upper part of Fig. 11 explains what is the geological fertilization. Although this is a kind of axiom process, quantitative data confirmation is lacking. West African conditions are quite different from Asia, therefore the watershed characterization in terms of upland and lowland connected sequences is important in relation to the geological fertilization as shown in Fig.3 and 11. The upper part of Fig. 11 shows a concept of macro-scale ecological engineering, i.e., watershed ecological engineering and watershed agroforestry. The soils formed and nutrients released 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 farming and lowland sawah systems in a watershed composed of a watershed agroforestry, 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, surface and subsurface water also contributes 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.9. For the upland based farming, such soil erosion destroys biological productivity. For sawah-based rice farming, however, such eroded topsoil, although the amounts should be appropriate, from the upland is a source of fertile parent materials for lowland sawah soils. The appropriate soil erosion can be 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. 9, 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, except a few examples (Wakatsuki et al 1992, 1993, Rasyidin et al 1994). Ecological engineering researches to evaluate the geological fertilization processes and to develop the technology to enhance and control the processes are important in future.

(2) Multi-functionality of sawah systems as constructed wetland

The lower half of the Fig. 11 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 or mitigated. 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 and anaerobic microbes, which increase nitrogen fixation in the sawah system through increase of photosynthesis as a functional wetlands. The technology development and quantitative evaluation of nitrogen fixation in sawah including the role of algae will be important future research topics. 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). The technology development of the nitrogen fixation by sawah systems, such as 50-200kg N/ha/y, through the integrated management of water, soil microbes, algae and rice plant is the very challenging research subject in SSA. 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 (Fig. 7).

Acknowledgement

The authors would like to express their deep gratitude to the Ministry of Education, Science, Sports and Culture of Japan for financial assistance, Grant-in-Aid for Specially Promoted Scientific Research, No. 19002001 and also to the JSPS for financial assistance for Grant-in-Aid for Scientific Research (S), No. 15101002.

References

Abe, S. S., Masunaga, T. Yamamoto, S., Honna, T. and Wakatsuki, T. 2006. Comprehensive assessment of the clay mineralogical composition of lowland soils in West Africa. *Soil Sci. Plant Nutr.* **52**: 479-488.

Barrera-Bassols N. and Zinck, J.A. 2000. *Ethnopedology in a Worldwide perspective, An annotated bibiliography,* ITC Publication No. 77, Enschede, the Netherlands,

Buddenhagen, I.W. and Persley, G.J. 1978. *Rice in Africa*, Academic Press , 355pp

Buri, M. M., Ishida, F., Kubota, D., Masunaga, T., and Wakatsuki, T. 1999. Soils of flood plains of West Africa: general fertility status. *Soil Sci. Plant Nutr.* **45**: 37-50.

Buri, M. M., Masunaga, T., Wakatsuki, T. 2000. Sulfur and zinc levels as limiting factors to rice production in West Africa lowlands. *Geoderma* **94**: 23-42.

Darmawan, Kyuma, K., Saleh, H. Subagjo, Masunaga, T., and Wakatsuki, T. 2006a.

Effect of green revolution technology from 1970 to 2003 on Sawah soil properties in Java, Indonesia: I. Carbon and nitrogen distribution under different land management and soil types, Soil Sci. Plant Nutr., 52(5): 634-644

Darmawan, Kyuma, K., Saleh, H. Subagjo, Masunaga, T., and Wakatsuki, T. 2006b.

Effect of green revolution technology from 1970 to 2003 on Sawah soil properties in Java, Indonesia: II. Changes in the chemical properties of soils, Soil Sci. Plant Nutr., 52(5): 645-653

De Datta, S.K. and Buresh, R. J. 1986. Integrated nitrogen management in irrigated rice, *Adv. Soil Sci*., 10:143-169

Eswaran, H., Kimble, J., Cook, T., and Beinroth, F.H. 1992: Soil Diversity in the Tropics: Implications for Agricultural Development. *In* Lal R and Sanchez P ed., "*Myths and Science of Soils of the Tropics*", 1-16, SSSA Special Publication Number 29, Wisconsin, USA

Eswaran, H., Almaraz, R., van den Berg, E. and Reich, P. 1997. An assessment of the soil resources of Africa in relation to productivity. *Geoderma*, **77**, 1-18

Evenson, R.E. and Gollin, D. 2003. Assessing the impact of the Green Revolution, 1960 to 2000, *Science*, **300**:758-762

FAOSTAT 2006

Fashola, O.O., Oladele. O., Alabi, M.O., Tologbone, D. and Wakatsuki, T. 2007a. Socio-economic factors influencing the adoption of Sawah rice production technology in Nigeria. *J. Food, Agriculture & Enivironment-JFAE*, 5:239-242

Fashola, O.O., Ademiluyi, Faleye, T, James, D. and Wakatsuki, T. 2007b. Machinery systems management of walking tractors (power tillers) for rice production (Sawah) in Nigeria, . *J. Food, Agriculture & Enivironment-JFAE*, 5:284-287

Greenland, D.J. 1997. *Sustainability of Rice Farming*, CAB Int'l, U.K. and IRRI, Los Banos, 273pp

Hirose, H. and Wakatsuki, T. 2002. *Restoration of Inalnd Valley Ecosystems in West Africa,* Nourin Tokei Kyoukai, Tokyo. 600pp

Hsieh, S.C. 2003. *Agricultural Technology Transfer to Developing Countries*, National Pintung University of Science and Technology Press, Taipei, 310pp

IITA 1989/1990. *Annual Report 1989/1990* International Institute of Tropical Agriculture, Ibadan, 20-21pp

Issaka, R. N., Ishida, F., Kubota, D., and Wakatsuki, T. 1997. Geographical distribution of selected soil fertility parameters of inland valleys in West Africa. *Geoderma* **75**: 99-116.

Jamin, J.Y. and Widmeijer, P.N. 1995. *Characterization of Inland Valley Agro-ecosystems: a Tool for their Sustainable Use*. Proceedings of the 1st Scientific Workshop of the Inland Valley Consortium, WARDA, Boauke, November 6-10, 1995, 325pp

JICA, 2003. *Study on international cooperation in rice farming in West Africa*, Japan International Cooperation Agency, JICA, Tokyo, 92pp+ Apendixes

Kawaguchi, K. and Kyuma, K. 1977. *Paddy Soils in Tropical Asia, Their Materials, Nature and Fertility*, University Hawaii Press, pp258,

Kiple, K.F and Ornelas, K.C. 2000. *The Cambridge World History of Food*, Cambridge Univ. Press, Cambridge. 2153pp.

Kyuma, K. 2004. *Paddy Soil Science*, Kyoto University Press, Kyoto, 280pp

Kyuma, K., Kosaki, T., and Juo, A.S.R. 1986. Evaluation of the fertility of the soils. In: *The Wetlands and Rice in Subsaharan Africa* Juo, A. S. R. and J. A. Lowe (Eds) , 43-58pp, Inter. Inst. Trop. Agric. , Ibadan

Levinson, D.H. 2005. *State of the Climate in 2004*. BAMS, American Meteorological Society, 1-89pp

Ministry of Food and Agriculture, Ghana 2007a. Inland valley rice development project, IVRDP, Consultancy Services for Surveys, Design and Construction

Supervision of Water Management Structures (LOT 1) PHASE 1, FINAL DESIGN REPORT, 96pp

Ministry of Food and Agriculture, Ghana 2007b. Inland valley rice development project, IVRDP, Consultancy Services for Surveys, Design and Construction

Supervision of Water Management Structures (LOT 5) PHASE 1, FINAL DESIGN REPORT, 55pp

Moormann, F. R., and Veldcamp, W.J. 1978. Land and rice in Africa: constraints and potentials. In: *Rice in Africa* Buddenhagen, I. W. and G. J. Persley (Eds), pp29-43 Academic Press, London

Ofori, J., Hisatomi, Y., Kamidouzono, A., Masunaga, T., and Wakatsuki, T. 2005. Performance of Rice Cultivars in Various Sawah Ecosystems Developed in Inland Valleys, Ashanti Region, Ghana, *Soil Sci. Plant Nutr.*, 51:469-476

Okigbo, B.N. 1990. Sustainable Agricultural Systems in Tropical Africa, In: *Sustainable Agricultural Systems*. Edwards, A., Lal, R., Madden, P., Miller, R.H., and House. G. (Eds), pp323-352, SWCS, Iowa

Qian, W., Debg, Y., Zhu, Y. and Dong, W. 2002. Demarcating the worldwide monsoon, *Theor. Appl. Climatol*. 71:1-16

Rasyidin, A. and Wakatsuki, T. 1994. Characterization of Precipitation and River Water Chemistry for Measuring Rates of Weathering and Soil Formation in Iu-River Watersheds, Southwestern Japan. *Soil Sci. Plant Nutr.*, 40:319-332

Ruthenberg, H. 1980. *Farming Systems in the Tropics*, Oxford Univ. Press, London, 424pp

Sanchez, P. 1976. *Properties and Management of Soils in Tropics*, Wiley & Sons, New York, 619pp

Smaling, E. M. A., Dyfan, T., and Andriesse, W. 1985 a. *Detailed Soil Survey and Quantitative Land Evaluation of the Rogbom-Makene and Matam-Romangoro Benchmark Sites, Makeni, Sierra Leone*, Wetland Utilization Research

Project, Phase II, ILRI, Wageningen, The Netherlands
Smaling, E. M. A., Kiestra, E., and Andriesse, W. 1985 b. *Detailed Soil Survey nd Quantitative Land Evaluation of the Echin-Woye and Kunko Benchmark Sites, Bida, Niger State, Nigeria*, Wetland Utilization Research Project, Phase II, ILRI, Wageningen, The Netherlands
Soil Survey Staff, 1998. *Keys to Soil Taxonomy*, 6th ed., SMSS of USDA, Washington DC, 306pp
Soil Survey Staff, 1999. *Soil Taxonomy, A Basic System of Soil Classification for Making and Interpreting Soil Surveys,* Natural Resources Conservation Service of USDA, Washington D C, 869pp
Takase, K. and Kano, T., 1969. "Development Strategies on Irrigation and Drainage" in Asian Agriculture Survey, Asian Development Bank, 520pp
Tian, G., Ishiada, F., and Keatinge, D. 2001. *Sustaining Soil Fertility in West Africa*, SSSA Special Pub. No.58, 321pp
Trenberth, K.E., Stepaniak, D.P., Caron, J.M. 2000. The Global Monsoon as Seen through the Divergent Atmospheric Circulation. *Journal of Climate*, 13:3969-3993
Wakatsuki, T. 2002. Sustainable agricultura development of West Africa during global environmental crises, In : *Restoration of Inland Valley Ecosystems in West Africa*. Hirose, S. and Wakatsuki, T. (Eds), pp1-82, Nourin Tokei Kyoukai, Tokyo
Wakatsuki, T. and Rasyidin, A. 1992. Rates of Weathering and Soil Formation, *Geoderma* 52:251-261
Wakatsuki, T., Rasyidin, A., and Naganawa, T. 1993. Multiple Regression Method for Estimating Rates of Weathering and Soil Formation in Watersheds. *Soil Sci. Plant Nutr.*, 39:153-159
Wakatsuki, T., Shinmura, Y., Otoo, E., and Olaniyan. 1998. Sawah system for integrated watershed management of small inland valleys in West Africa. In FAO ed., Water Report N0.17, *Institutional and Technical Options in the Development and Management of Small Scale Irrigation*, pp45-60, FAO, Rome
Wakatsuki, T., Otoo, E., Andah, W.E.I., Cobbina, J., Buri, M.M., and Kubota, D. (eds). 2001. *Integrated Watershed Management of Inland Valley in Ghana and West Africa: Eco-technology Approach*, Final Report on JICA/CRI joint study project, CRI, Kumasi, Ghana and JICA, Tokyo, 337pp
Wakatsuki, T. and Masuanga, T. 2005. Ecological Engineering for Sustainabel Food Production and the Restoration of Degraded Waterheds in Tropics of low pH Soils: Focus on West Africa. *Soil Sci. Plant Nutr.*, 51:629-636
Wakatsuki, T., Buri, M.M., and Fashola, O.O. 2005. Ecological Engineering for sustainable rice production and the restoration of degraded watersheds in West Africa. In: *Rice is life: Scientific Perspectives for the 21st Century*. Toriyama, K., Heong, K.L., and Hardey, B.(Eds), pp363-366, IRRI, JIRCAS, NARO, NIAS, NIAES, NIRE, APO, MAFF, Tsukuba
Walling, D.H. 1983. The sediment delivery problem. *J. Hydrological Sci*., 65:209-237
WARDA 1988. *WARDA's Strategic Plan: 1990-2000*. Bouake. 66pp.
WARDA, 2002. The African Rice Initiative (ARI): NERICA Consortium Security in Sub Saharan Africa. 40pp.
WARDA, 2004. *Strategic Plan: 2003-2012*, WARAD-The Africa Rice Center, Bouake. 58pp
Windmeijer, P.N. and Andriesse, W. 1993. *Inland Valley in West Africa: An Agroecological Characterization of Rice-Growing Environment*, ILRI, Wageningen, 160pp.

Table 6 Comparison between biotechnology and eco-technology options for improvement of rice production

(1) For Water shortage and flooding
Biotechnology: Genes for deep rooting, tolerance in submergence, C4-nature, Osmotic regulation genes,
Eco-technology of Sawah based soil and water management, bunding, leveling, puddling, well, weir, tank irrigation, and System rice intensification. Dyke construction and drainage

(2) For Poor nutrition, acidity and alkalinity
Biotechnology: Gene of Phosphate and micronutrient transporter
Eco-technology of Sawah based N fixation, increase P availability and micro- as well as macronutrient. Geological fertilization, Watershed agro-forestry, organic matter and fertilization. Use of birds feculent for the enrichment of P.

