A GUIDE TO “SAWAH” TECHNOLOGY OF RICE PRODUCTION FOR THE LOWLANDS

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For the Introduction of Sawah Manual (based on the paper submitted to the First African Rice Congress, Dar Es Salaam , Tanzania, July 31-4 August, 2006)

Green Revolution Strategies for African Rice-Based Cropping Systems

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Abstract

Sustainable diversification for rice-based cropping systems is not a major problem in Sub Sahara Africa (SSA). Current major problem is how to realize the sustainable intensification, i.e., Green Revolution. The green revolution has yet occurred in SSA due to the lack of the necessary prerequisite conditions to apply the green revolution technologies. SSA needs eco-technologies that can improve farmers' rice fields similar to the biotechnologies that can improve rice varieties. What critical now for the green revolution in SSA is the eco-technology rather than biotechnology. The lacking of the concept and appropriate technical term, therefore lacking appropriate research and the development of "Sawah" technology made confusion and delay in balanced development of rice cultivation in SSA. Contrary to Asian farmers' fields, the farmers' rice fields in SSA, and specially their farming technologies, are not ready to accept irrigation, fertilizer, and high yielding varieties (HYV). Although we has been discussed researches and developments on irrigation, fertilizers and HYV for the last thirty years, the discussions have not touched on whether the prerequisite conditions are lacking in SSA. The concept and technologies of Sawah is such an example. The term sawah refers to leveled, bunded, and puddled rice field with water inlet and water outlet, which can be connecting irrigation and drainage facilities if possible. 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 growing environment, i.e., lowland paddy fields, the author proposes to use the term "Sawah" in SSA. Simply speaking the basic infrastructures for the green revolution are lacking. 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 contrl, fertilizers cannot be used efficiently. Consequently, the high yielding varieties perform poorly and soil fertility cannot be sustained hence the green revolution could not take place. 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 milion 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 even enhance the restoration of the afforestration in the watershed to form a watershed agroforestry.

Introduction

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

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 SSA especially in West Africa (Table 2: The data were compiled from FAOSTAT 2006, WARAD 1988, 2002, and 2004, JICA 2003). This is very promising change to complete the green revolution finally in West Africa. 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 expansion of area from 0.53 to 1.8 million ha and yield increase from 1.4 to 2.0 t/ha of rainfed lowland, mainly inland valley, which increased annual paddy production from 0.75 to 3.4 million tones during the same period. Expansion from 0.23 to 0.56 million ha and the yield increase from 2.8 to 3.4 t/ha of irrigated lowland were the second contributors. Annual paddy production from irrigated ecologies has increased from 0.64 to 1.9 million tones during the same period. Only very minor contributions were from the rainfed upland, i.e., from 1.5 to 1.8 million tones of paddy production, from 1.5 to 1.8 million ha of cultivated area and no yield increase during the same period.

These trend clearly show that natural resource management technology, especially through the improvement of water control in lowland, especially rainfed lowland palyed 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 by 2015.

New Concept of Sawah Ecotechnology for Green Revolution

For the sustainable increase of rice yield and production, sufficient areas of sustainable sawah fields (Fig. 1), leveled, bunded, and puddle fields have to be developed. The sawah development should be viable for diverse lowland ecologies and soci-economic, especially land ownership conditions in SSA. Apart from the conventional and costly expansion of irrigated area, the way for rapid expansion of ecotechnology based low cost and self-support sawah fields have to be researched and developed in the rainfed lowland, especially in inland valleys (Wakatsuki et al 1998, 2005, Hirose and Wakatsuki 2002). Taiwan team has played a pioneering role in technical cooperation for sawah based rice cultivation in Africa during 1965 to 1975. However as this technical cooperation only continued fro some 10 years, confusion and stagnation occurred in the 1980s (Buddenhagen, I.W. and Persley, G.J. 1978 and IITA 1989/1990).

Although the development of irrigation schemes, large and small, is ongoing steadily even not rapidly, the most impressive efforts observed by the author in the past 20 years were that inland valley development for improving water conditions of the rice-growing environment through bunding and leveling, which are rapidly ongoing in West Africa despite scarce funding (Table 2). This is thanks to the efforts of these countries and based mainly farmers's self-support efforts. Decreasing trend of rainfall in recent years might enforce farmers to shift partly from upland to lowland. Various donor countries and WARDA's inland valley consortium (IVC) also contributed to encourage these developments. A USD$ 23 million inland valley rice development project based on the sawah approach in Ghana, which is financed by African Development Bank, is a good example (Wakatsuki et al 2001, Hirose and Wakatsuki 2002).

These lowland development activities are called “intensified lowland”, “partial water control”, just “lowland development”, “amenagement or System du Chinois after the activities by Taiwan team” in French, or “contour bund system”. These are all covered by the “sawah concept and sawah technology and development” (Wakatsuki et al 1998). Rice farmers, West African countries themselves, and donor countries have accelerated the trend towards various sawah based rice cultivation with various levels of soil and water management technologies even well not defined clearly (Figs. 1). SSA needs eco-technologies that can improve farmers’ rice fields similar to the biotechnologies that can improve rice varieties (Fig. 2, Table 3: Ofori et al 2005). What critical now for the green revolution in SSA is the eco-technology rather than biotechnology. Rice growing ecologies are extremely diverse in West Africa 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 valley bottom nature of inland valleys and on the targeting farming systems Because of obvious benefits of geological fertilizations (Fig. 10) 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 development in diverse valley bottom characteristics (Fig.5). Small machinery, such as power tiller, has to be examined to accelerate the sawah development (Fashola et. al 2006). Tropical Asian experiments and collaboration for sawah development and for animal traction and power tiller operation for sawah based rice farming will be very useful (Hsieh 2003).

The concept and the term “sawah” refers to man-made improved rice fields with demarcated, leveled, bunded and puddle rice fields with water inlet and water outlet, which, if possible, can be connecting various irrigation facilities, such as irrigation canals, pond, spring, pump, water harvesting, and flooded sawah etc (Fig.1-5). Rainfed sawahs without any irrigation facilities are also far better than rainfed fields for rice growth and of cause for rice green revolution. Drainage facilities are also useful. The term “sawah” originates from Malayo-Indonesian. The English and French terms, Paddy or Paddi, also originated from the Malyo-Indonesian term, Padi, which means rice plant. In order to avoid confusion between upland paddy fields and man-made leveled, bunded and puddle rice fields, i.e., typically irrigated rice growing environment, i.e., lowland paddy fields, the author proposes to use the term “Sawah” in SSA (Wakatsuki et al 1998).

