(Scientific session 1)

Multi-functionality of *sawah* eco-technology: why *sawah*-based rice farming is critical for Africa's green revolution*

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Abstract

Sustainable agricultural rice production is realized by balanced application at farmers' fields of both: (1) varietal improvement through biotechnology, and (2) the improvement of rice ecological environment through eco-technology. Compared to the biotechnological research and development, eco-technological research and development has been largely neglected in Sub Saharan Africa (SSA) during the last 40 years. Rice Green Revolution (GR) comprises three core technologies: (1) irrigation, (2) agrochemicals input, and (3) high-yielding varieties (HYV). Although all three technologies had been available in the past 40 years, they have not been effective at farmers' fields in SSA. Thus, there has been a considerable paddy yield gap between African Research Institutes (5-8 t/ha) and those of farmers (1-3 t/ha) for the past 40 years. During this period, three major components of GR technologies have been researched on and developed. Although they have been available at the experimental fields of various research institutes in Africa, these technologies have not been effectively adapted in African rice farmers' fields. Almost all institute-based technologies have not been scaled up to farmers' fields. Thus, the GR is yet to be realized.

All scientific technologies have some limited operational conditions in the fields. The *sawah* ecotechnology is the prerequisite condition for applying the three GR technologies (Sawah hypothesis 1). The term "*sawah*" is of Indonesian origin. To control water in farmers' fields need *sawah* systems. If no sawah systems available, farmers can not control water. Majority of African farmers' fields are not ready to accept most of the scientific technologies developed at research institutes like IITA and AfricaRice. Thus, in order to effectively apply these scientific technologies, farmers have to develop typical *sawah* or other similar alternatives which can conserve soil and control water. Essential components of such sawah development are: (1) demarcation by bunding based on topography, hydrology and soils, (2) levelling and puddling to control and conserve soil and water, and (3) water inlet to get water (through various irrigation facilities) and water outlet to drain excess water. These are the basic characteristics of *sawah* fields.

The *sawah* ecotechnolgy can improve irrigation and fertilizer efficiency. Thus it can help to cope with water shortage and poor nutrient (especially N and P) supply. It can also neutralize acidity and/or alkalinity as well as improve micronutrient supply. With this, the improved HYV can perform better and we can realize GR in Africa. Thus the *sawah* ecotechnology is the prerequisite condition to apply for the three GR technologies to be successful. The lowland *sawah* can also sustain rice yield higher than 4t/ha through macro-scale natural geological fertilization and micro-scale mechanisms to enhance supply of various nutrients. For optimum results, appropriate lowlands must be selected, developed and soil and water managed properly. If we can apply further such improved agronomic practices as System Rice Intensification or others using the *sawah* systems, paddy yield can exceed 10 t/ha.

After continued long-term basic and action researches during 1986-2010, our *sawah* research programs could finally establish basic technology sets for the system. This is the "site specific personal irrigated *sawah* systems development and management by farmers' self-support efforts'' (s*awah* ecotechnology) in diverse inland valley agro-ecologies at forest transitional zone in Ghana and at derived and core Savanna zones in Nigeria. We believe that the core technology to contribute to GR in Africa is the *sawah* ecotechnology described in a separate paper entitled "Farmers' personal irrigated *sawah* systems to realize the green revolution and Africa's rice potential''. Presently, the *sawah* ecotechnology has arrived at the stage of conducting large scale action research to scale up past successful results. This is the final stage of the road map to disseminating the *sawah* ecotechnology in the whole of Ghana and Nigeria in order to realize rice GR in both countries, and this is expected to extend to Togo and Benin as well as to the entire SSA.

Introduction

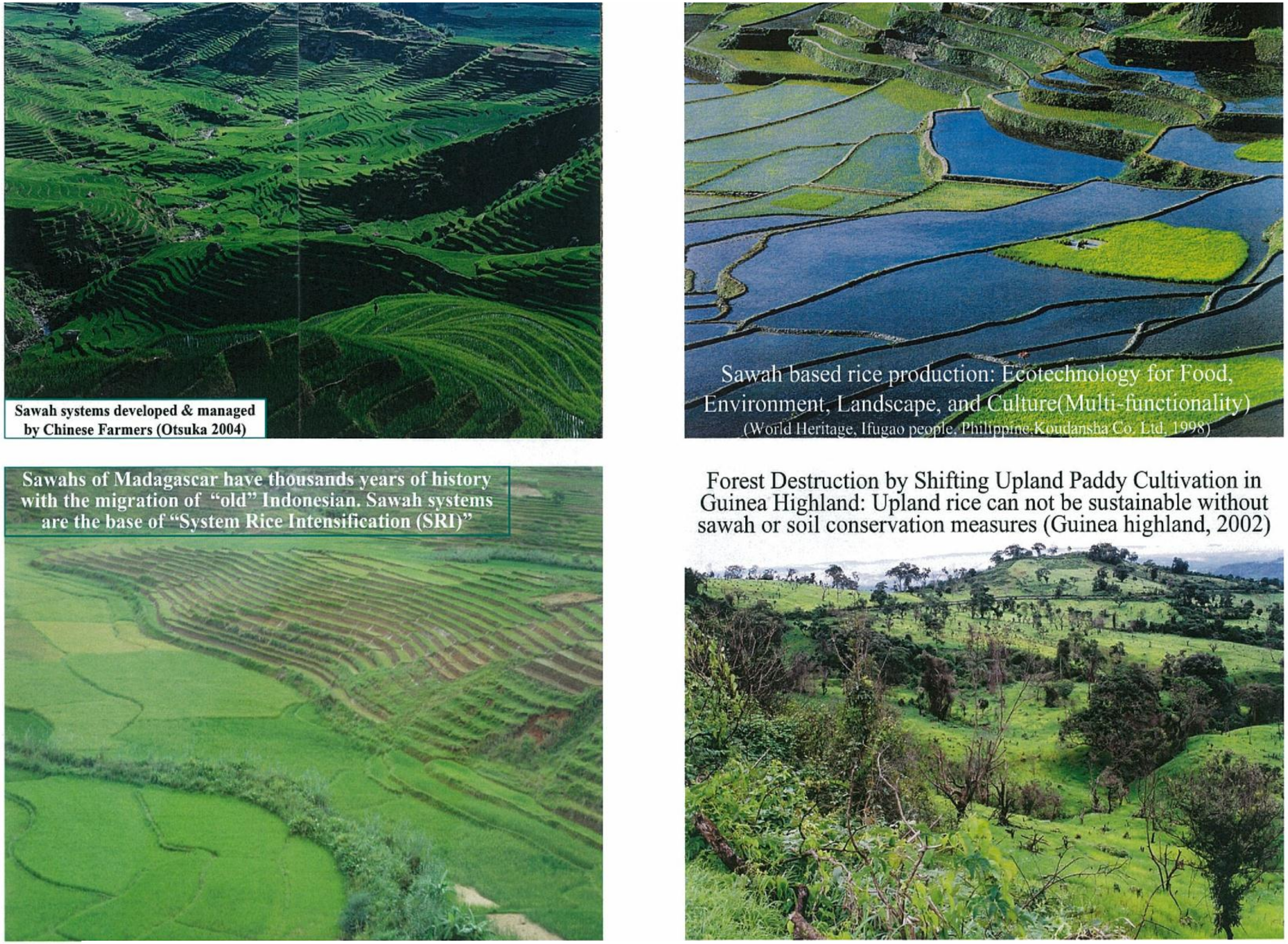
In 1935, Dr. G. Inazuka, a breeder at Iwate Prefectural Experimental Station, Japan, successfully bred the Norin 10 variety of wheat. This was collected in 1948 by scientists under US-occupied forces in Japan. In 1953, the variety was transferred to Dr. N. Borlaug at Chapingo, Mexico. By 1957, Dr. Borlaug had used Norin 10 to quickly breed and release 14 high-yielding wheat varieties. This research was the start of the dramatically successful green revolution (GR) and the start of Consultative Group of Intgernational Agricultural Research (CG) centers in the 1960s-1970s (Evenson and Gollin 2003, Hesser 2006, Hardin 2008, Renkow and Byerlee 2011). Norin 10 was the first crop variety in which the characteristics of a semi-dwarf gene, sd1, were identified. We now know that all high-yielding varieties (HYV) of wheat, maize and rice have the same sd1 gene (Ashikali et al. 2002, Matsuoka 2004). Thus Dr. G. Inazuka is actually the "grandfather" of the GR.