(3) For Weed control
Biotechnology: Gene of weed competition, rapid growth.
Eco-technology of Sawah based weed management through water control and trans-planting. Leveling quality of sawah is important. Duck and rice farming.

(4) For Pest and disease control
Biotechnology: Resistance genes.
Eco-technology of Sawah based silica and other nutrients supply to enhance immune mechanisms of rice. Mixed cropping.

(5) For Food quality
Biotechnology: Vitamin rice gene.
Eco-technology of Sawah based nutrition control. Fish, duck and rice in sawah systems

(6) For Carbon Sequestration
Biotechnology: Breeding of high biomass productive genes
Eco-technology: High biomass production and conservation of soil organic matter in Sawah soil

Table 7 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	(3-5)	7	(17)
Inland basins	107.5	(1-4)	45	(10)
Flood plains	30.0	(5-10)	12	(31)
Inland valleys	85.0	(5-15)	36	(42)

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.

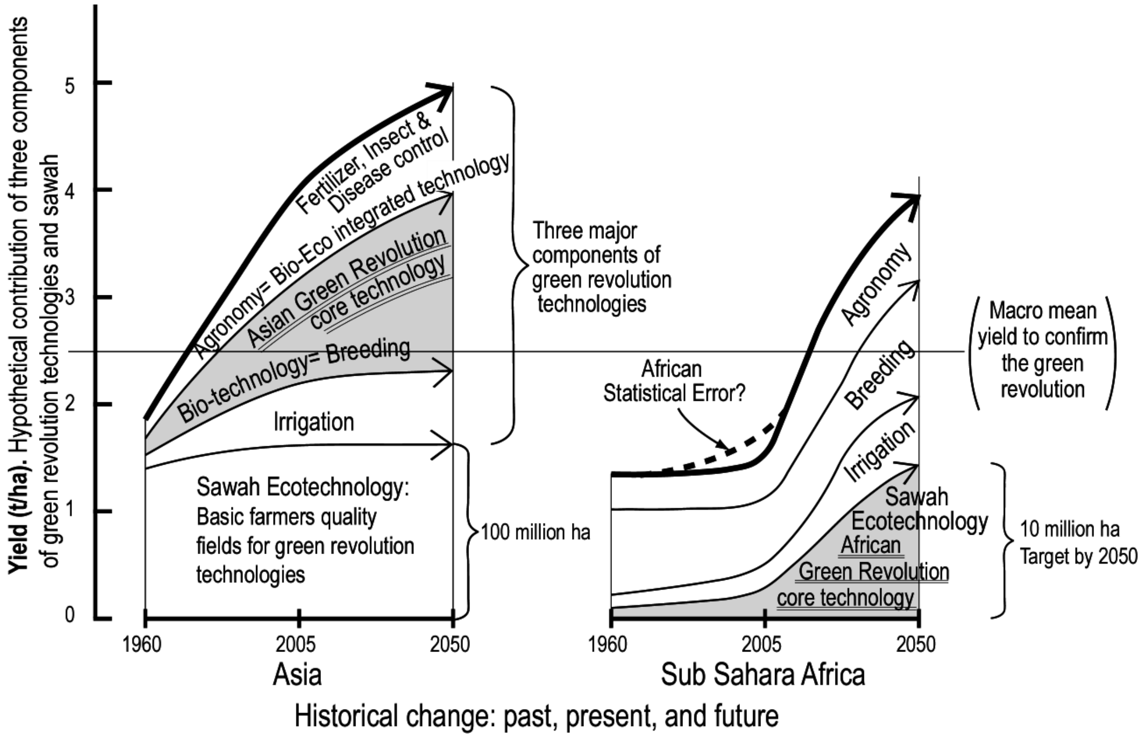


Fig. 7　Sawah hypothesis (I):

Hypothetical contribution of three green revolution technologies and sawah eco-technology during 1960-2005 and during 2005-2050 in Sub Sahara Africa and Asia.

The bold lines during 1960-2005 are based on mean rice yields based on FAOSTAT 2006. Bold lines during 2005-2050 are the expected or target trend based on the sawah hypothesis (I) by the authors.

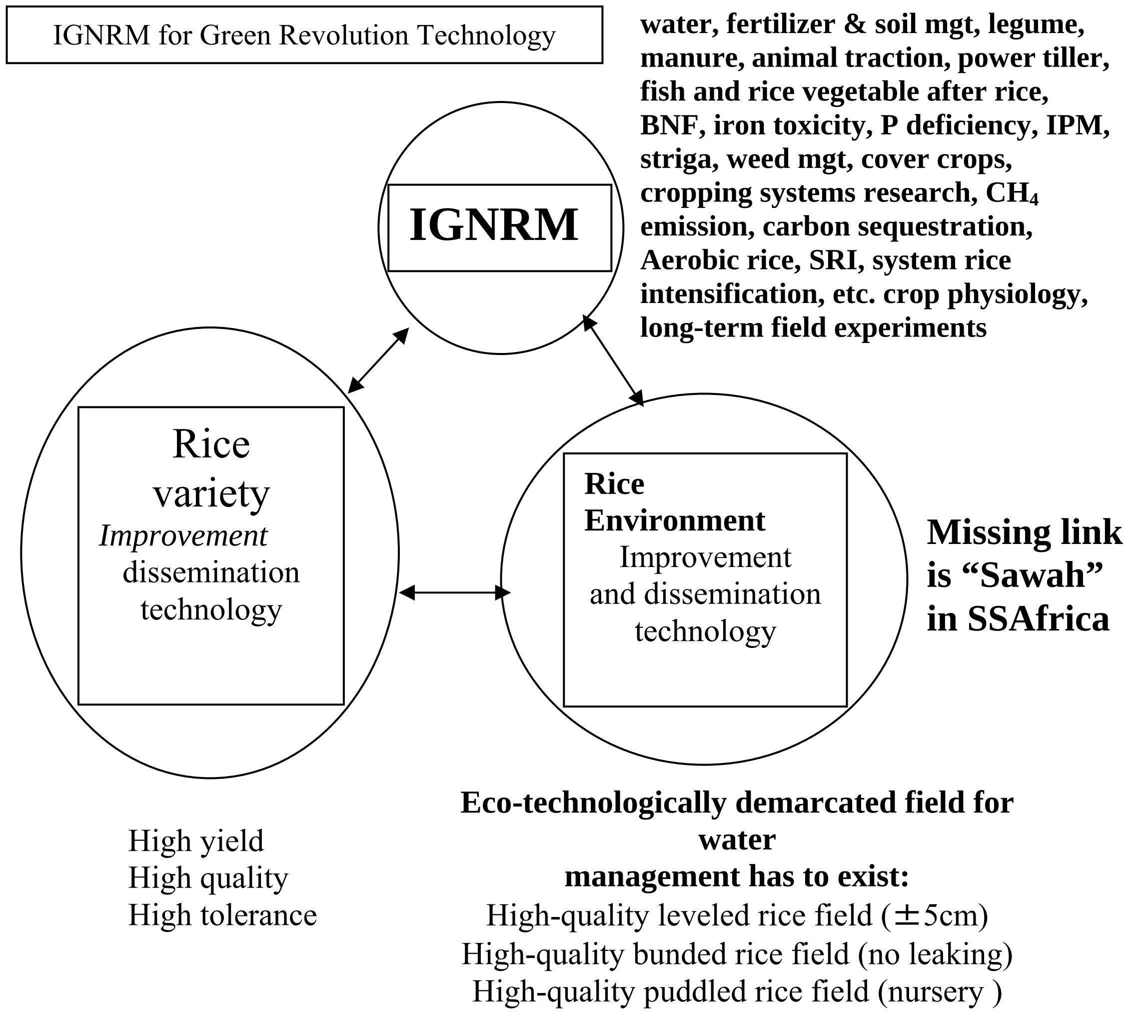


Fig. 8 Concept of "Integrated Genetic and Natural Resources Management (IGNRM)" for green revolution technology:
The missing link is Sawah which is lacking in the majority of famers' fields.

Can watersheds in SSA sustain the Sawah system?
The high rates of soil erosion and lowland sawah soil formation can be compensated by high rate of soil formation: Again, ecological balance is a Key

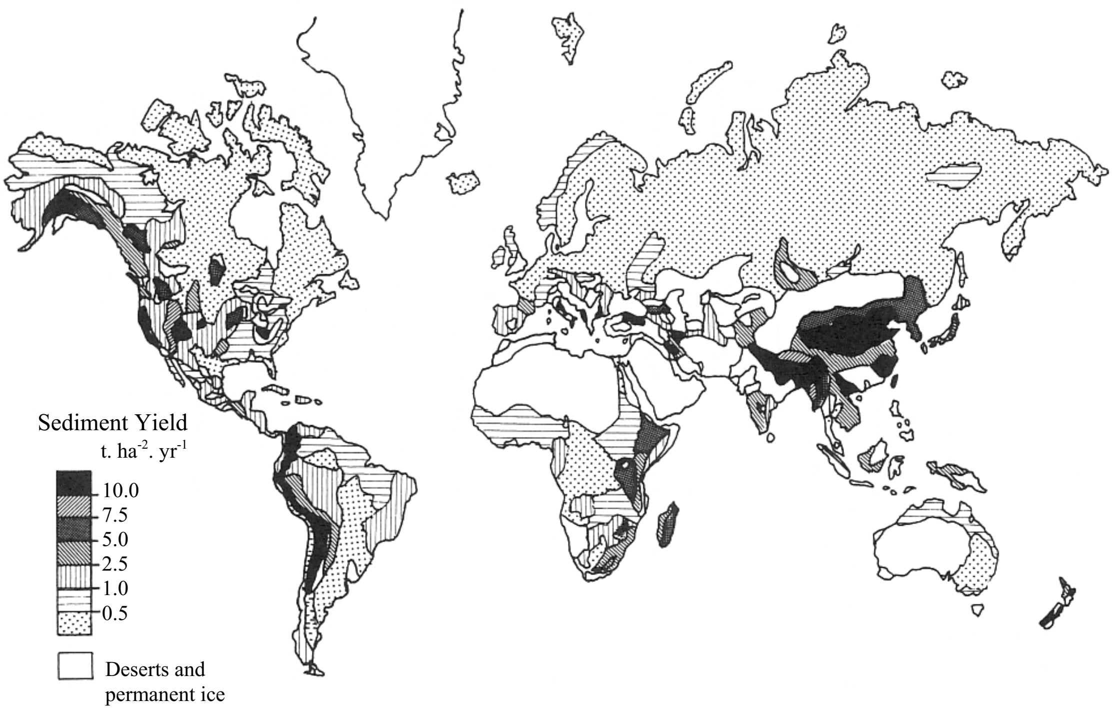
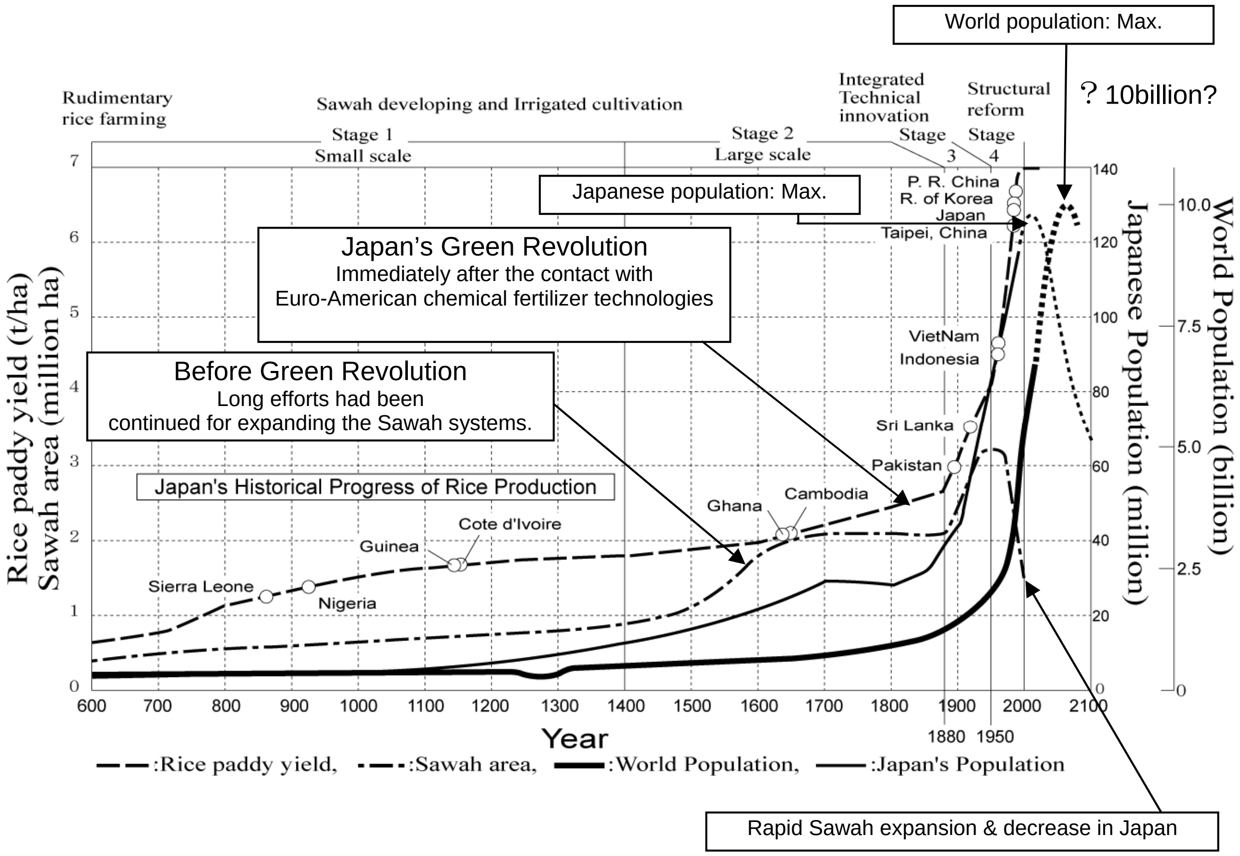


Fig. 9　Rates of soil erosion in the Worlds (Walling 1983)

Farmers' Sawah fields are the most important infrastructure.
Farmers' fields come first.