The Sawah Hypothesis (I)

On December 26, 2004, the concept of and the term “TSUNAMI” were lacking in the vocabulary of people in Indian Ocean locations such as Sumatra, Indonesia, Sri Lanka, India and Thailand. This seriously exaggerated the tsunami disaster. The lack of the concept and appropriate technical term for improving the rice growth environment, such as “sawah” creates confusion in the research and sustainable development of rice cultivation in West Africa. As seen from the success of NERICA, a clear concept and key technical term are very important for integrated genetic and natural resource management (IGNRM). Unlike in Asian rice farmers’ fields, Sub Sahara African farmers’ fields, and therefore the farming technologies, are not ready to accept various IGNRM technologies, such as irrigation, fertilizers, integrated pest management IIPM), and high yielding varieties (HYV). Rice farmers’ field demarcation based on topography, hydrology and soil is the starting point for scientific observation, technology generation and application (Fig.6). Although we has been discussed researches and developments on irrigation, fertilizers and HYV for the last thirty years, the discussions have not touched on whether the prerequisite conditions are lacking in

SSA. The concept and technologies of Sawah is such an example. Simply speaking the basic infrastructures for the green revolution, such as sawahs, are lacking (Fig. 1 and 6). Irrigation without farmers' sawah farming technologies has proved inefficient or even damaging because of accelerated erosion and waste of water resources. In the absence of water control, fertilizers cannot be used efficiently. Consequently, the high yielding varieties perform poorly and soil fertility cannot be sustained hence the green revolution could not take place (Sawah hypothesis I).

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. 7 (Walling 1983), soil erosion and hence lowland soil formation in West Africa are very low in comparison with Asian watersheds. High rates of soil erosion and lowland sawah soil formation can be compensated by high rate of soil formation in Asia because of active geological formation and ample monsoon rainfall. Paradoxically, extreme diversity of lowland in West Africa (Fig. 5) may relate to the low rate of soil erosion and weak lowland soil formation.

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

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

Balanced Approach between Biotechnology and Ecotecnology

The technologies of genetic improvement of rice (variety) and the rice growing environment (sawah) must be researched and developed in good balance for IGNRM (Fig. 2). 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). The sawah system development and management are the technologies that should transfer to farmers. Since bunding, leveling and puddling need very hard and skilled works as well as obvious additional benefits of geological fertilization, rainfed lowland will be the primary target for sawah development (Fig. 4 and 10). The ecology of the majority of rice farmers' fields is extremely diverse in naturally and farming systematically, therefore even the good quality of pure seeds cannot be evaluated properly (Fig.7). Sawah is also a means by which such ecologically diversified rice fields bringing into relatively homogenous and classified fields to evaluate appropriate variety. The successful IGNRM needs classified demarcated lands such as sawahs. The technology of rice variety improvement and dissemination has a clear concept and target such as high yield, pest, draught and poor nutrient tolerant, and high eating quality varieties. The remarkable achievement of the breeding program at WARDA is clear. However there were no such clear concepts and targets in the researches of natural resource management in West Africa. The missing link for the green revolution is a sawah concept and technology targeting the expansion of high quality but with low cost. The basic infrastructure for the green revolution is bunded, leveled, and puddled fields with good layout of terraced sawahs in watersheds (Fig.4, 5, 10). If sawah systems are successfully introduced to farmers' rice fields, the integrated genetic and natural resources management (IGNRM) technology generations to deal with water, soil, and fertilizer management, low P availability problem, weed and striga management, IPM, control of CH4 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.9). Sawah based farming can also encourage diversification of rice farming systems in SSA. Long term experiments on the effect of cropping system researches such as legume, biological nitrogen fertilizer (BNF) and organic manure will be possible. Iron toxicity has been often cited in West Africa that can be tackled only properly in sawah based IGNRM. Some pest and disease such as African rice gall midge (AfRGM) and rice yellow mottle virus (RYMV) problems may even be partly mitigated through enhancing the health growth of rice. Above all sawah systems supply the rice fields that can apply scientific technologies (Fig. 7 and 9).

African Lowlands Characterization in Comparison with Asian Lowlands in Watersheds

Because of diverse soils, hydrology, climate, vegetation, topography, and geology as well as socio economic and cultural and historical conditions, the technologies for sawah development and management must fit such diverse conditions. This is an important research and development target for sustainable rice production (Fig. 4, 5 and 6). There is information on the potential area of lowland sawah development, such as 330,000 ha in Benin, 230,000 ha in Burkina Faso, 200,000 ha in Togo, one million ha in Ghana, and so on. This area estimation is, however, still at the preliminary stage. Details survey and characterization targeting sawah type lowland development are necessary (Table 4, Fig. 3, 4, and 5).

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

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

Intensive Sustainability of Lowland Sawah System: Sawah Hypothesis (II)

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

Mechanisms of Intensive Sustainability of Lowland Sawah Systems

(1) Geological Fertilization Theory

The upper part of Fig. 10 explains what is the geological fertilization. Although this is a kind of axiom process, quantitative confirmation data are lacking. West African conditions are quite different to Asia. Watershed characterization in terms of upland and lowland connected sequences is important in relation to the geological fertilization as shown in Fig.2. The upper part of Fig. 10 shows a concept of macro-scale ecological engineering, i.e., watershed ecological engineering and watershed agroforestry. The soils formed and nutrients released during rock weathering and soil formation processes in upland are accumulated at least partly in lowland through geological fertilization processes, such as soil erosion and sedimentation as well as surface and ground water movements or colluvial processes. The sustainable integration of upland forestry, upland farmings and lowland sawah systems in a watershed composed a watershed agroforestry, which can be a typical model of watershed ecological engineering. The optimum land use pattern and landscape management practices optimize the geological fertilization processes through the control of optimum hydrology. Irrigation water also contribute the increase of the supply nutrients, such as Si, Ca, Mg and K as well as sulfate. This is an eco-environmental basis for long-term intensive sustainability of sawah-based rice farming in Asia.

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

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

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

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

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

Diversification Strategy for African Rice-Based Cropping Systems

In terms of diversification, traditional African rice based cropping systems are leading world agriculture even now. Traditional mixed cropping systems are remarkable, such as Nupe, Igbo, and House systems (Ruthenberg 1980, Okigbo 1990, Hirose and Wakatsuki 2002). The systems will contribute to improve world diversity agriculture in near future. The top priority in SSA agriculture at the moment is, however, the sustainable intensification. The green revolution must be realized first. Then intensive diversification will be major advantages in African agriculture because of existing rich tradition of diversity agriculture.

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Windmeijer, P.N. and Andriesse, W. 1993. Inland Valley in West Africa: An Agroecological Characterization of Rice-Growing Environment, ILRI, Wageningen, 160pp.

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 and protein content in comparison with the other cereals, the production data of FAO were divided by 8 for Cassava and 5 for Yam to estimate cereals equivalent (Sanchez 1976, Kiple and Ornelas 2000).