Since the dramatic success in Latin America and Tropical Asia in 1960-1970s, similar variety-oriented research for GR has been intensively and extensively conducted in sub-Saharan Africa (SSA). Probably in response to the view that the failure to realize GR was due to the absence of appropriate varieties for the continent (Sanchez 2002), the Africa Rice Center innovated the new rice cultivar for Africa (NERICA). The NERICA technology has in deed shown to be very promising (FAO 2007). In 2005, the Millennium Village Project (MVP) was established in 14 hunger and poverty hotspots cutting across diverse agroecological zones in the region. This was in fulfilment of one of the recommendations in accordance with the Millennium Development Goals (MDGs) of the UN. In spite of all these interventions, the GR is yet to be realized in SSA. Hence, SSA remains the only region where population continues to grow while per capita agricultural production is stagnated, with cereal yields rarely exceeding 1 t/ha (Hazell and Wood 2008). It is even more worrisome to note that despite the intensive variety-oriented research and wide technology dissemination, the path to successfully realising GR in SSA remains unclear (Otsuka 2006, Otsuka and Kalirajan 2006, Orr et al. 2008, Wopereis et al. 2008).

In 2007, the Alliance for Green Revolution in Africa (AGRA) began large-scale activities (Toenniessen et al. 2008). The government of Japan has committed strong support to increasing rice production in Africa through the establishment of the Coalition for African Rice Development (CARD 2008) based on the Fourth Tokyo International Conference on African Development (TICAD4) held in May 2008 at Yokohama, Japan. Similar to the UN MVPs, AGRA and CARD have big scale activities for GR. All of these world major organizations have hypothesized that the core technology to realizing a GR in Africa will be varietal improvements achieved by bio-technology, as was the case in tropical Asia 40 years ago. However, their advocacy for HYV is not without stressing some natural resources management (NRM) oriented modifications. Hence, although the central target of especially AGRA and CARD is varietal improvement, their programs include soil and water management aspects. A more realistic approach to sustainable agricultural production is by balanced application at farmers' field of both: (1) varietal improvement through biotechnology, and (2) the improvement of rice ecological environment through eco-technology. We believe therefore that the core technology to contribute to GR in Africa is eco-technology, such as the *sawah* ecotechnology.

Compared to the biotechnological research and varietal improvement, eco-technological research and technology development have been largely neglected in SSA during the last 40 years. Although there is a research concept to improve natural resource management (NRM), no clear research concept to improve lowland soil and water condition exists in Africa. The *sawah* ecotechnology is such a missing concept to improve natural resources in majority of African rice farmers' fields. For over 25 years (1986-2010) now, we have been using various research funds to engage in basic and action researches in collaborations with Africa Rice Centre, IITA, JIRCAS-Japan, Ghana's Soil Research Institute (SRI) and Crops Research Institute(CRI), National Center for Agricultural Mechanization (NCAM), National Cereals Research Institute (NCRI), and University of Nigeria, Nsukka (UNN) as well as University of Agriculture, Abeokuta and various other universities in Nigeria. So far in this our involvement in the on-going long-term research, our team have been able to verify the importance of water control through the *sawah* system. At farmers' level, our *sawah* research programs finally could establish basic technology sets of "site specific personal irrigated *sawah* systems development and management by farmers' self-support efforts"(hereinafter referred to as *sawah* ecoetchnology) in diverse inland valley agro-ecologies at forest transitional zone in Ghana and derived and core Savanna zones in Nigeria. In 2011, our sawah team could demonstrate sawah ecotechnology successfuly on the huge flood plains in collaboration with Kebbi state FadamaIII and ADP staffs, Nigeria. One powertiller could develop 7 ha of the pump based irrigated sawah systems with 7t/ha of paddy yield during April to September, within 6 months.

Our sawah ecotechnology arrived the stage of conducting large scale action research to scale up past successful results. This will be the final stage of the road map to disseminating the *sawah* approach in the whole of Ghana and Nigeria. The ultimate aim is to realize rice GR in both countries and in the entire SSA.