Japanese experience

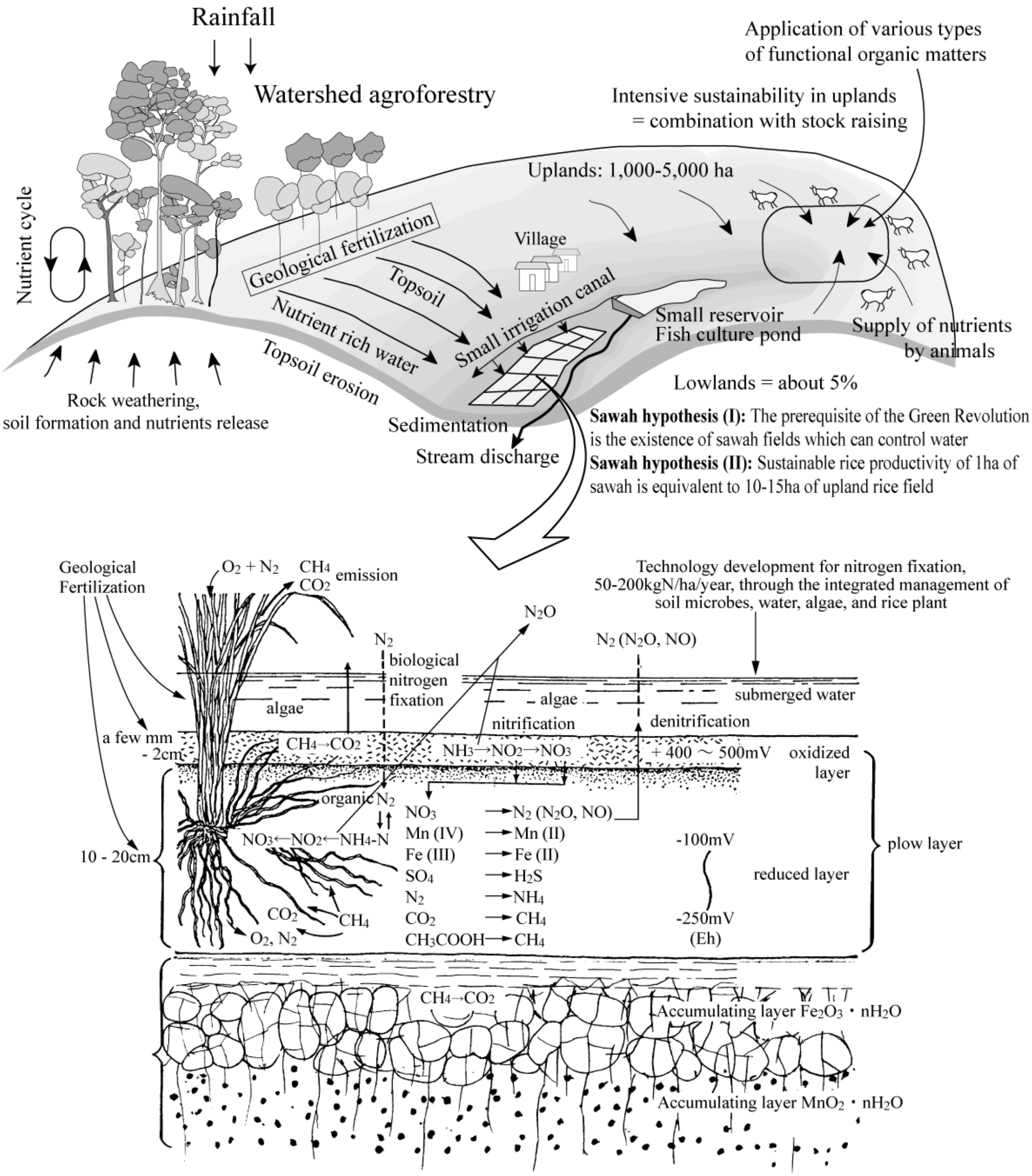


Transition of population, rice yields, and Sawah areas in Japan
in comparison with Asia and Africa
(Takase & Kano, 1969, modified)

Fig. 10 Historical paths of rice yields & Sawah areas in Japan in comparison with rice yields in Asia and Africa with Japanese and the world population trends in the past and near future. (JICA 2003, modified)

(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.

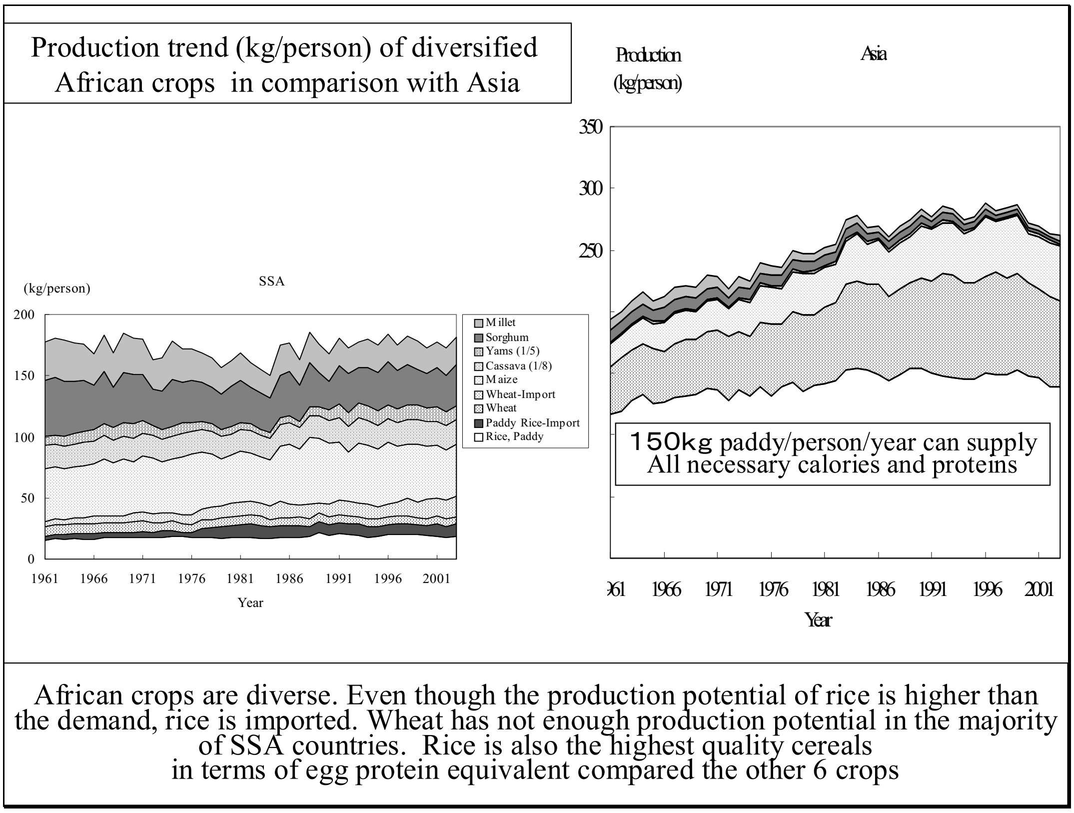


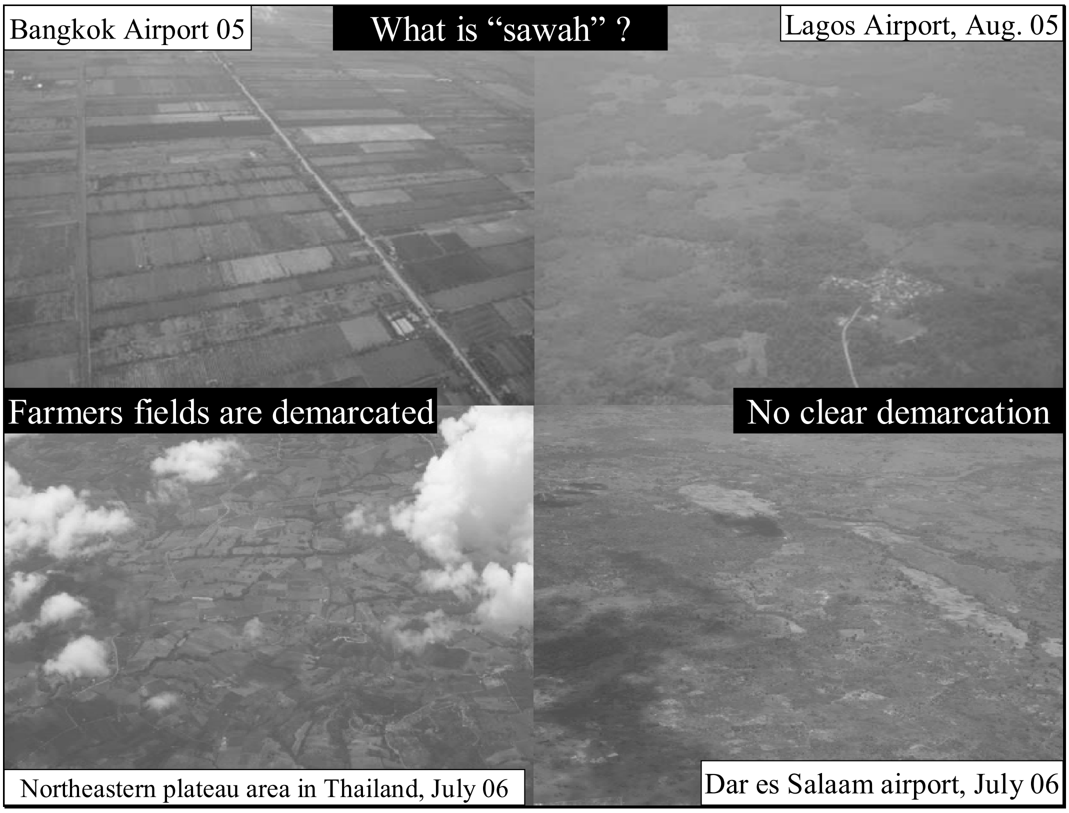
(2) Sawah system as multi-functionally constructed wetland for enhanced supply of N, P, Si and other nutrients.

Technological development for enhancing multi-functionality of wetland sawah in a diverse agro-ecologies for SSA is a key in IGNRM.

Fig. 11　(1) Macro- and (2) Micro-scale ecological mechanisms of intensive sustainability of lowland sawah systems


Why was the Green Revolution not Successful in
the Sub-Saharan Africa?: Sawah (SUIDEN) Hypothesis (1)
T. Wakatsuki, Kinki University
Guinea, Aug.03
No Sawah, No Green Revolution
Inland valley, Sierra Leone, Jan.89
Water control through sawah system is a prerequisite for Green Revolution in SSA
Fish & Rice
Nupe's indigenous rudimentary sawah system, Nigeria,Sep.05
CRI/JICA Sawah Project, Ghana, Aug.01


Production trend (kg/person) of diversified African crops in comparison with Asia
(kg/person)
SSA
Millet
Sorghum
Yams (1/5)
Cassava (1/8)
Maize
Wheat-Import
Wheat
Paddy Rice-Import
Rice, Paddy
Year
Production (kg/person)
Asia
150kg paddy/person/year can supply All necessary calories and proteins
Year
African crops are diverse. Even though the production potential of rice is higher than the demand, rice is imported. Wheat has not enough production potential in the majority of SSA countries. Rice is also the highest quality cereals in terms of egg protein equivalent compared the other 6 crops



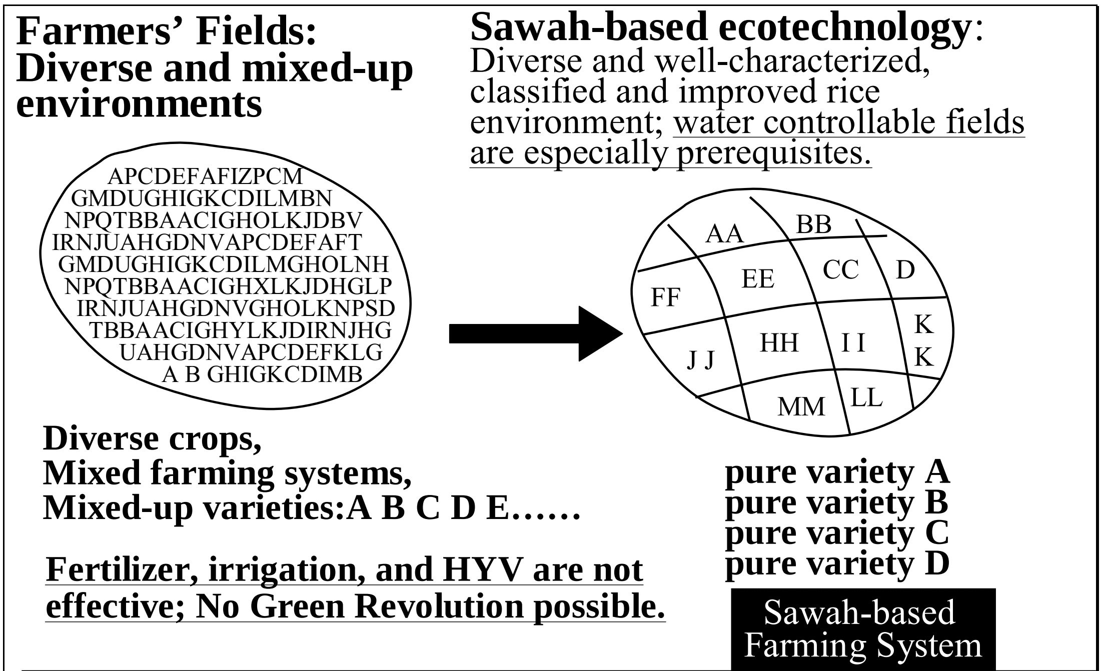


Fig. 7 Successful Integrated Genetic and Natural Resource Management needs classified and demarcated land ecotechnology.