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

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

Asia- food production (kg/person)

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

West Africa- food production (kg/person)

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

Must add the similar data on Ghana and Nigeria

Table 2. Estimation of rice production trend by rice ecology in West Africa during 1984-1999/2003 and 2015 estimation by the author (JICA 2003, WARDA 1988, 2002, 2004, FAOSTAT 2006)

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

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

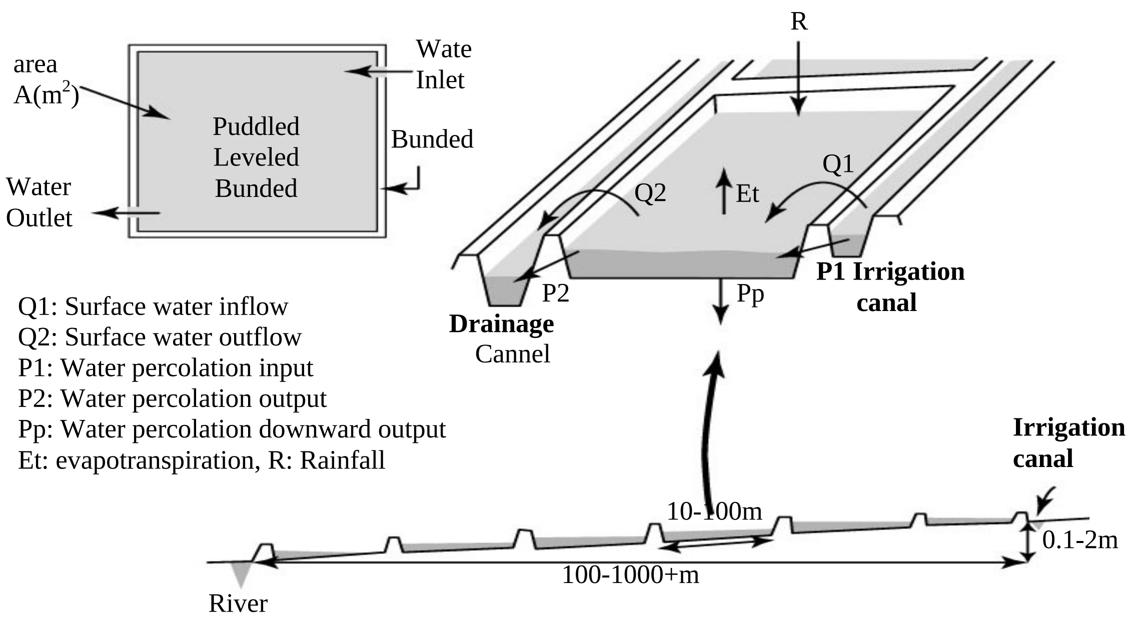
	Entry No.	Cultivar	ECOTECHNOLOGICAL YIELD IMPROVEMENT					
			Irrigated Sawah		Rainfed sawah		Upland like fields	
			HIL	LIL	HIL	LIL	HIL	LIL
			(t/ha)		(t/ha)		(t/ha)	
BIOTECHNOLOGICAL	1	WAB	4.6	2.9	2.8	1.6	2.1	0.6
	2	EMOK	4.0	2.8	2.9	1.3	1.4	0.5
	3	PSBRC34	7.7	3.5	3.0	2.1	2.0	0.4
	4	PSBRC54	8.0	3.7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

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

Table 4. Distribution of lowlands in Sub Sahara Africa
Windmeijer and Andriesse (1993); Sawah area estimation by Wakatsuki (2002)

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

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

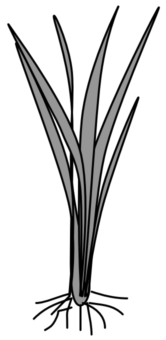


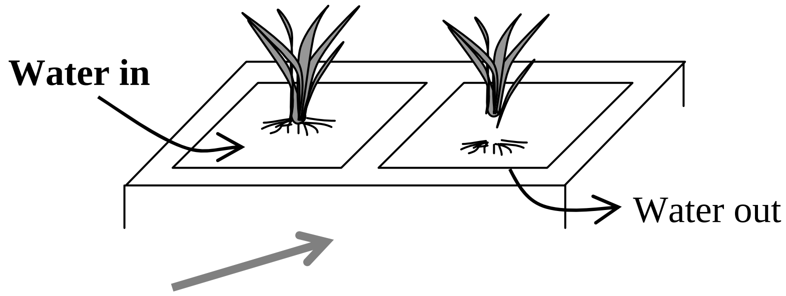
Possible layout of SAWAH on typical inland valley bottom slope in West Africa.