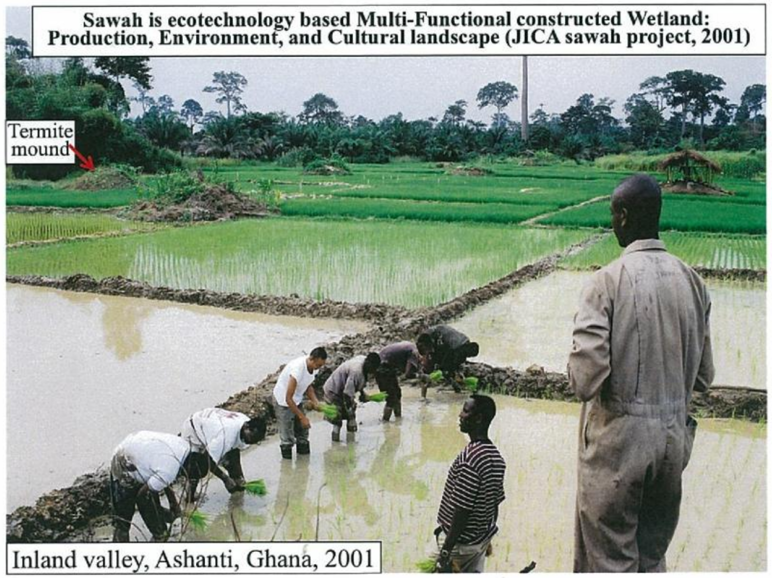


Photograph 1. showing sawah systems and non sawah systems

Lowland paddy field at Sokawe, Kumasi, Ghana
Three Green Revolution technologies can't apply

Once Sawah system was developed, yield can reach at least 4t/ha. If improved rice agronomy can practice, such as System Rice Intensification, yield reach to 10t/ha (CRI sawah team, Ghana)

Biemso No.1, Zongo site in 2002
Pudling, soil moving & leveling



Sawah is ecotechnology based Multi-Functional constructed Wetland: Production, Environment, and Cultural landscape (JICA sawah project, 2001)

Inland valley, Ashanti, Ghana, 2001

Photograph 2. Traditional non sawah and Sawah systems developed by farmers, Ashaniti, Ghana

What is *Sawah*, Paddy and Irrigation?

The English term, paddy, originates from Indonesia, and means rice plant or rice grain with husk. The term *sawah* is also of Indonesian origin, and refers to a bunded, puddled and leveled rice fields with water inlet and outlet to improve water control, especially control of flooding water depth and movement, and thus soil fertility (Wakatsuki et al. 1998). Thus *sawah* ecotechnolgy can improve irrigation and fertilizer efficiency, and with the technology, the improved varieties can perform well

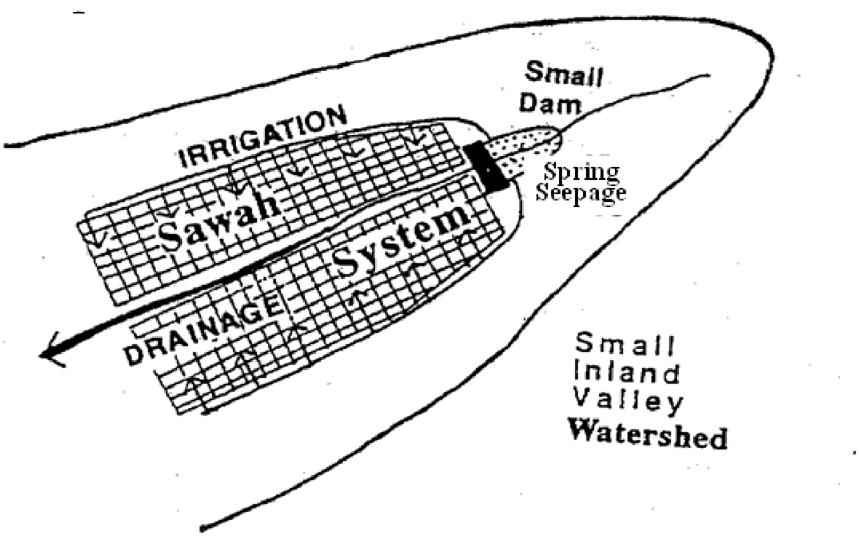


Figure 1. Sawah system with irrigation and drainage facilities for control of water in an inland valley watershed

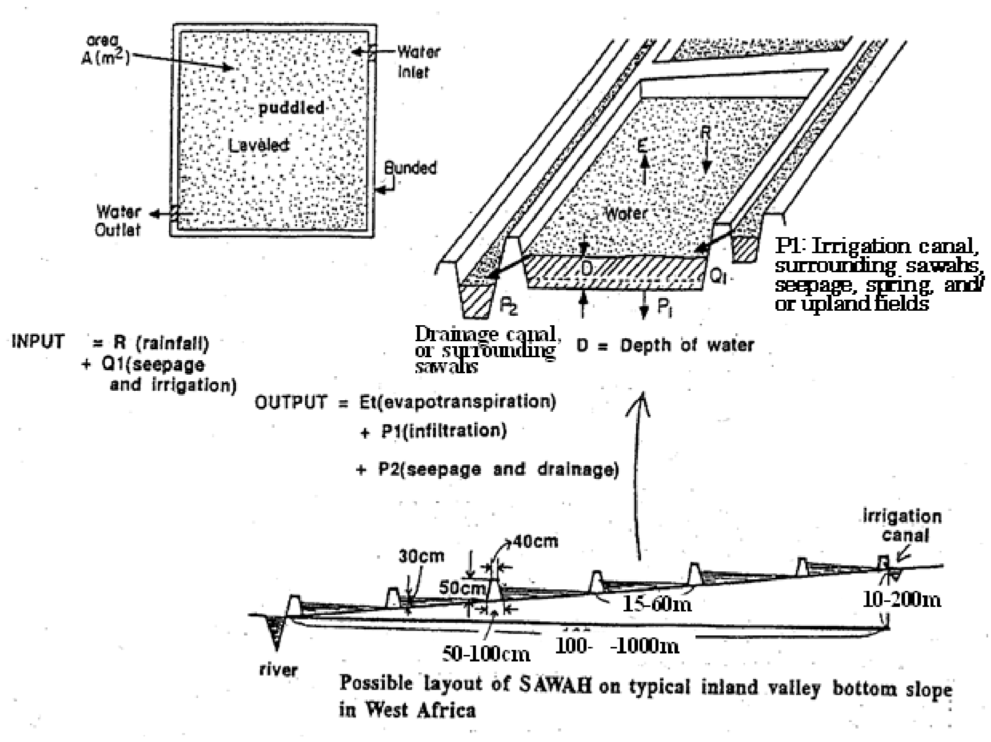


Figure 2. Sawah: A leveled, bunded, and puddled rice field with inlets and outlet to control water

to realize GR in Africa. Suffice it to say that the *sawah* ecotechnology is the prerequisite condition to apply the three GR technologies successfully. As shown in Figure 1, a *sawah* system composeds from *sawah* fields and irrigation/drainage facilities in a small inland valley watershed. The lowland *sawah* can also sustain rice yield higher than 4t/ha through macro scale natural geological fertilization from upland and micro scale mechanisms to enhance various nutrient supply, if appropriate lowlands are selected, developed and soil and water managed properly.