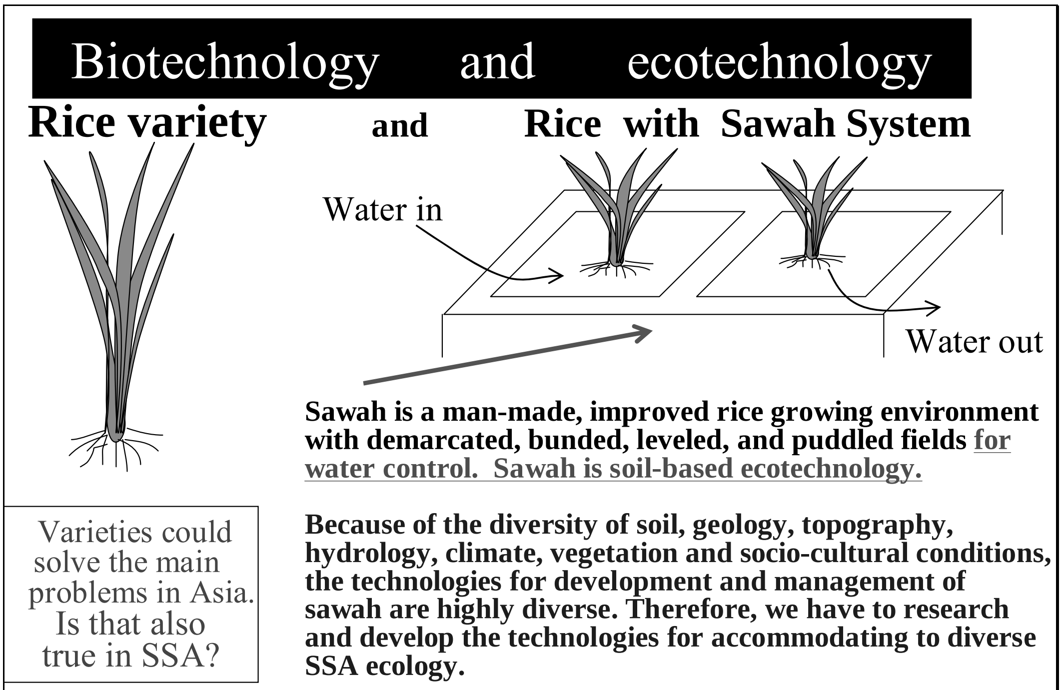


Fig. 2 Rice (variety) and environment (Sawah) both in bio & ecotechnologies must be improved and developed in a balanced manner.

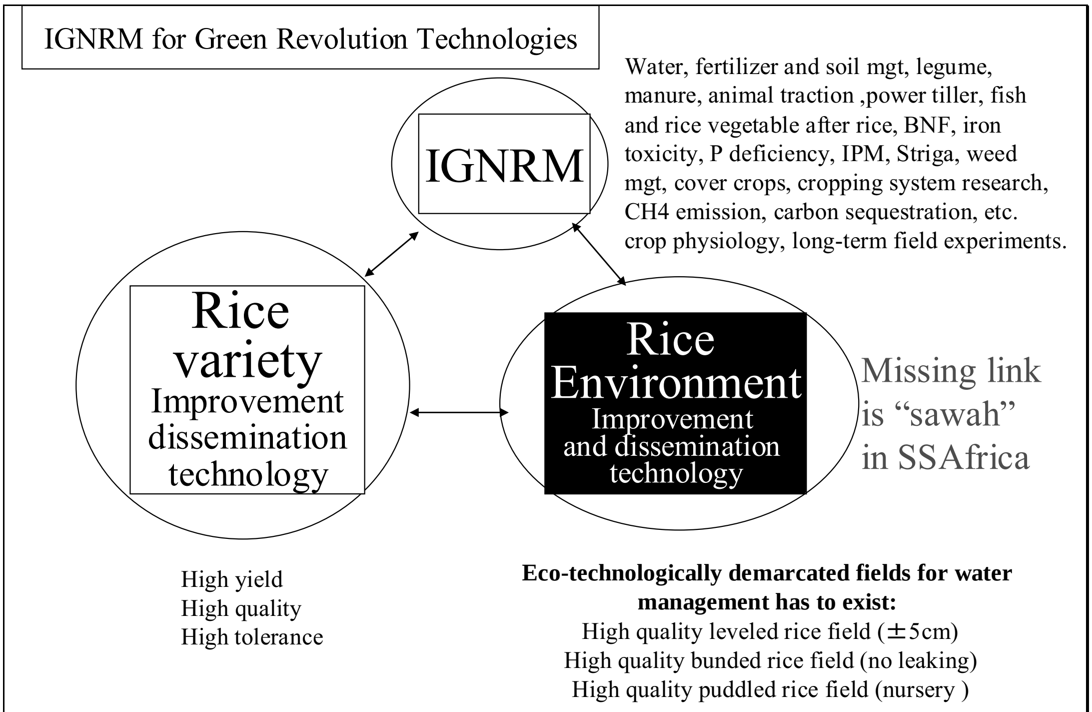
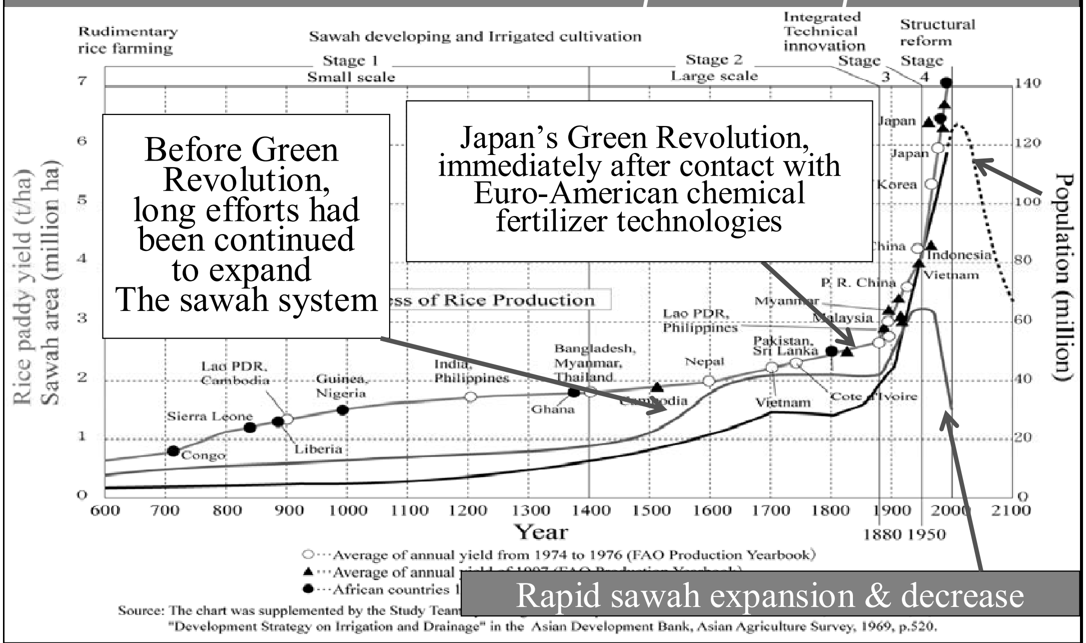


Fig. 8 Concept of Integrated Genetic and Natural Resources Management (IGNRM) for green revolution technologies
<u>The missing link is Sawah which is lacking in the majority of famers’ fields</u>

Farmers' sawah fields are the most important infrastructure.
Farmers' Fields come First. *Japanese Experience*



Population, rice yields & sawah areas of historical path in Japan in comparison with Asia & Africa Takase & Kano,1969, modified

Sawah: Lacking in the Concept, Terms and Ecotechnologies

This has been disturbing the balanced approach for rice development in West Africa and SSA in the last 30 years.

Confusion about paddy, irrigation, water control, and the sawah system

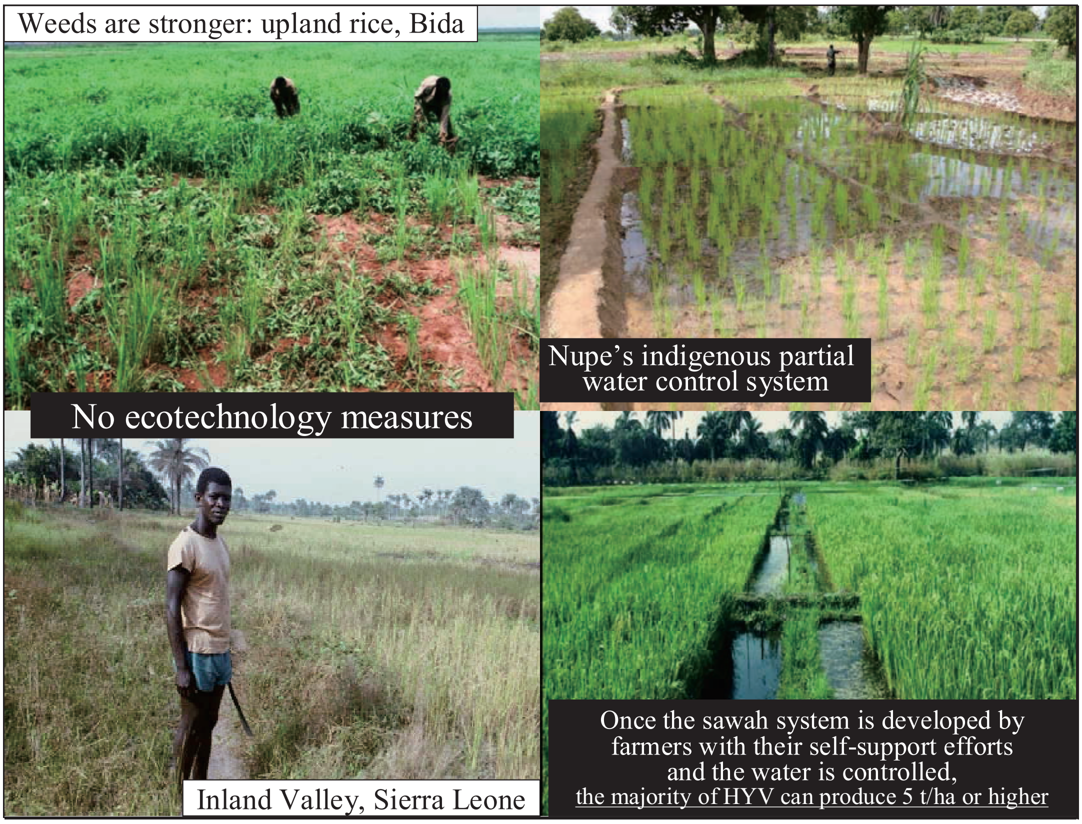
Farmers' work　　Governmental work

- Sawah Hypothesis (1): Prerequisites for Green Revolution:
  Are the farmers' field conditions ready to accept
  the irrigation water, fertilizer and HYV, or not?
- Sawah Hypothesis (2): We have to overcome the scarce nutrients and water. Sustainable rice productivity under the sawah system is 10-15 times higher than those in upland rice fields.
- We must remember that lack of the concept & terms made the "Tsunami" disaster enormous in Sumatra.