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

Biotechnology and Ecotechnology

Rice variety and Rice with Sawah Systems





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

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

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

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

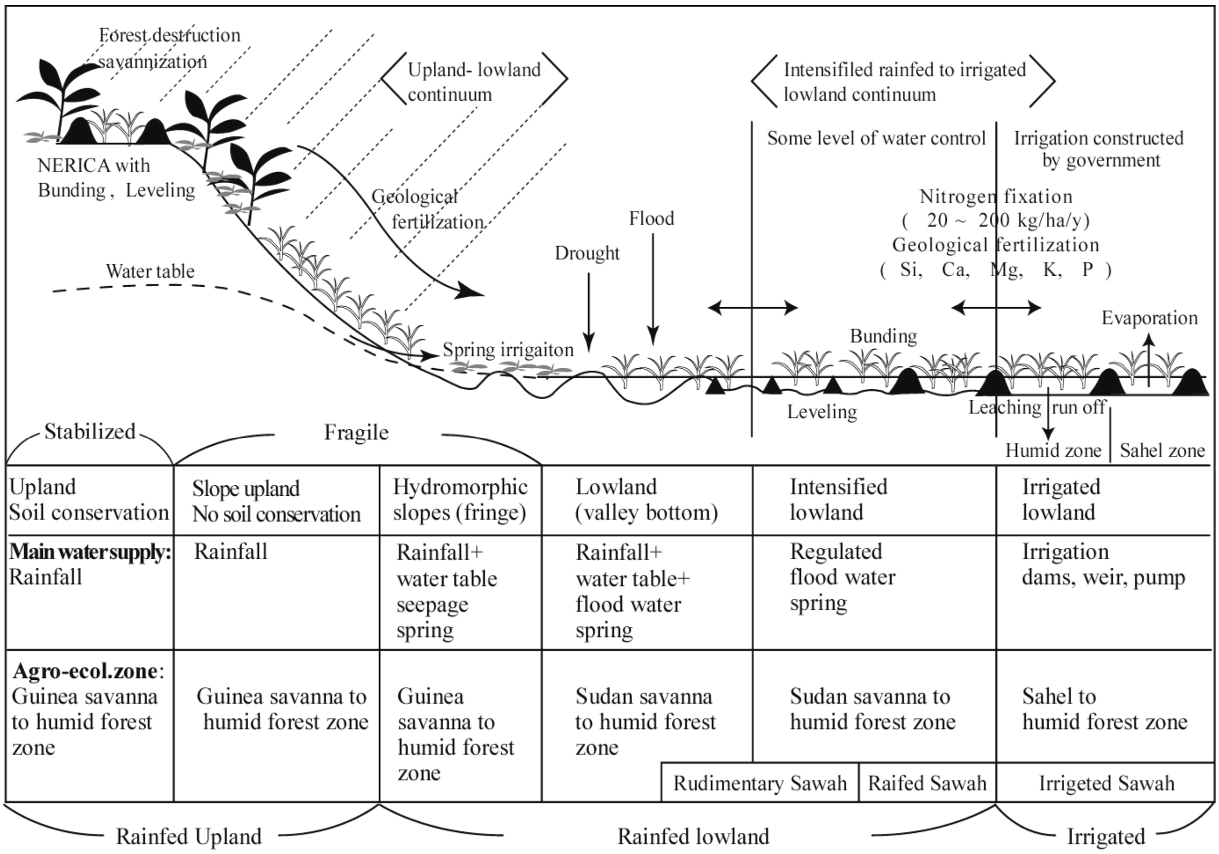
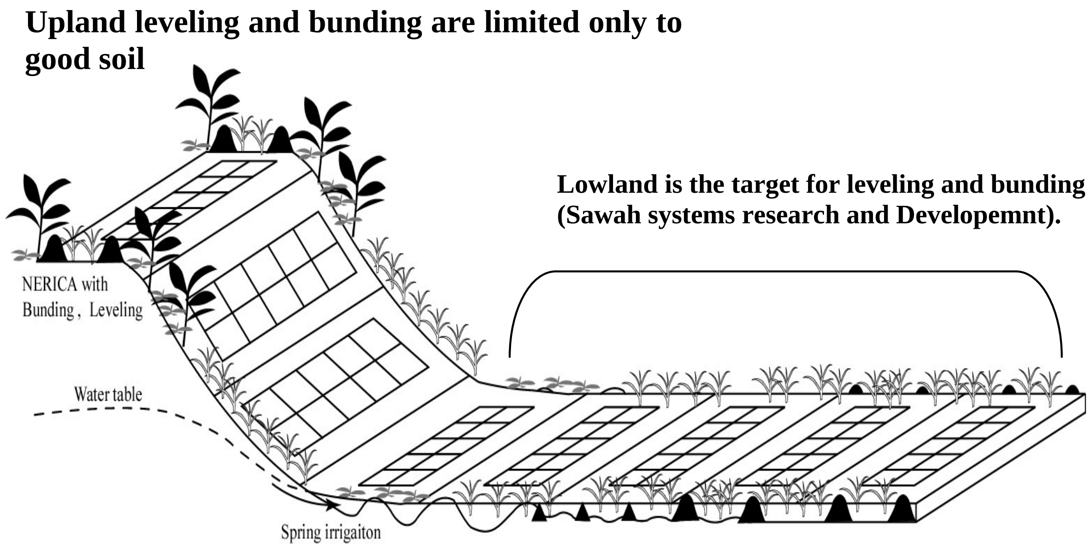
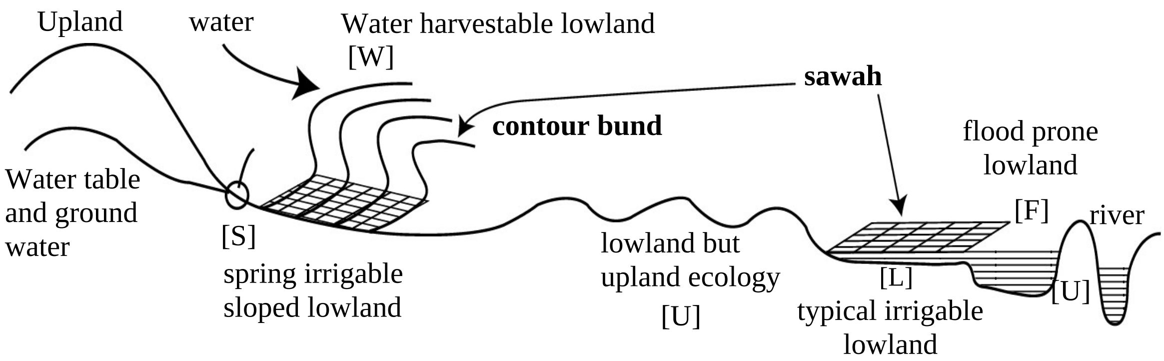


Fig. 3. Rice ecologies along upland-lowland continuum in West Africa (JICA 2003, WARDA 2004)



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

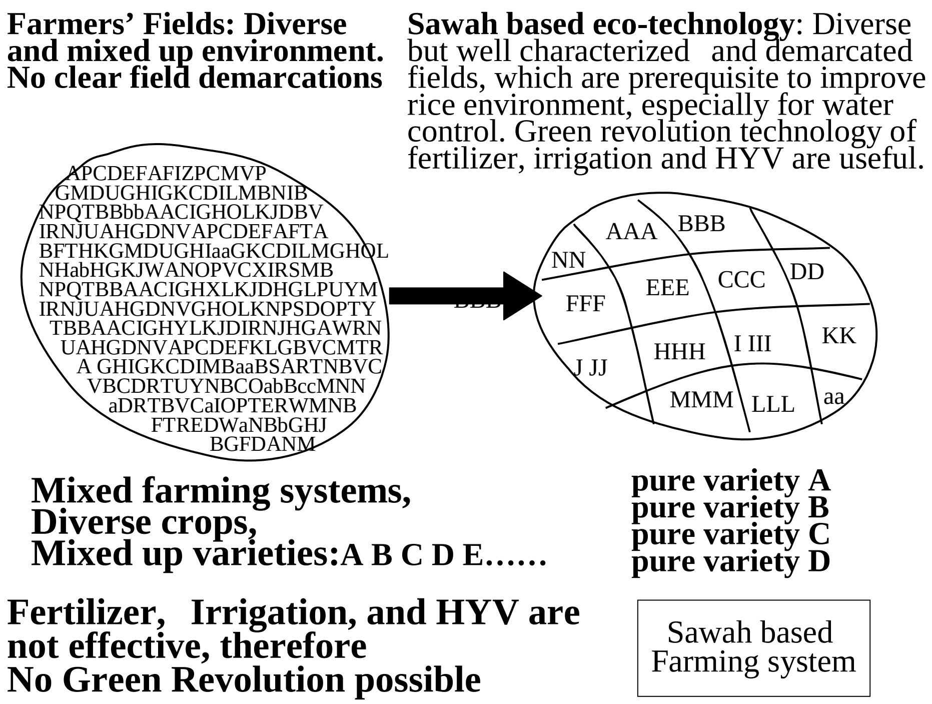


Fig. 6. Successful Integrated Genetic and Natural Resource Management (IGNRM) Needs Classified Demarcated Land Eco-technologically

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

Fig. 7. Rates of Soil Erosion in the Worlds (Walling 1983)

Farmers' sawah fields are the most important infrastructure: farmers' fields come the first Japanese Experiences