Most of the paddy fields in Asian countries correspond to the definition of the term *sawah*. Therefore, the paddy fields are almost equivalent to *sawah* for Asian scientists. However in West Africa, the term paddy refers to just a rice field including upland rice fields. In order to avoid confusion and to stress the focal point to realizing the long-awaited rice GR through the improvement of rice ecological environment using eco-technology, the term *sawah* is used to describe the improved man-made rice-growing environment and the rice plant growing in it.

Another frequent source of misunderstading in West Africa is the term irrigated rice. In Asia, the meaning of this term is clear, as the *sawah* has been historically developed by local farmers using hundreds or even thousands of historical years, before the coming of irrigation projects recently (after 1970s) by Asian governments. However, since both irrigation and *sawah* are new and the concept of *sawah* has been lacking, there have been many irrigation systems without proper *sawah* development in West Africa and SSA.

In a well planned and developed *sawah* field, the water inlet and outlet should be installed at the bunds with gate connecting with irrigation and drainage (Figure 2, upper part). Proper knowlegde, especially of sloping pattern and hydrology, of the field is needed to do this. In an extensive watershed, the interval of bunding is guided by the slope (Figure 2, lower part). The aim should be to maintain an interval that would permit adequate levelling of the puddled soil for optimum water control.

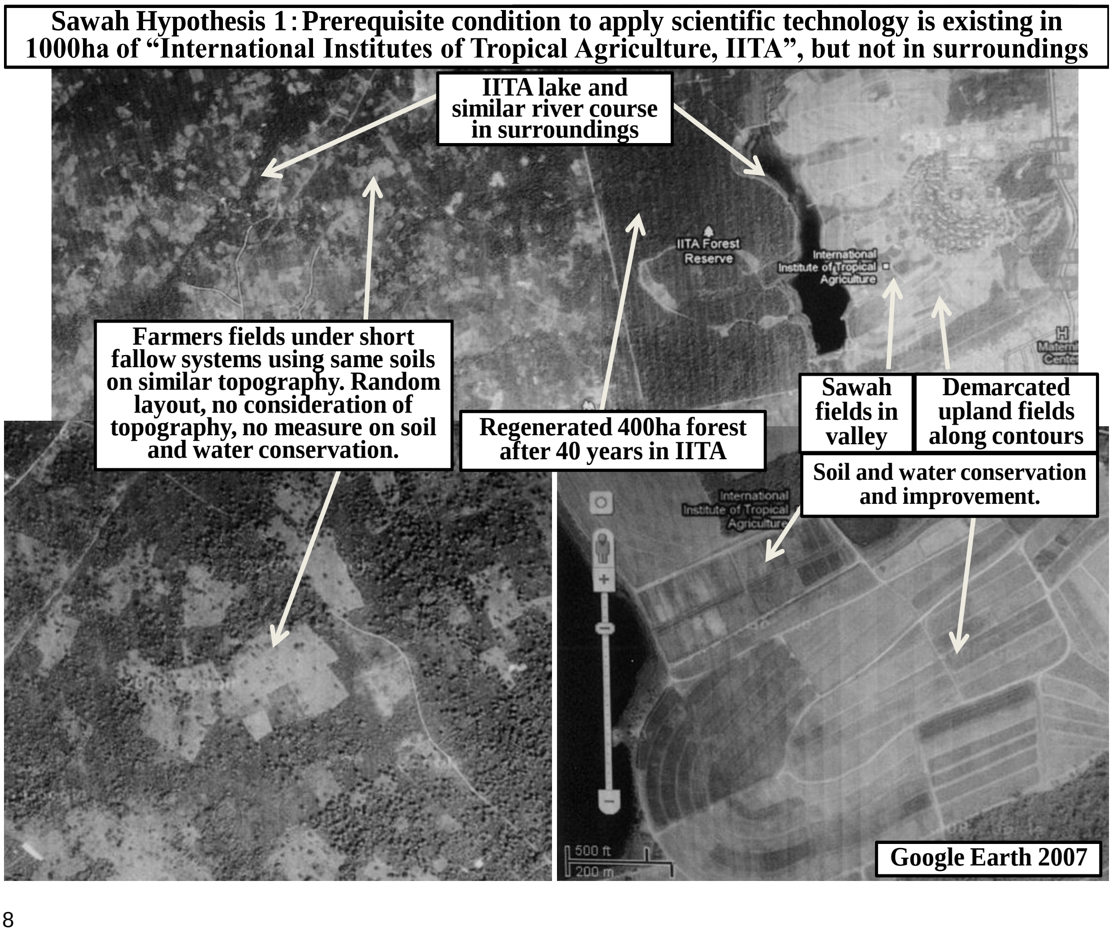
***Sawah* Hypothesis (I) for a Green Revolution in Sub-Saharan Africa**

There has been a considerable paddy yield gap between African Research Institutes (5-8 t/ha) and those of farmers (1-3 t/ha) for the past 40 years. During this period, three major components of GR technologies, (improved seeds, fertilizers & other agrochemicals, and irrigation) have been researched on and developed. Although they have been available at the experimental fields of various research institutes in Africa, these technologies have not been effectively adapted in African rice farmers' fields. Almost all institute-based technologies have not been scaled up to farmers' fields. Thus, the GR is yet to be realized. The Google airphotograph and the Figure 3 below explains the reason. All scientific technologies have some limited operational conditions in the fields. A very scientific requirement of the technology that calls for experience or skills acquired through training and practical field application is the demarcation of the field into basins using the bunds (Google airphotograph below and Figure 3). The good demaration not only helps to control water and conserve soils but also encourages the expression of the beneficial physical and biochemical interactions going on either upland or lowland soil. As shown in Googple airphotograph below, necessity of fields demarcation is not only lowland but upland as well.