No proper English/French ecotechnological concept and term to improve farmers' rice fields, Sawah or SUIDEN (in Japanese)

Suiden (Japanese) =SAWAH (Malay–Indonesian)

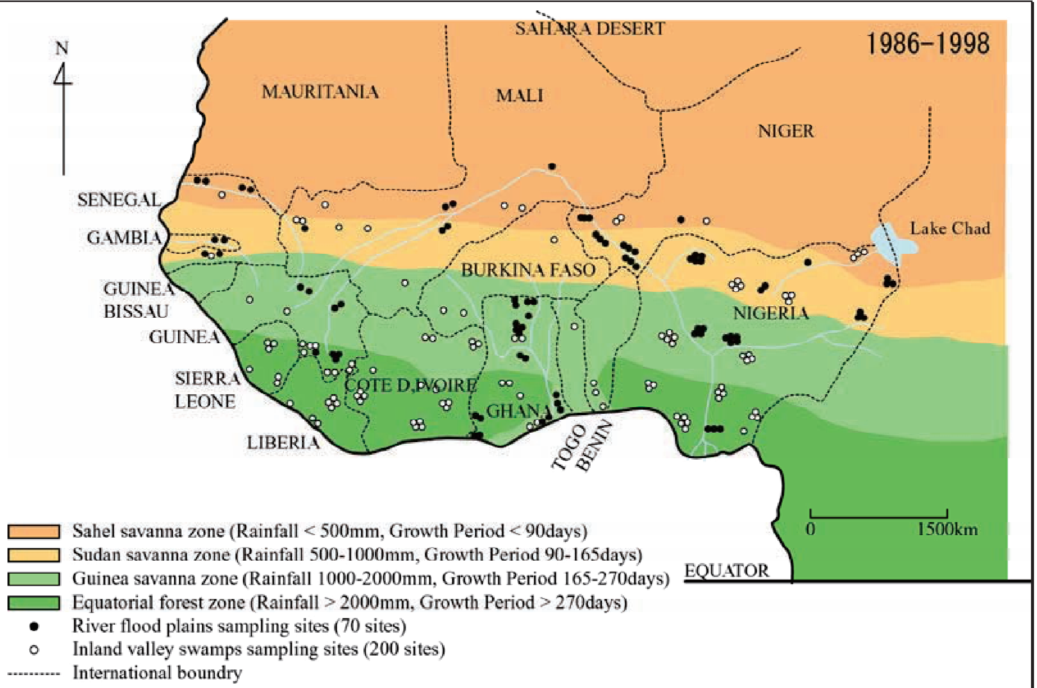
	English	Indonesian	Chinese (漢字)
Plant Biotechnology	Rice	Nasi	米, 飯, 稲
	Paddy	Padi	稲, 籾
Environment Ecotechnology	(Paddy) ?	Sawah	水田



The mean gain yields of 23 rice cultivars in lowland ecologies at low (LIL) and high input levels (HIL), Ashanti, Ghana (Ofori & Wakatsuki, 2005)

	Entry No.	Cultivar	← ECOTECHNOLOGICAL YIELD IMPROVEMENT: Irrigated sawah HIL (t/ha)	Irrigated sawah LIL (t/ha)	Rainfed sawah HIL (t/ha)	Rainfed sawah LIL (t/ha)	Upland-like fields HIL (t/ha)	Upland-like fields LIL (t/ha)
BIOTECHNOLOGICAL IMPROVEMENT	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

Due to the cost of green revolution technology, the yield must be higher than 4 t/ha

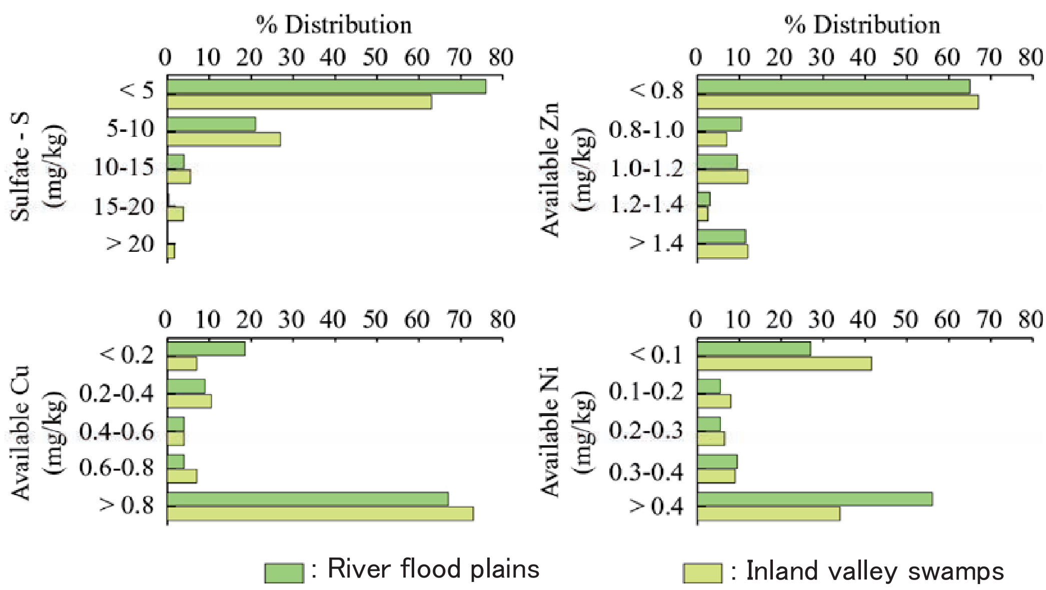


West Africa Map showing the selected sampling sites of lowland soils. (Buri and Wakatsuki, 2000)

The mean values of fertility properties of inland valleys (IVS) and flood plains (FLP) of West Africa in comparison with lowland top-soils of tropical Asia and Japan

Location	Total C (%)	Total N (%)	Available P (ppm)**	Exchangeable Cation (cmol/kg) Ca	K	Mg	eCEC	Sand (%)	Clay (%)	CEC /Clay
IVS	1.3	0.11	9	1.9	0.3	0.9	4.2	60	17	25
FLP	1.1	0.10	7	5.6	0.5	2.7	10.3	48	29	36
T. Asia*	1.4	0.13	18	10.4	0.4	5.5	17.8	34	38	47
Japan	3.3	0.29	57	9.3	0.4	2.8	12.9	49	21	61

*Kawaguchi and Kyuma (529 sites), 1977,** Bray II.
Source: Hirose and Wakatsuki (268 sites), 1997.



S & Zn Deficiency: The frequency distribution of topsoil (0-15cm) available nutrients in West Africa lowlands. (Buri & Wakatsuki. 2001)

How can we overcome such low level nutrients & scarce water in Sub Sahara West Africa?

- Developing lowland sawah is the answer.
- The integrated management of lowland & upland such as watershed agro-forestry is also the key ecotechnology.
- The core region of West Africa has similar climate, soil, hydrology and crops to those in the northeastern Thailand; the important site in Asian-African collaboration in the future.

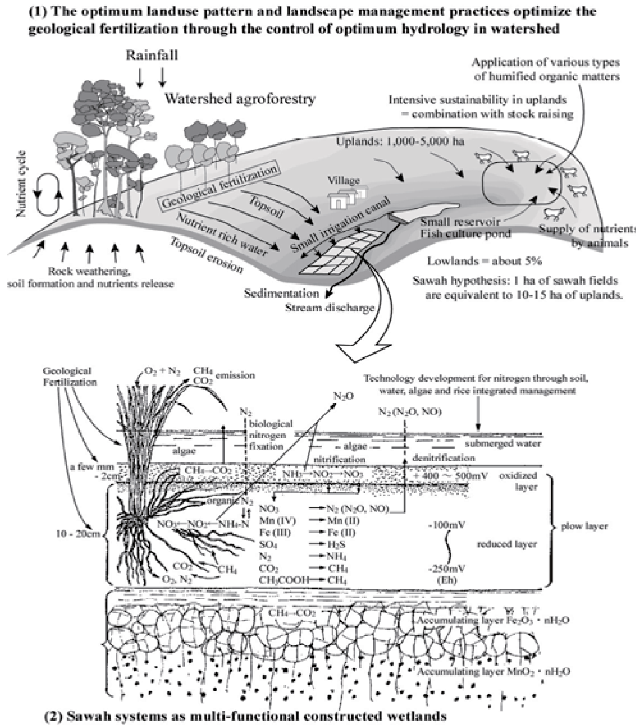
Sawah hypothesis (II): Sustainable productivity of lowland sawah fields are more than 10 times higher than the upland fields; This is not scientifically experimented results, but experienced results in Asia

1 ha sawah = 10-15ha of upland

	Upland		Lowland (Sawah)
Area (%)	95 %		5 %
Productivity (t/ha)	1-3 1≦**		3-6 2**
Required area for sustainable 1 ha cropping	5 ha	:	1 ha

* Assuming 2 years cultivation and 8 years fallow in sustainable upland cultivation, while no fallow in sawah

**In the case of no fertilization

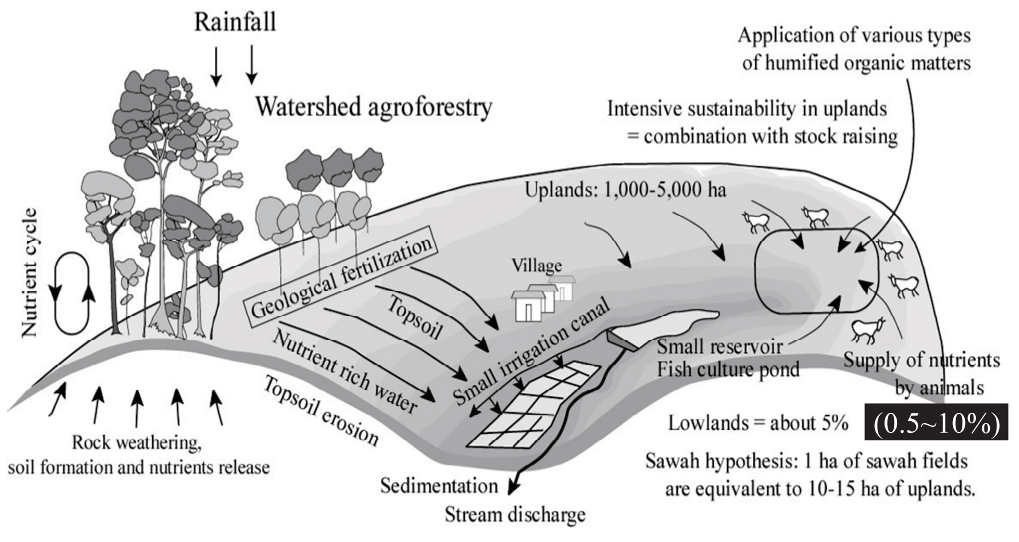


Macro- and Micro-scale Ecological Mechanisms of Intensive Sustainability of Lowland Sawah System

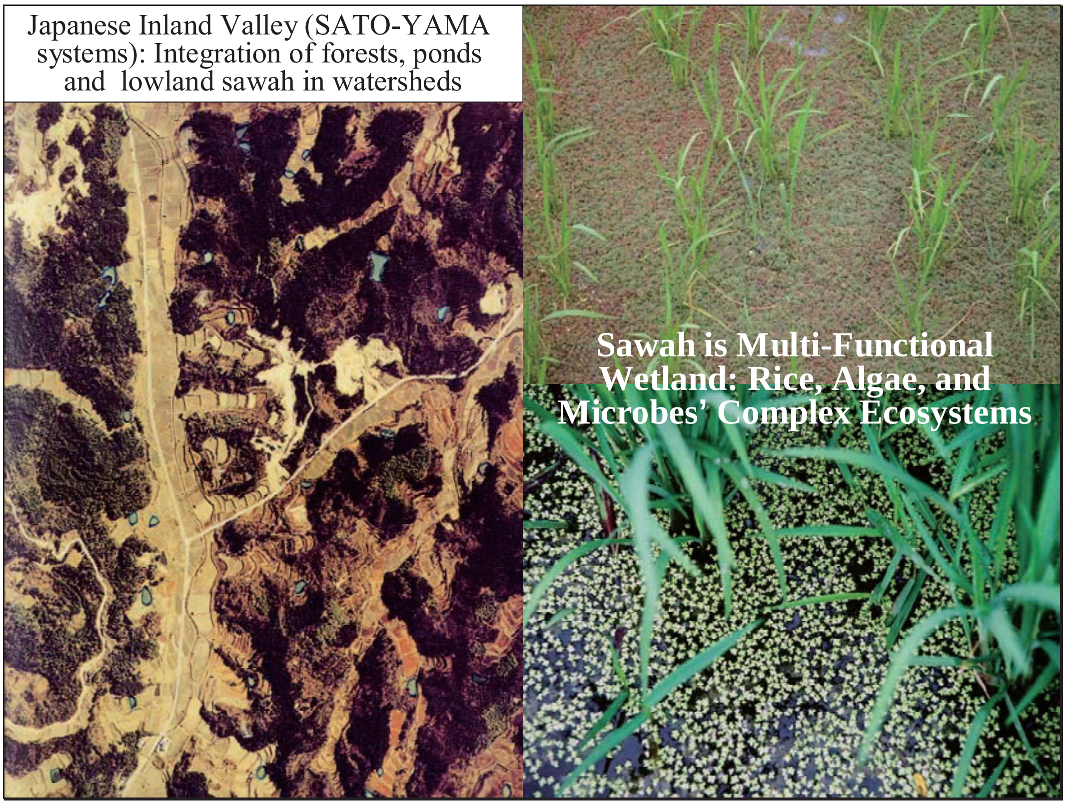
(1) Geological Fertilization: the lowland can receive water, nutrients, and fertile topsoil from the uplands.