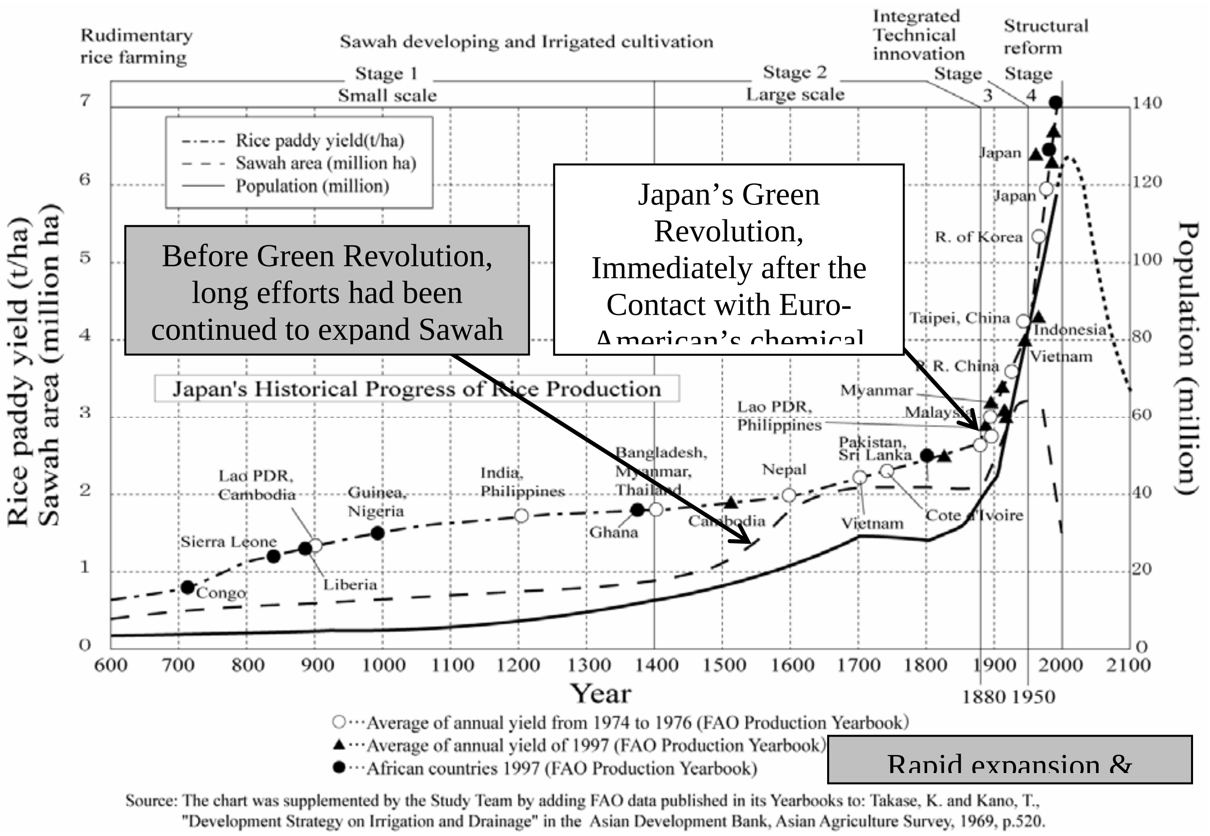


Fig. 8. Rice yields & sawah area of historical path in Japan in comparison with rice yields in Asia & Africa. Japanese Population trend in past and near future is also shown.(JICA 2003, modified)

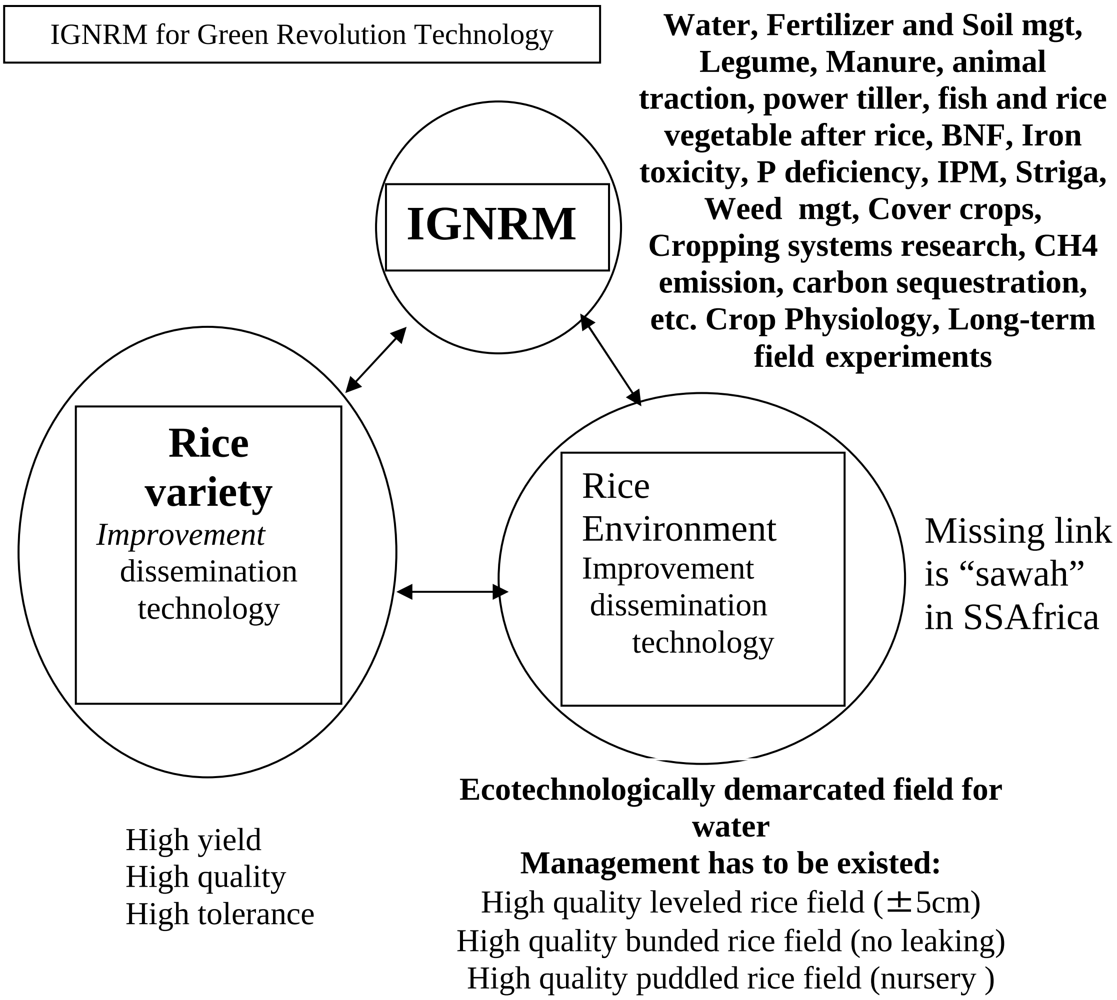
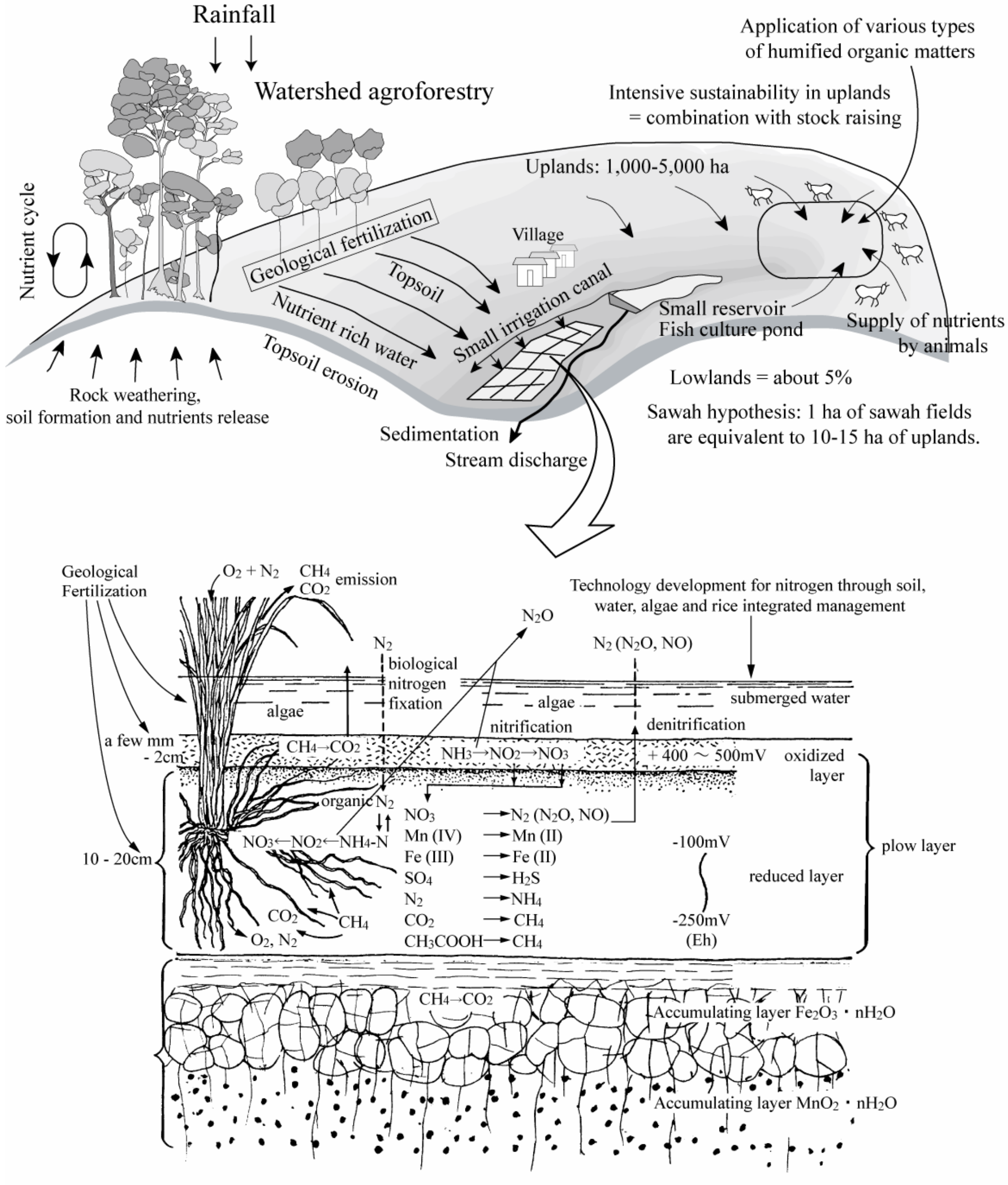