To control water in farmers' fields, for example, need sawah systems. Majority of African farmers' fields are not ready to accept most of the scientific technologies developed at research institutes like IITA and AfricaRice. The sawah ecotechnology is the prerequisite condition for applying the three Green Revolution technologies (Sawah hypothesis 1). To increase rice production, both “varietal improvement” by breeding studies using bio-technology and “improvement of ecological environments of farmers’ fields” by “sawah” studies using eco-technologies are equally important. The two technologies are complementary to each other. Biology and ecology (environment) are the two basic components of agriculture. However, “sawah” studies to improve farmers’ ecological environments have been largely neglected in Africa. As shown below, thus we must accelerate sawah development in Africa.

Our first *sawah* hypothesis for realising GR in Africa is that farmers’ *sawah* should come first. This paper explains that the core technology for GR in SSA is *sawah* eco-technology (Figure 4) (Wakatsuki et al. 1998, Wakatsuki et al. 2001, Hirose and Wakatsuki 2002, Wakatsuki and Masunaga 2005, Wakatsuki et al. 2005 and 2009, Oladele et al. 2010, Abe and Wakatsuki 2011). This paper and companion paper in this workshop (Wakatsuki et al. 2011) also explain five key technologies necessary for the *sawah* approach to achieve a GR in SSA.

The rice GR must include three core technologies – (1) irrigation, (2) fertilizers and agrochemicals, and (3) use of HYV. Although these three technologies have been available for the past 40years, they have not been effective in farmers’ fields in SSA. In order to apply these scientific technologies, farmers’ fields must develop *sawah* or other similar alternatives typically in the lowlands that can conserve soil and control water (*Sawah* hypothesis I, Figure 4). Essential components with regard to land development are (1) demarcation by bunding based on topography, hydrology, and soils, (2) puddling and leveling to control and conserve soil and water, and (3) water inlets to get water (using various irrigation facilities) and water out-lets to drain



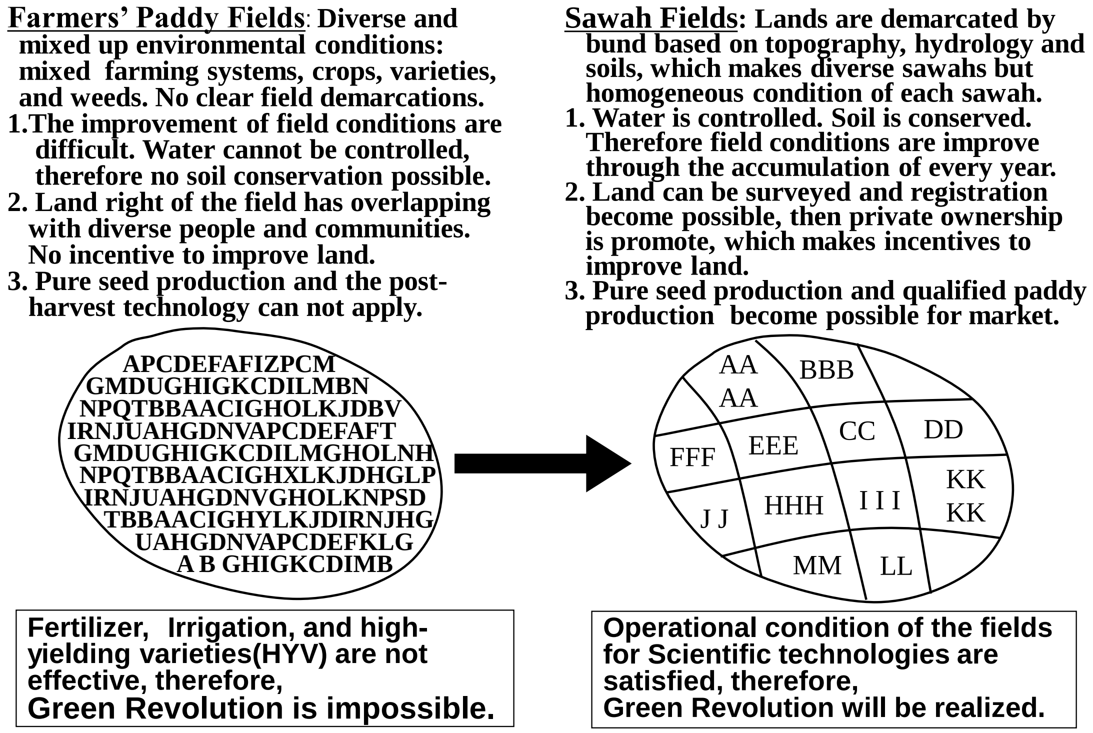


Fig 3. Sawah hypothesis (1): Farmers' Sawah should come first to realize Green Revolution. Farmers fields have to be classified and demarcated ecotechnologically. Then scientific technology can be applied.

excess water. These are the characteristics of *sawah* fields. For various social and historical reasons since the 1500s, these basic land and infrastructure developments to make the scientific technologies necessary for a green revolution possible have been disturbed n SSA (Hirose and Wakatsuki 2002).