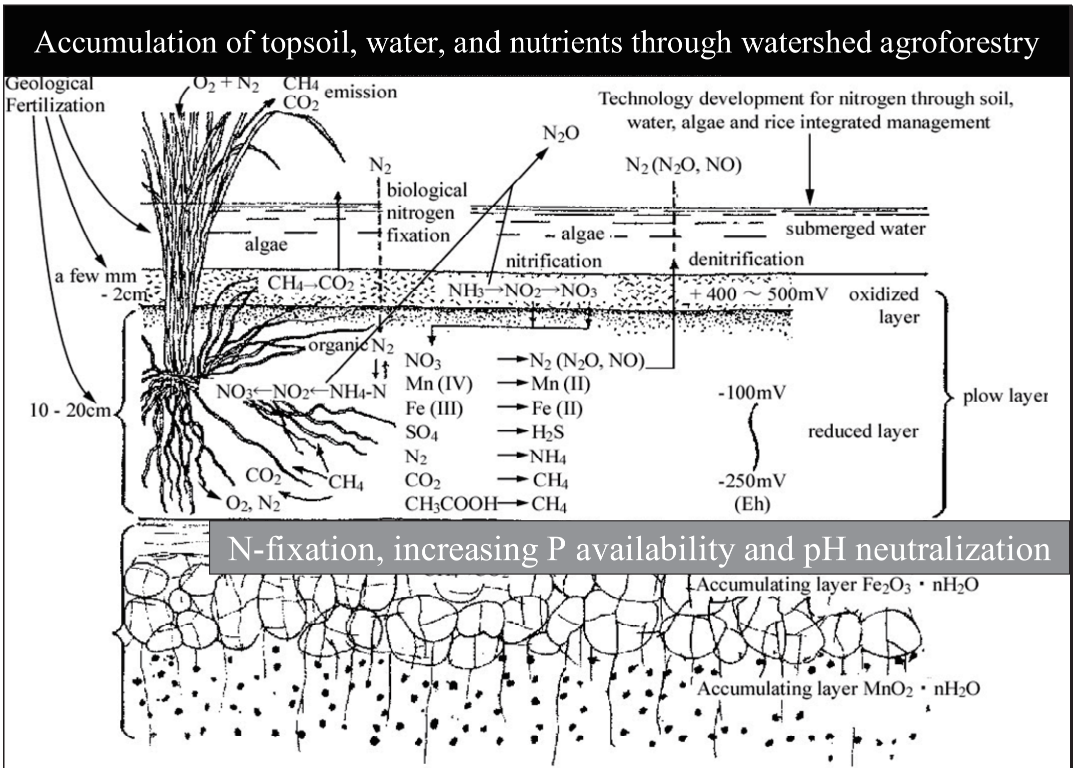
(2) Multi-functional Constructed wetlands for controlling weeds and enhancing supply of N, P, Si, and other Nutrients

(1) The optimum landuse pattern and landscape management practices optimize the geological fertilization through the control of optimum hydrology in watershed



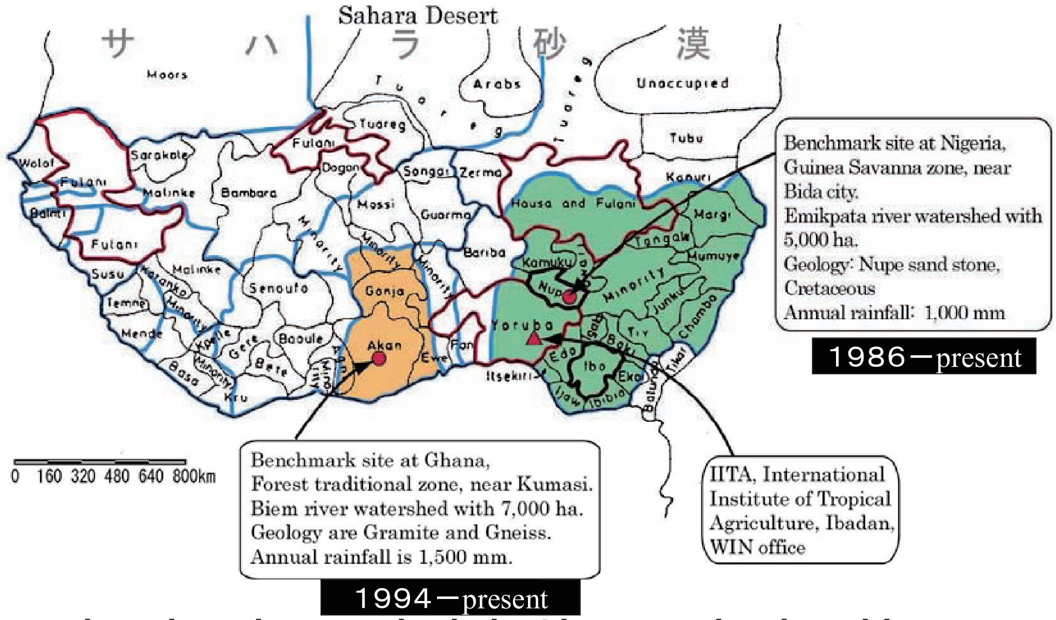
The concept of Watershed ecotechnology.
i.e.,(1)Watershed Agro-forestry and
(2)Multi-functional sawah-type wetland are the key components





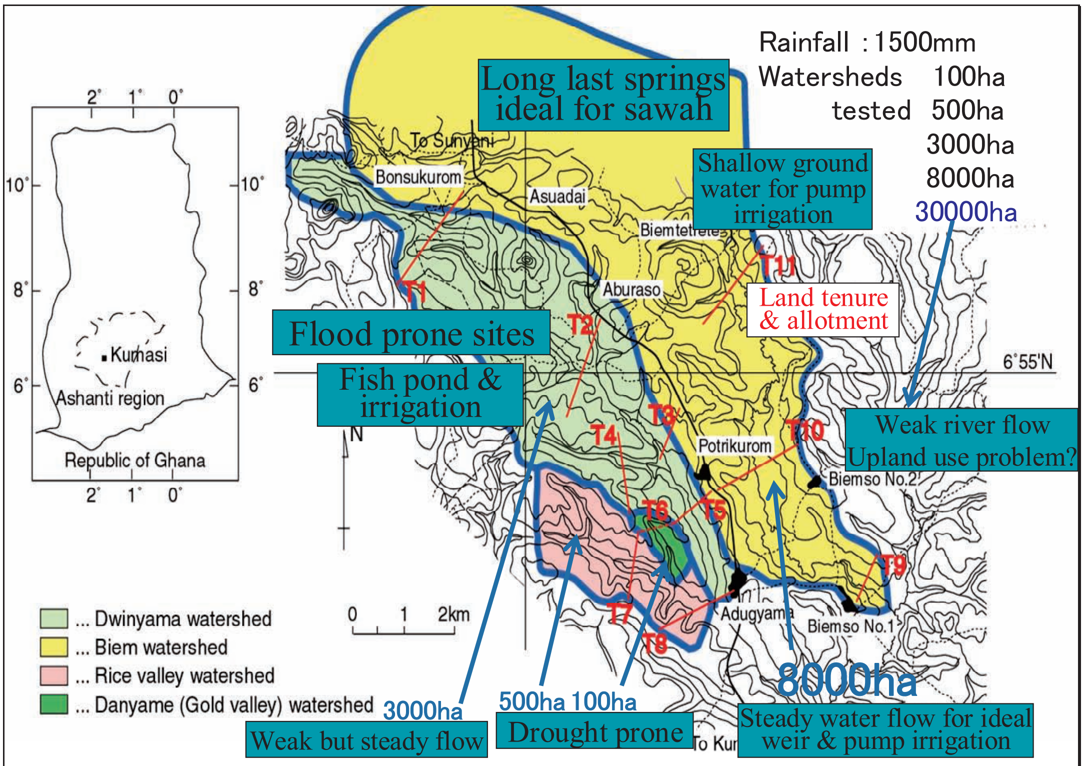
(2) Sawah systems as multi-functional constructed wetlands

Examples of eco-technological research & development



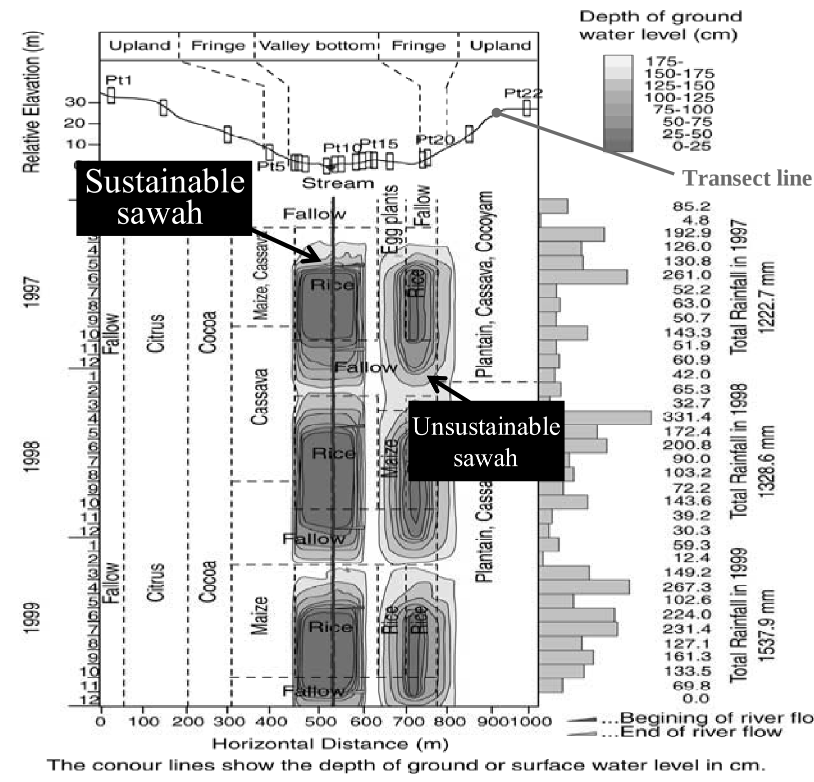
Two benchmark watersheds in Ghana & Nigeria. This map shows the countries with the major ethnic groups in West Africa

CRI-CSIR/JICA Sawah Project for integrated watershed management, 1997-2001

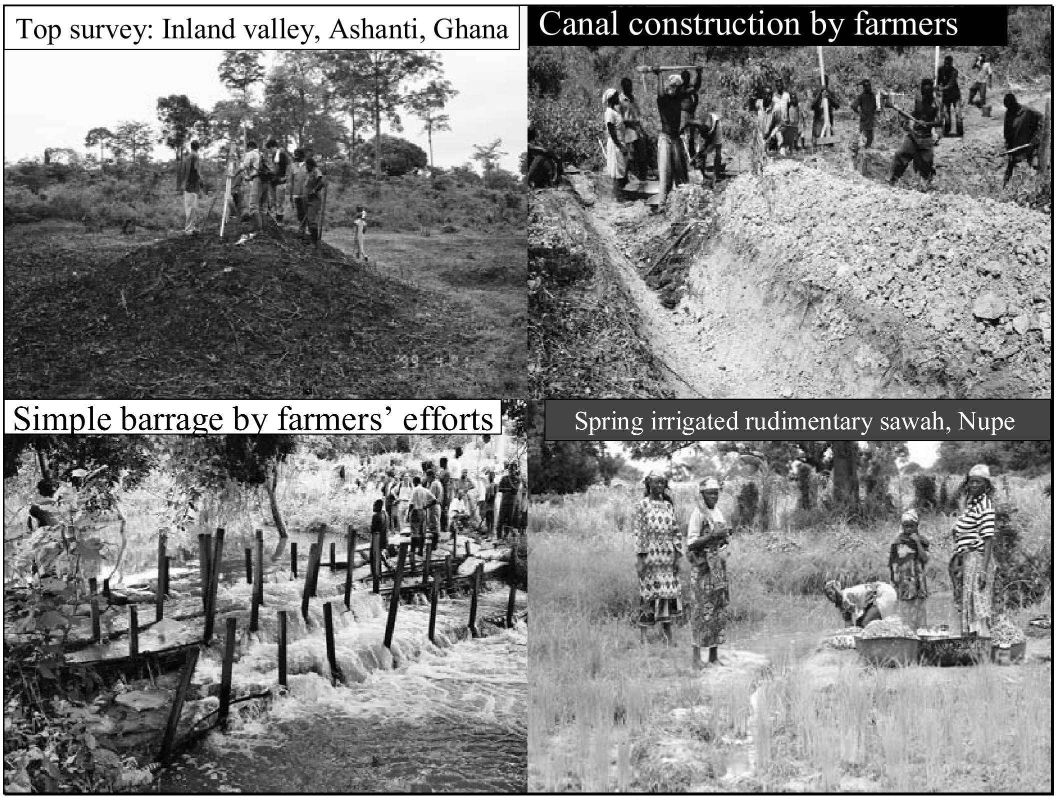


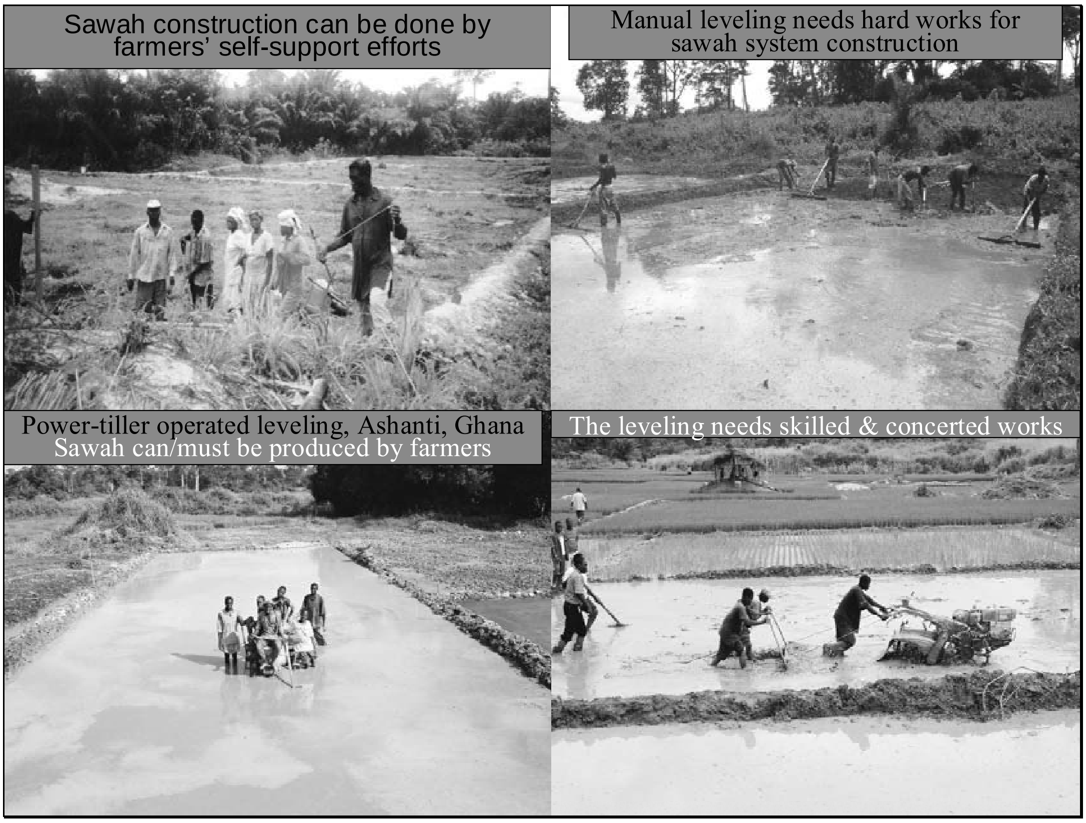
Research sites showing the location of transects in the watersheds.