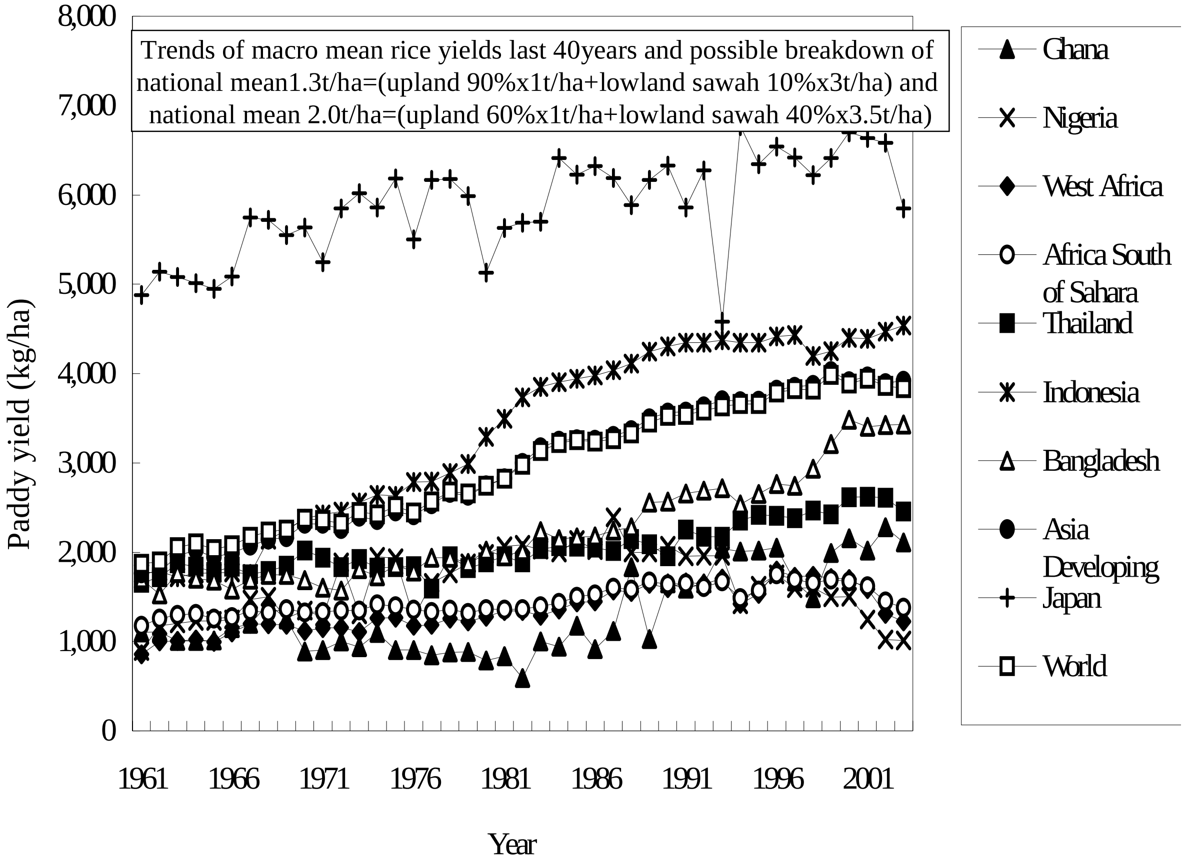
Fig. 9. Concept of Integrated Genetic and Natural Resources Management (IGNRM) for green revolution technology: Missing link is Sawah which is lacking in majority of famers’ fields

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



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

Fig. 10. (1) Macro- and (2) micro-scale ecological mechanisms of intensive sustainability of lowland sawah systems