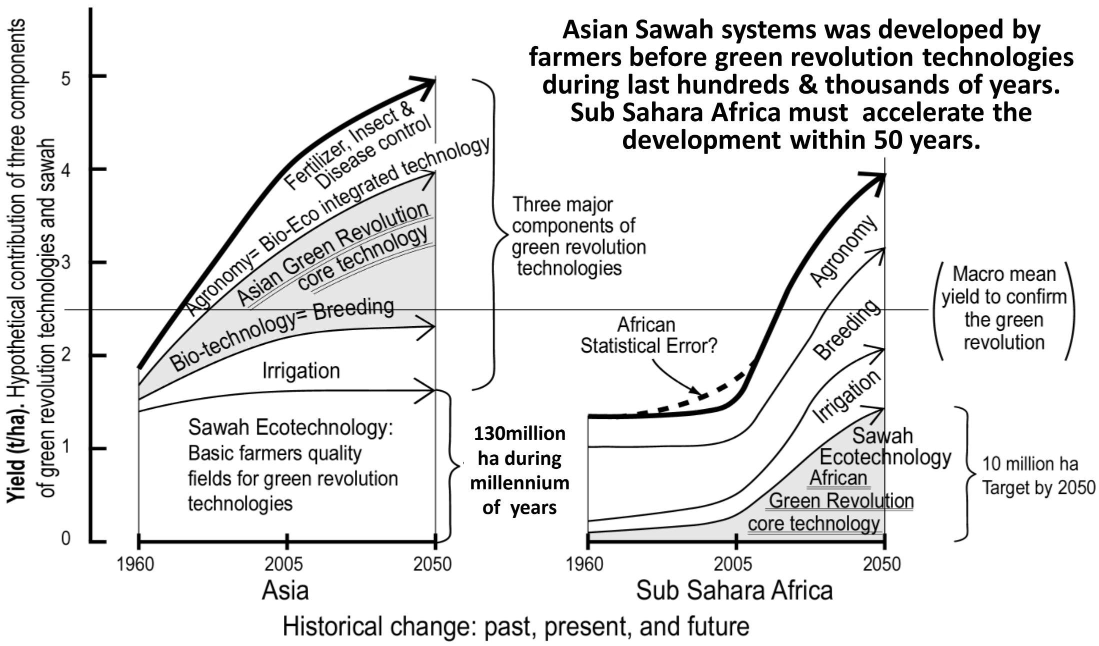


Fig.4. Sawah hypothesis(1) for Africa Green Revolution:

Hypothetical contribution of three green revolution technologies & sawah system development during 1960-2050. Bold lines during 1960-2005 are mean rice yield by FAOSTAT (2006). Bold lines during 2005-2050 are the estimation by the authors.

As shown in Figure 4 below, Asian sawah systems were developed by farmers selfsupport efforts before GR technologies using last hudnreds and thousands years. These are the basic infrastructures to apply High Yielding Varieties (HYV), Fertilzer and government assisted irrigation technologies. However there are very limited such infrastrutures to apply GR technologies. Thus Sub Saharan Africa have to accelerate the sawah system developemt to realize GR.

Sawah Hypothesis (II) for Intensive long-term Sustainability and to combat global warming

The upper part of Figure 5 illustrates the concept of watershed eco-technology or "Watershed Agroforestry"(Wakatsuki and Masunaga 2005). The soils formed and the nutrients released during rock weathering and soil formation processes in upland areas arrive and accumulate in lowland areas through geological fertilization processes. These processes include soil erosion and sedimentation, surface and ground water movement, as well as formation of colluviums. Ideal land-use patterns and landscape management practices will optimize the geological fertilization processes by ensuring optimum hydrology in a given watershed. Irrigation, surface, and subsurface water also contribute to increase in the supply of such nutrients as Si, Ca, Mg, K and sulfate. This contribution provides an ecological engineering basis for sustainability of intensive lowland *sawah*-based rice farming (Greenland 1997, Wakatsuki et al. 1998, Hirose and Wakatsuki 2002, Ofori et al. 2005, Wakatsuki and Masunaga 2005).

The lower half of Figure 5 shows the micro-scale mechanisms of the sustainability of the *sawah* system. The *sawah* system can be managed as a multi-functional constructed wetland. Submerged water can efficiently control weeds. Under submerged conditions, P availability is increased through the reduction of ferric iron. Both acid and alkaline soil pH are neutralized or mitigated by appropriate regulation of submergence. Hence, micronutrient availability is also increased. These mechanisms encourage not only the growth of rice plants but also of various aquatic algae and other aerobic and anaerobic microbes, which increase N fixation in the *sawah* systems through increases in photosynthesis, hence the status of the *sawah* systems as functional wetlands. Puddling is important to encourage a collaboration of diverse microbes' consortia through various nanowire' interactions in the puddled soft *sawah* soils similar to marine sediments (Wakatsuki et al. 1998, Hirose and Wakatsuki 2002, Kyuma 2004, Wakatsuki et al. 2009, Nielsen et al. 2010).

Lowland *sawah* systems can sustainably produce paddy at approximately 2t/ha without any chemical fertilizer application (Hirose and Wakatsuki 2002, Wakatsuki et al. 2009). Furthermore, lowland *sawah* systems can support rice cultivation continuously for decades, centuries, or more without any fallow period. In contrast, upland slash and burn rice fields hardly ever sustains paddy yields in excess of 1 t/ha without fertilizer. In addition to this lower yields, upland paddy fields require a fallow period to restore soil fertility, typically 2 years of cultivation and 8 or sometimes more than 15 years of fallow. This means that 1 ha of sustainable upland rice cultivation requires at least additional 5 ha of land. Therefore, sustainable upland paddy yield is actually not 1t/ha but less than 0.2t/ha. In all, the sustainable productivity of *sawah*-based rice farming is more than 10 times higher than that of the upland slash and burn rice (*Sawah* Hypothesis II). We know this to be true based on a long history and experience (not experiments) of *sawah*-based rice farming in Asia, although no scientific or quantitative confirmation exists yet. We therefore must determine the

Macro-scale watershed eco-technological mechanisms to support Sawah hypothesis II: Geological Fertilization of eroded topsoils and accumulation of nutrient rich water in lowland Sawah

Sustainable green revolution by sawah and SATOYAMA systems for combating Global warming: (1) efficient use of water cycling and conservation of soil fertility, (2) Ecological safe carbon sequestration by CDM, Bio-char and humus accumulation in sawah Soil layers, which will eventually transfer to sea floor, and (3) increase soil productivity by bio-char and humus accumulation

Micro-scale eco-technological mechanisms to support Sawah hypothesis II: Enhancement of the availability of N, P, K, Si, Ca, Mg, and micronutrients and quality carbon accumulation