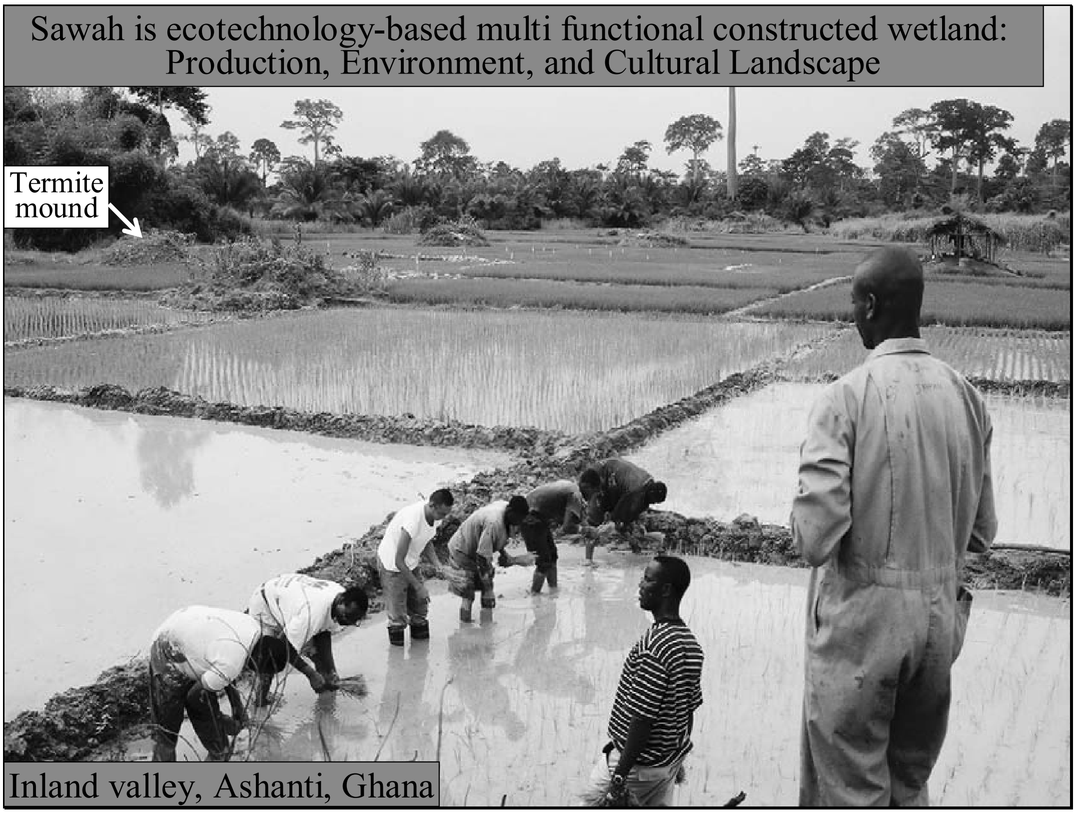
Although hydrology is the base for success of sawah, the performance of various ecotechnologies in watershed can be evaluated by water flow.

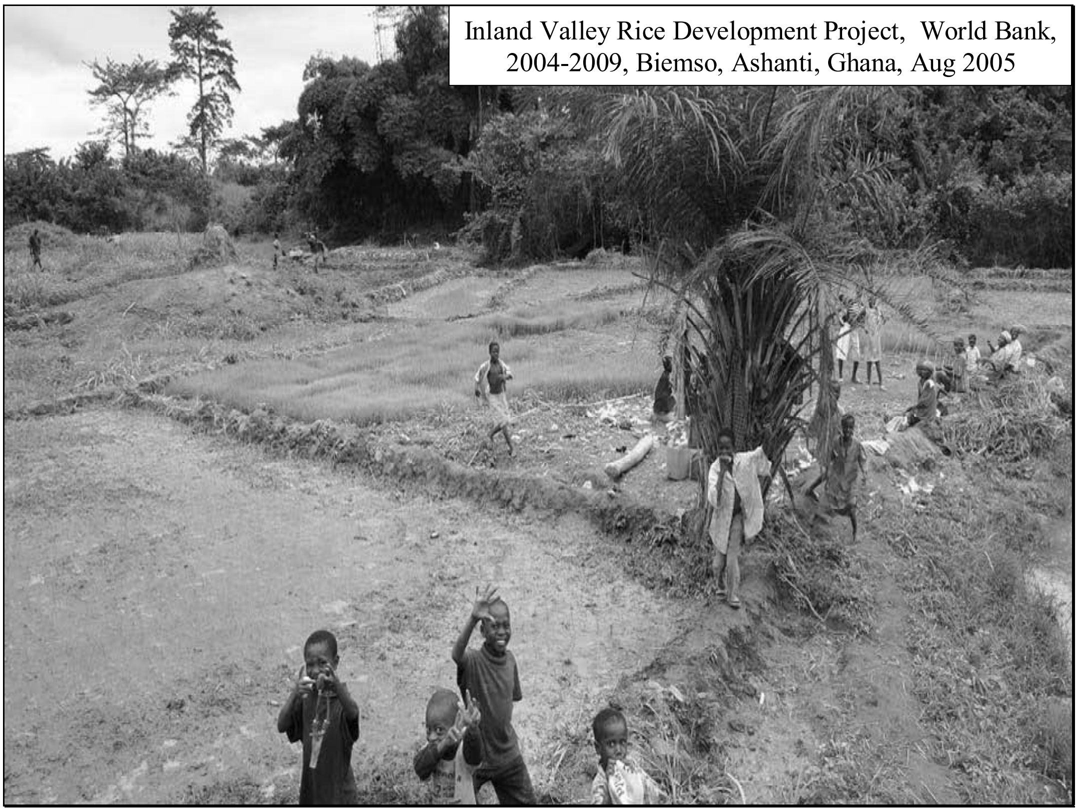


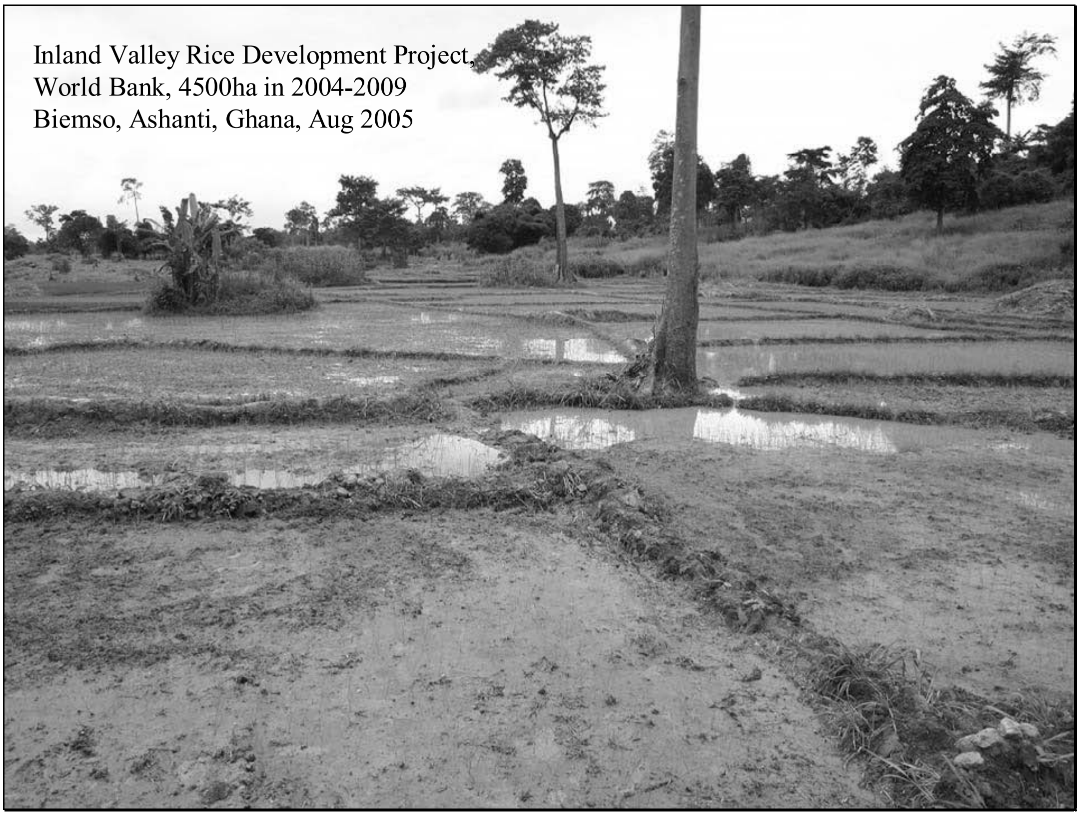
Cross-section of topography, rainfall pattern, ground/surface water and land use dynamics in stream flow inland valley (Transect 5), Dwinyan watershed, Ashanti Region, Ghana.



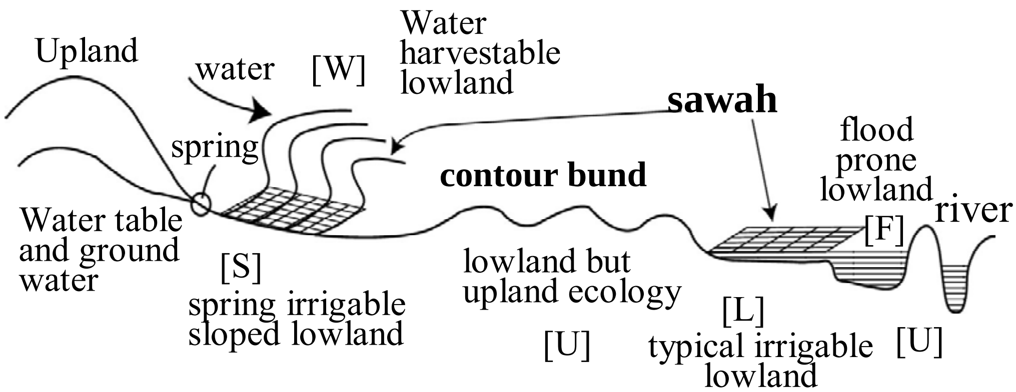

Sawah construction can be done by farmers' self-support efforts
Manual leveling needs hard works for sawah system construction
Power-tiller operated leveling, Ashanti, Ghana
Sawah can/must be produced by farmers
The leveling needs skilled & concerted works


Sawah is ecotechnology-based multi functional constructed wetland:
Production, Environment, and Cultural Landscape
Termite mound
Inland valley, Ashanti, Ghana


Inland Valley Rice Development Project, World Bank,
2004-2009, Biemso, Ashanti, Ghana, Aug 2005


Inland Valley Rice Development Project,
World Bank, 4500ha in 2004-2009
Biemso, Ashanti, Ghana, Aug 2005

Inland Valley Rice Development Project,
World Bank, 4500 ha in 2004-2009
Biemso, Ashanti, Ghana, Aug 2005



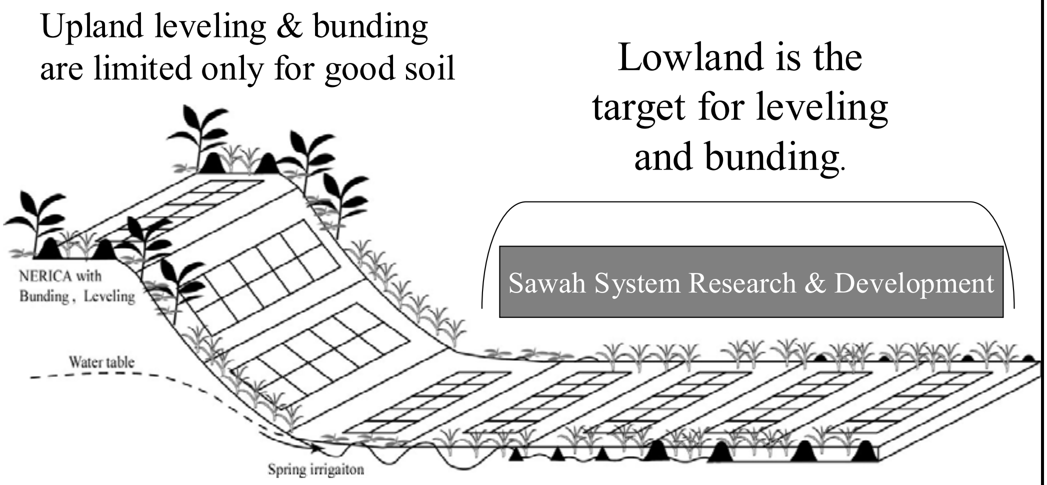
Irrigation options: Sawah to sawah/contour bund water harvesting, spring, dyke, river, pump, peripheral canal, interceptor canal, tank

Lowland sawah development priority

[S] > [L] > [F] > [W] > [U]

Concept of characterization and quantitative mapping of lowland diversity for sawah development (bunded, leveled, puddled rice land), depending on the watershed land use, lowland topography, soil, hydrology and Agroecological zones

Rice farmer's field demarcation based on soil, water, and topography is the starting point for scientific observation, technology generation, and application.