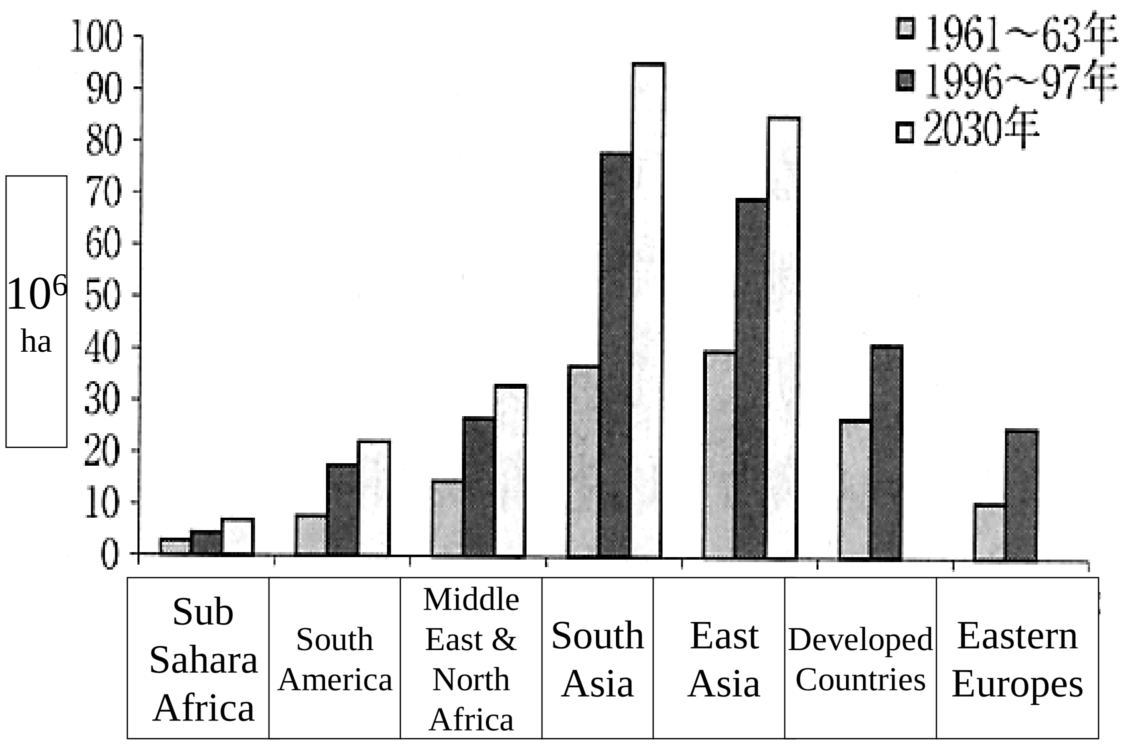
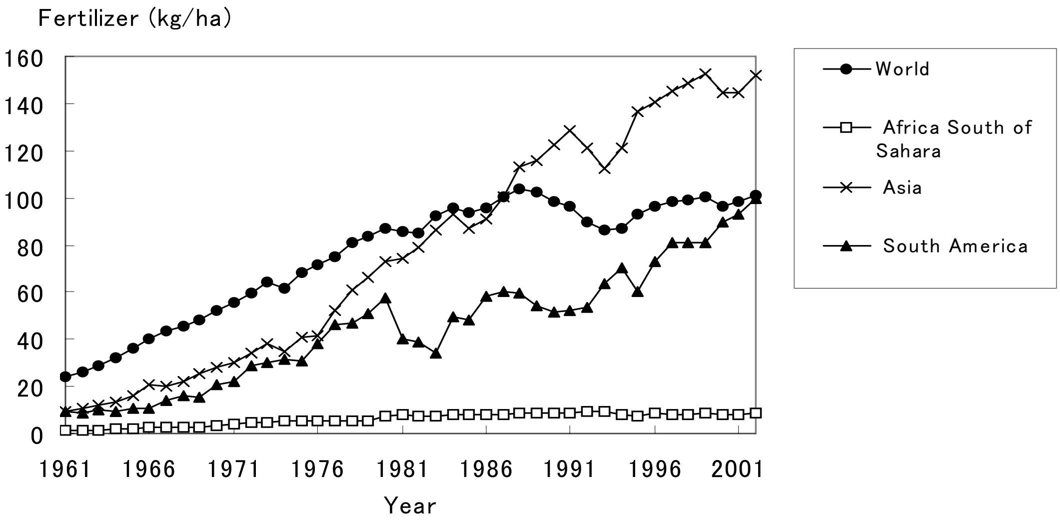
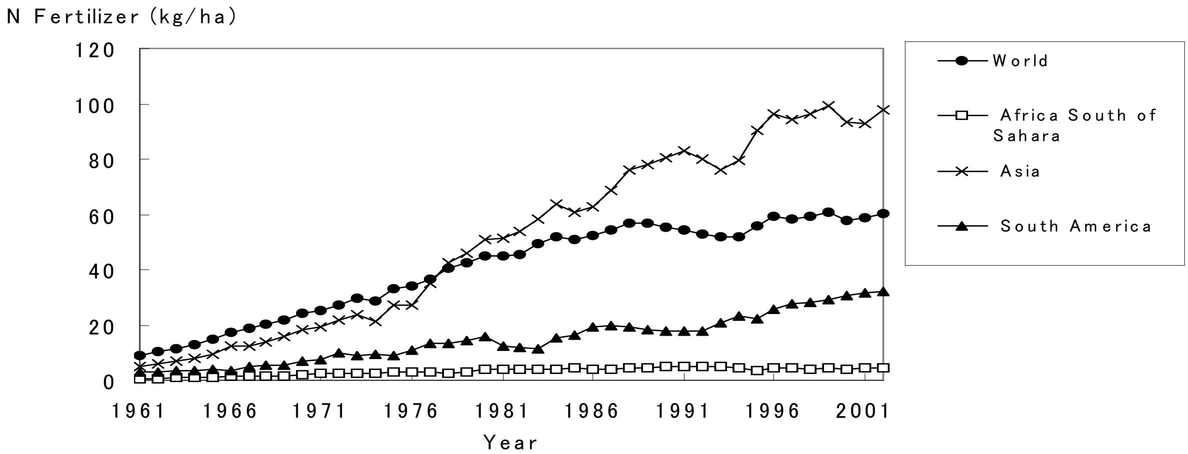


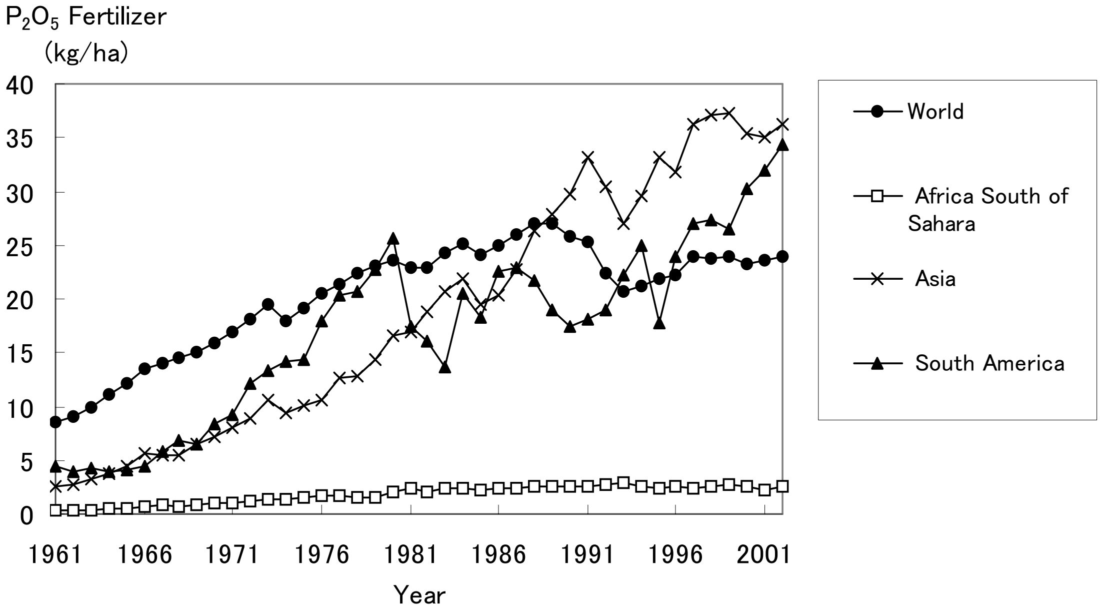
Fig　Irrigated area past, present and near future（FAOSTAT　2001、Yoshinaga and Watanabe　2002）