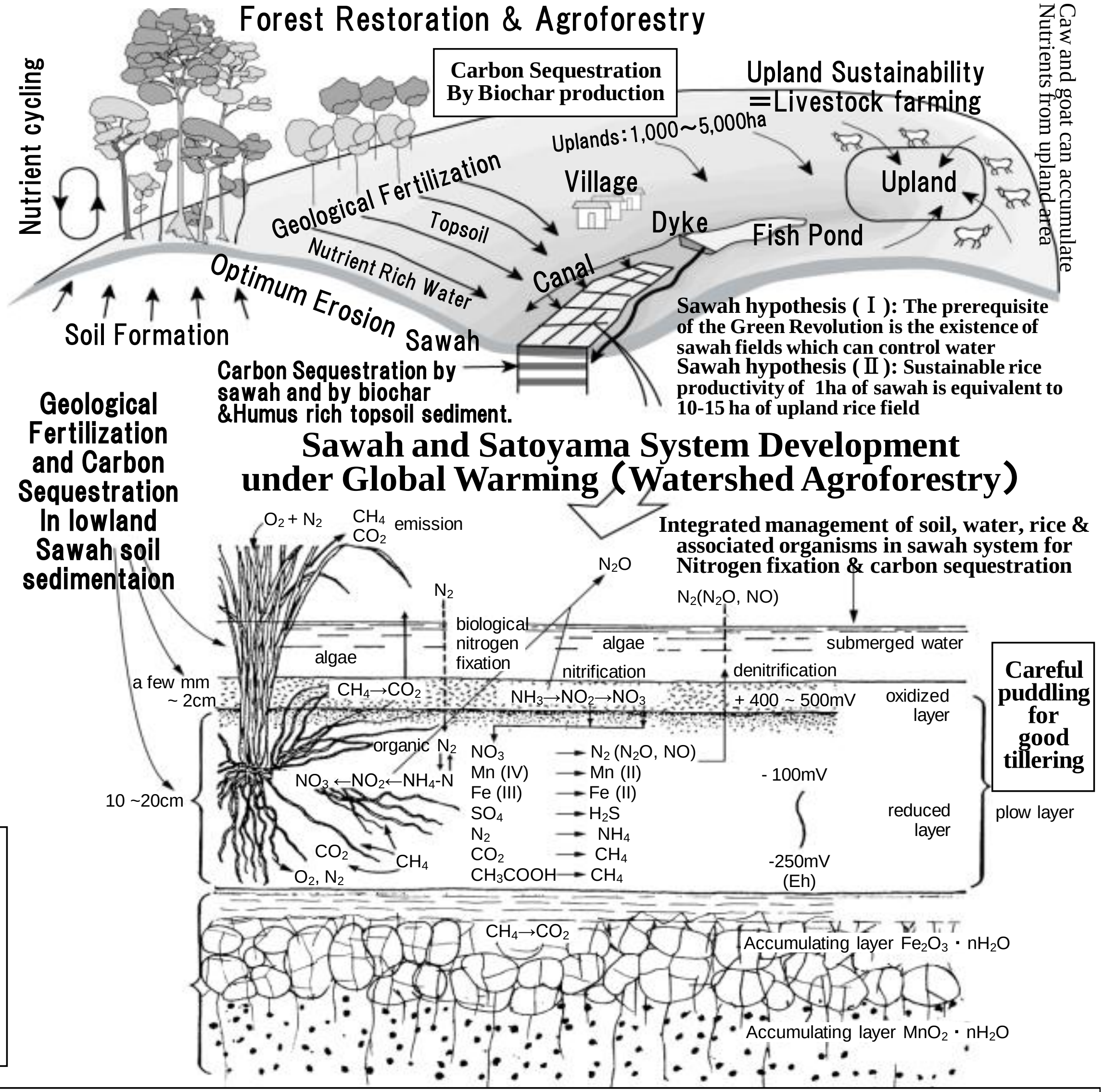


Figure.5 Sawah hypthesis (II): Watershed Agro-forestry for Sustainable Intensive Rice cultivation and to combat global warming

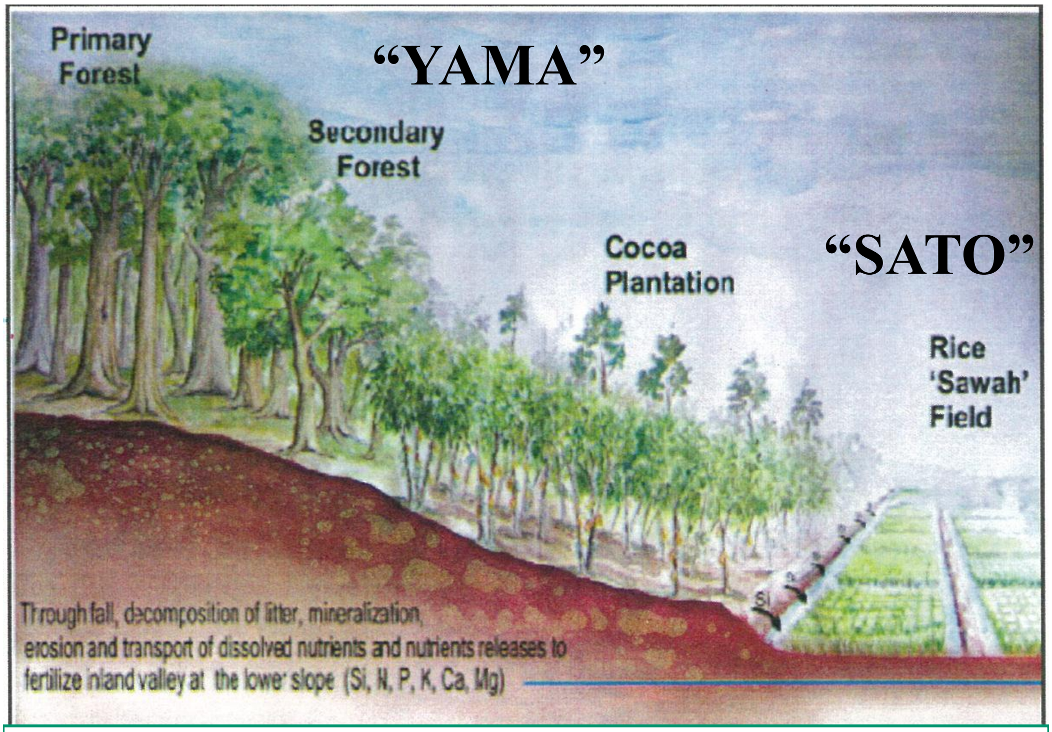


Figure 6. One Example of Africa SATO-YAMA Concept Map by Dr. Owusu, FoRIG, Ghana which is a watershed agro-forestry applicable to Cocoa belt region in West Africa.

sustainable yields quantitatively under SSA conditions. It is known that 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 forest conservation, which in turn enhances the sustainability of intensive lowland *sawah* systems through nutrient cycling and geological fertilization processes (watershed agroforestry or African SATO-YAMA system). SATO means villagers' habitat and YAMA means multipurpose forests managed by villagers. Because of sustainability of intensive lowland *sawah* systems, degraded upland fields can be converted to multipurpose forests. Thus as shown in Figure 5, *sawah* fields can contribute to the alleviation of global warming problems through the fixation of carbon in forest and *sawah* soils in ecologically sustainable ways (Hirose and Wakatsuki 2002, Wakatsuki et al. 2009).