Water table and water management continuum (WARDA2004, 2006)

Can watersheds in SSA sustain the sawah system? The high rate of soil erosion and lowland sawah soil formation can be compensated by the high rate of soil formation: Again, Ecological Balance is a Key

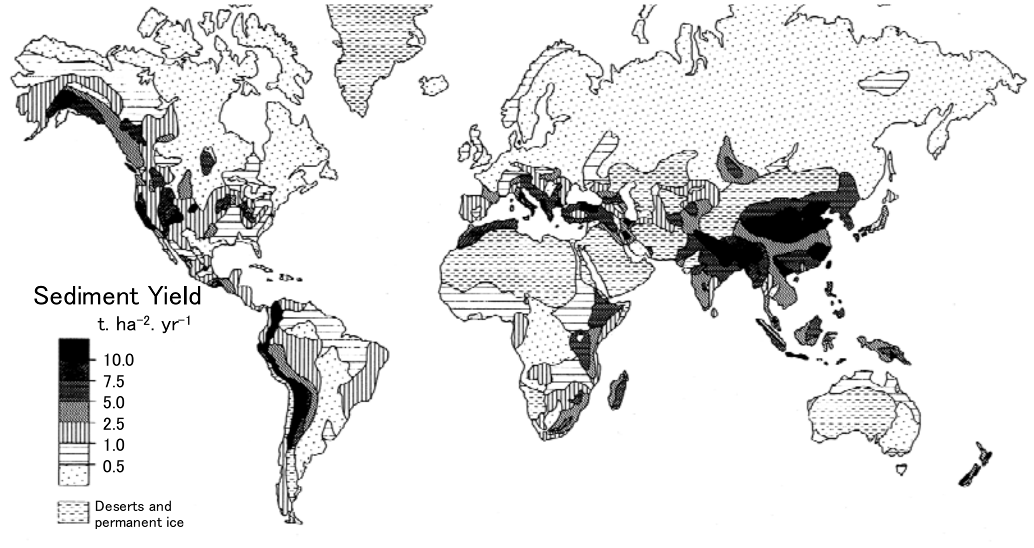


Fig. 1 Rate of soil erosion in the world (Walling1983)

Table 2 Estimation of rice production trends by each rice ecology in West Africa during 1984-1999/2003

The **2015** estimation is by the author
(WARDA Strategic Plan in 1988, African Rice Initiative 2002, Sakurai 2003, WARDA Strategic Plan 2004, FAOSTAT 2005)

	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	1	**1**
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**

Distribution of lowlands and potential irrigated sawah in SSA
(Hekstra, Andriesse, Windmeijer 1983 & 1993,
Irrigated sawah areas estimation by Wakatsuki 2002)

Classification	Area (million ha)		Percentage(%)
Coastal swamps	16.5	(3-5)	10-30%
Inland basins	107.5	(1-4)	1-3%
Flood plains	30.0	(5-10)	10-30
Inland valleys	85.0	(5-15)	3-10

Possible areas of sawah development (million ha)

Max. 20 million ha
(Estimated sawah areas came from the relative amount of water cycle in Monsoon Asia which has 100 million ha of sawah)

Conclusions

- Different from Asia, SSA's Green Revolution will be led by sawah type ecotechnology.
- The upland rice should be given low priority and be discouraged if lowland sawah development is possible.
- Major Constrains are:

(1) Demarcation of appropriate lowlands for sawah development

(2) Land-ownership systems to encourage sawah development

(3) Small machinery to accelerate the sawah development

(4) Education and training systems for sawah development and management

Conclusion:
Integrated ecotechnology and biotechnology are the base for

African Green Revolution

These are still rudimentary sawah (Bida, Nigeria), but the number of sawah-based rice farmers who are consciously developing water & soil management systems are steadily increasing in the past 15 years. The prerequisites will be soon satisfied therefore within 10-20 years, and the green revolution will be realized in SSA, especially in West Africa, if properly balanced strategy & policy were adopted for African green revolution.

質疑応答
Question and Answer Session

サブサハラアフリカでは何故緑の革命が遅れたか？：水田仮説（1）
Why was the Green Revolution not Successful in Sub-Sahara Africa?: Sawah (Suiden) Hypothesis (1)

若月　利之　Toshiyuki Wakatsuki
近畿大学農学部教授
Professor, Faculty of Agriculture, Kinki University, Japan

司会：杉本　充邦　Chair person: Mitsukuni Sugimoto
名古屋大学農学国際教育協力研究センター　准教授
Associate Professor, ICCAE, Nagoya University

Sugimoto, Chair:

Thank you very much, Professor Wakatsuki. Professor Wakatsuki has mentioned about utilization of water system in Africa and Asia. He mentioned about the difference of the Green Revolution in Africa and that in Asia. I'd like to ask the participants. Are there any questions?

Iijima:

Thank you very much for your presentation. Initially, you have mentioned that it is farmers who can develop the sawah system. However, I understand your conclusion as the government or donors should develop the sawah system. Which do you think is the case?

Wakatsuki:

I said the big irrigation scheme should be led by the government. On the other hand, works for the farmers' fields including the sawah system development should be led by the farmers. Fortunately in the case of Ghana, we have developed quality sawah systems which secure paddy yield higher than 4 t/ha, through farmers' self-support efforts. However, the sustainability of the sawah systems developed may be affected by the landowner systems. Therefore, we have to research in order to adjust or to modify the present landowner systems for sustaining and encouraging the sawah development.

Iijima:

Do you mean that the farmers themselves can solve their landownership problems? Because it's a very legal system, it must be the government which can solve this kind of landowner system.

Wakatsuki:

Since sawah systems can give much higher yield comparing to traditional rice production, some sawah farmers get some money power to solve the land tenure problems. But the other farmers may loss shortly after the sawah systems developed by the request of landowner. The important point is how we can adjust/modify/change such an African way of landownership system to encourage sawah system development.

Maybe we had better to ask Professor Onyango. Is there any possibility of encouraging African people to develop their own landowner systems to encourage agricultural development?

Onyango:

I think it is possible. The presentation was very productive and you indicated that the problem of sawah system is with the government especially on the infrastructure which is the same as the conclusions I reached in my presentation. The land ownership system if at all it has to be done legal must be done by the government. Therefore the government still comes in as the as farmer can not work in a vacuum. A farmer cannot develop the Sawah system you are talking about if they are not sure whether they will own that land tomorrow or not. Therefore the government still comes in. The idea you are trying to put up is correct but you need to integrate them, so that we know which part the farmer can play and which part the government plays. It is the government which has to come in first, because they have to demarcate land, issue title deeds transferring the ownership to farmers whether male or female. After that the Sawah system can be developed and the green revolution will take off. I think that is the approach. Thank you.

Iijima:

Thank you very much for your presentation. I think even if the land tenure problems are solved by changing the policy of the government, what is the mechanism to disseminate or to accelerate the lowland development by farmers. That is my first question. And the second is, what do you mean by the word "discouraging lowland rice systems through the active promotion of upland NERICA"? Do you mean that they might abandon their upland rice? And my third question is, at first you said the farmers are not ready to accept the green revolution technologies. What does the "accept" mean? Does it mean that the farmers still can not accept the green revolution technologies? Or, is it merely a problem of availability or something like that? What do you mean by "accept"?

Wakatsuki:

Actually, I don't know much about the approach of the dissemination of sawah technologies regarding your first question. Establishing an institutional organization is very important for developing the sawah system. However, the most important thing will be how we can organize the mechanisms or systems to give the training for sawah technologies to many, maybe ten million Sub-Sahara African farmers, and encourage them to improve their yields through sawah systems. How can we do this in a relatively short time?

I think the key issue is training farmers in sawah technologies. We have to train numerous leading farmers in each country. Then such leading farmers will train the groups of their neighboring farmers. This farmer-to-farmer training system will be important. To train the leading farmers, I suggest the massive collaborative and integrated action research should be implemented. The most effective way of training is the on-the-job training in sawah technologies, skills, and knowhow with the international organizations such as Africa Rice, and national scientists as well as engineers, extension officers, and leading farmers in diverse agro-ecosystems in each country.

As shown in Fig.10, the sawah area expansion has taken long history of millennium years in Japan. The majority of the other Asian countries also have developed their sawah systems in historical years of hundreds or more. Because of extremely rapid expansion of population, we have to find out the way for rapid expansion of sawah systems in Sub-Sahara Africa in a short time, within 50 years or so.

As shown in Fig. 10, there are two eras of rapid expansion of sawah area in Japan, i.e., during 1500-1650 of the Sengoku era and 1900-1950 of the Meiji restoration era. About one million ha of sawah area was developed in each of the period.

The upland rice cultivation rapidly degrades the soil if proper soil and water conservation measures are not given. This is the important fact in relation to the second question. If we want to develop soil and water conservation measures, the sawah system development in lowland should be given priority. Therefore, if we stress too much on upland rice cultivation, lowland sawah development will be delayed because of scarce resource allocation for new sawah development. However, of course when no lowlands are available, upland rice would be an only selection.

Concerning the third question, if no sawah system exists, three green revolution technologies, i.e., high yielding varieties, fertilizer, and irrigation, are not accepted by farmers. The sawah system is the missing prerequisite to accept the green revolution technologies. This is the main topic of this presentation, which is described as the Sawah Hypothesis (I).

Iijima:

For the integration, although rice is very important, there are many other important crops such as yam and cassava. How can yam and cassava cultivation be integrated into the lowland sawah systems.

Wakatsuki:

Since yam and cassava cultivations are mainly done in the uplands, there would be no friction with lowland sawah. In some areas like Nupe and Bida, cassava is grown after rice in the lowlands. In some areas like Abakaliki in the south eastern Nigeria, cassava is planted in the upper part of toposequence, and yam is at a lower slope, and rice is cultivated at the valley bottom in a watershed.

Iijima:

Although maize and cassava can be integrated in agro-forestry systems, do you think that maize and cassava cultivations should be discouraged eventually?

Wakatsuki:

I don’t think so. As I have just mentioned, maize cultivation could degrade soils in the long run if no adequate soil conservation measures are given. However, concerning the upland rice, I think the upland cultivation should be discouraged if lowlands are available. If only uplands are available, an upland NERICA can be grown. In summary, although there may be priority crops depending on the agro-ecology and environment, we need to implement balanced research and technological development for improving rice growing environment such as sawah systems, in comparison with that for improving rice varieties.

Iijima:

Thank you very much.

Sugimoto, Chair:

Thanks for your discussion.

Profile

若月　利之　**Toshiyuki Wakatsuki**

近畿大学農学部教授

Professor, Faculty of Agriculture, Kinki University, Japan

Contact: Faculty of Agriculture, Kinki University
Nakamachi 3327-204, Nara 631-85051, Japan
Tel: +81-742-43-9250
Fax: +81-742-43-9250
Email: wakatuki@nara.kindai.ac.jp

1977 年京都大学大学院農学研究科博士課程修了。1981 年から 2003 年まで島根大学、ついで 2004 年から近畿大学農学部教員、現在に至る。この間、1986 年 3 月から 1989 年 2 月まで、国際熱帯農業研究所(IITA)で、国際協力機構(JICA)派遣の長期及び短期水田稲作専門家として西アフリカ全域の稲作生態の調査研究を実施。又、西アフリカに適した水田システムの実証的研究に従事。帰国後、1992 年から現在まで、文科省（日本学術振興会）の科研や JICA の研究協力プロジェクト等により、ナイジェリア中央部のヌペ人地域とガーナのアシャンテイ地域の集水域（各 1 万 ha 規模）をベンチマークサイトとして、持続可能な水田システムの実証的開発研究を実施している。研究テーマは西アフリカにおける緑の革命の実現による食料増産と劣化環境修復のための集水域生態工学。専門分野は土壌学、生態工学、アフリカ水田開発分野における国際協力研究。

Academic career

Professor Toshiyuki Wakatsuki graduated from Post-Graduate School of Kyoto University in 1977.

Professional career

Professor Wakatsuki worked on Sawah ("suiden" in Japanese) based rice culture in West Africa as a JICA expert at the International Institute of Tropical Agriculture (IITA), Nigeria, from 1986 to 1989. Since 1992, Professor Wakatsuki has been funded by JICA, JSPS, FASID and MESIC and has organized various long-term on-farm research and development projects at two benchmark watersheds in Nupe of Central Nigeria, Guinea Savanna zone, and Ashanti in Ghana. His main research field is sustainable increase of food production and restoration of degraded environment through ecological watershed engineering in West Africa. Soil science, ecological engineering and African Sawah development are his professional research fields. Professor Wakatsuki worked as a professor of the faculty of agriculture, Shimane University, Japan, and has been a professor of the faculty of agriculture, Kinki University, Japan.