Fertilizer (kg/ha)
160
140
120
100
80
60
40
20
0
1961
1966
1971
1976
1981
1986
1991
1996
2001
Year
World
Africa South of Sahara
Asia
South America

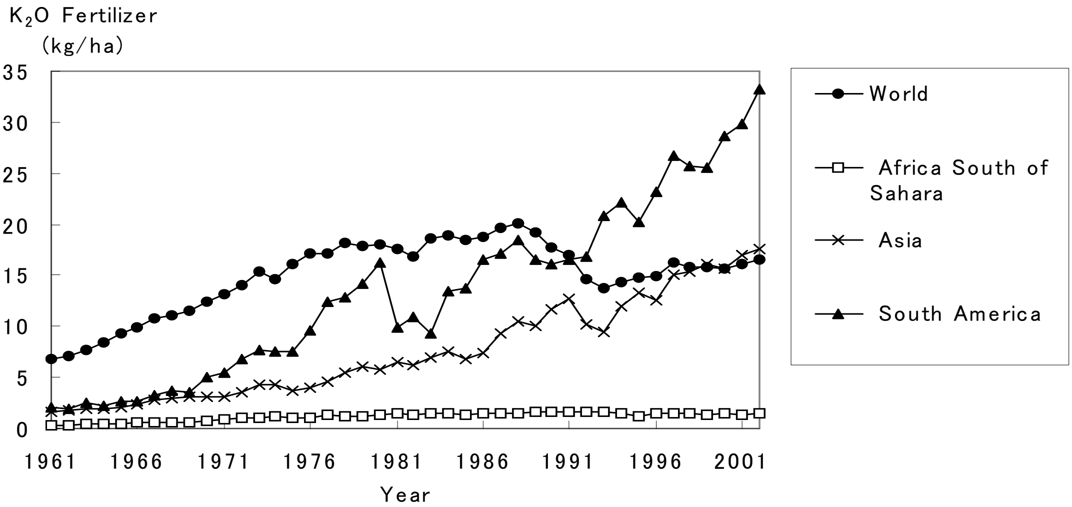
$N+P_2O_5+K_2O$


N Fertilizer (kg/ha)
120
100
80
60
40
20
0
1961
1966
1971
1976
1981
1986
1991
1996
2001
Year
World
Africa South of Sahara
Asia
South America

N

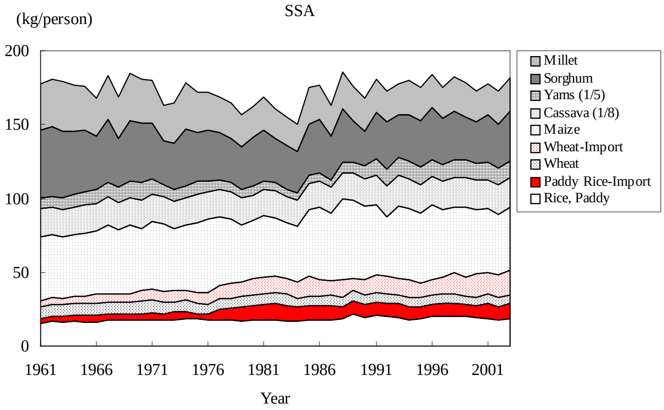

P_2O_5 Fertilizer
(kg/ha)
40
35
30
25
20
15
10
5
0
1961
1966
1971
1976
1981
1986
1991
1996
2001
Year
World
Africa South of Sahara
Asia
South America

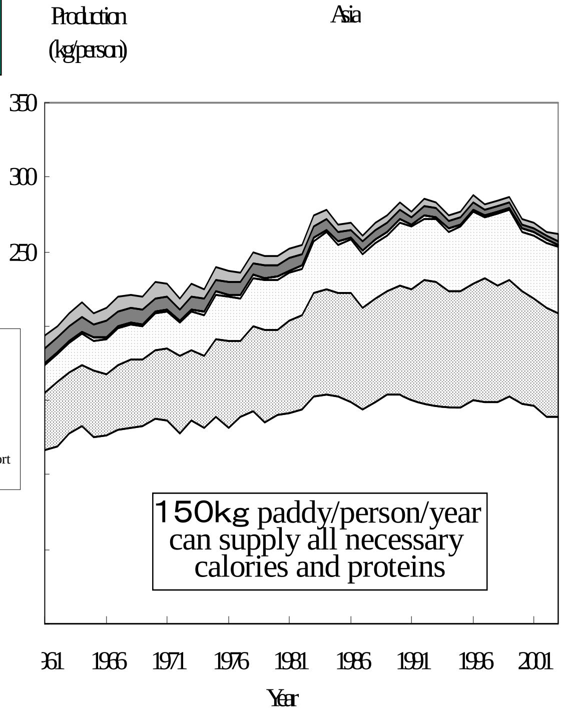
P_2O_5


K_2O Fertilizer
(kg/ha)
35
30
25
20
15
10
5
0
1961
1966
1971
1976
1981
1986
1991
1996
2001
Year
World
Africa South of Sahara
Asia
South America

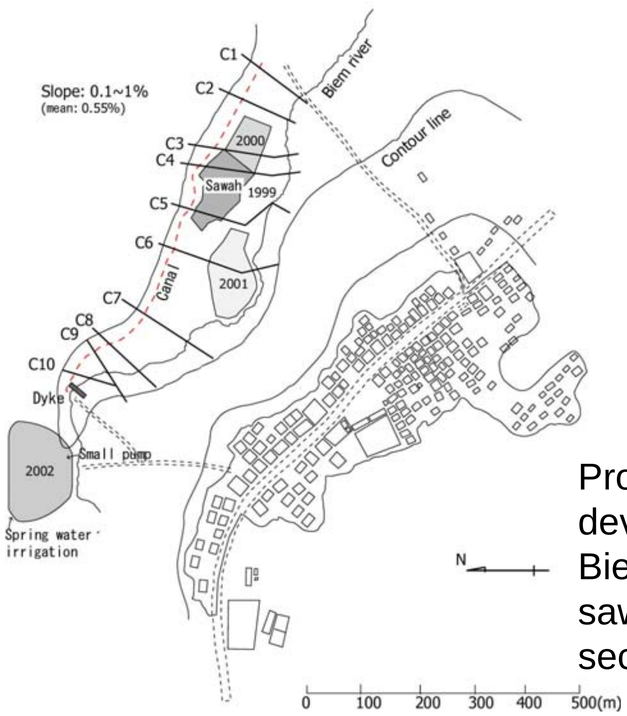
K_2O

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





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



Proceedings of development of Biemso No. 1 sawah with cross section lines (C1~10).