Comparison between biotechnology and *sawah* ecotechnology options for rice production

Figure 7 shows that the use of biotechnologically improved rice varieties alone cannot bring about the expected results in SSA. There is the need for *sawah*-based ecotechnology to complement biotechnology in the region. Some of the different approaches of biotechnology and ecotechnology to solving agronomic problems are itemised in Table 2.

As itemised in Table 2, *sawah* ecotechnolgy can improve irrigation and fertilizer efficiency. Thus it can improve water shortage, poor nutrition especially for N and P supply, and neutralize acidity and alkalinity to improve micronutrient supply. With this, improved varieties can perform well to realize GR in Africa. Thus the *sawah* ecotechnology is the prerequisite condition to apply the three GR technologies successfully. The lowland *sawah* can also sustain rice yield higher than 4t/ha through macro scale natural geological fertilization from upland and micro scale mechanisms to enhance various nutrient supply, if appropriate lowlands are selected, developed, and soil and water managed properly.

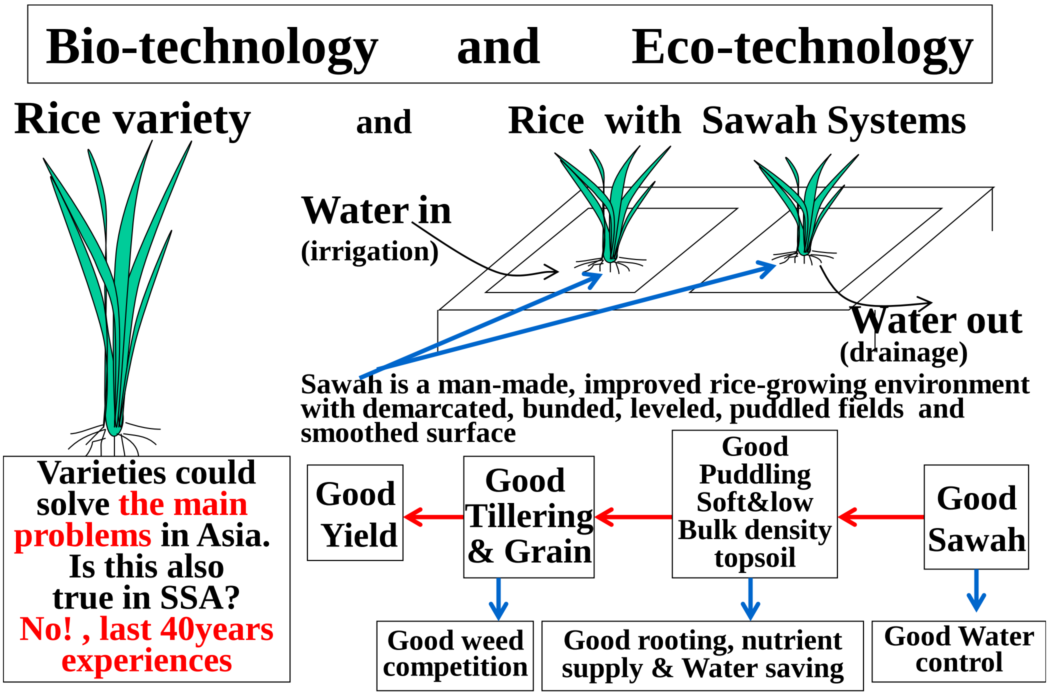


Figure 7. Rice (variety) and environment (Sawah) improvement. Both Bio & Eco-technologies must be developed in good balance

Table 2. Biotechnology and ecotechnology differ in their approaches to solving agronomic problems

Agronomic problem	Biotechnology	Ecotechnology
Water shortage	Genes for deep rooting, C4-nature and osmotic regulation	*Sawah*-based soil and water management: bunding, puddling, levelling and surface smoothening with various water harvesting and irrigation facilities
Poor nutrition, acidity and alkalinity	Genes for phosphate and micronutrient transportation	*Sawah*-based C and N fixation, increased P and micro- and macronutrient availability; geological fertilization; watershed agroforestry; and P-rich bird feculent
Weed control	Gene for rapid growth and enhanced weed competition.	*Sawah*-based weed management through proper levelling and smoothening, transplanting and water control; multifactorial enhancement of tillering; duck and rice farming
Pest and disease control	Various genes for resistance	*Sawah*-based silica and other nutrients supply to enhance immune mechanisms of rice; mixed cropping
Food quality	Vitamin rice gene	*Sawah*-based nutrition control; fish, duck and rice in *sawah* systems

Conclusions

In Table 3 multi Functionality of sawah systems in watershed has summaride. Lowland *sawah* can produce about 2t/ha of sustainable paddy yield without any chemical fertilizer application. However, in upland slash-and-burn rice fields, the yield without fertilizer rarely exceeds 1 t/ha, and fallow periods are needed to restore fertility, effectively reducing the sustainable yield to less than 0.2t/ha. Sustainable productivity of *sawah*-based rice farming is therefore more than 10 times higher than that of upland slash-and-burn rice. This *Sawah* hypothesis II has to be examined quantitatively under SSA conditions. Accordingly, the development of 1 ha of lowland *sawah* field enables the conservation or regeneration of more than 10 ha of upland forest area. *Sawah* fields can, therefore, contribute to not only increased food production but also to conservation of forest, which in turn enhances sustainability of intensive lowland *sawah* systems through nutrient cycling and geological fertilization processes (African SATOYAMA system). Furthermore, they contribute to the alleviation of global warming problems in the long run after solving food shortage, through the fixation of C in forest and *sawah* soils in ecologically sustainable ways.

The paper has shown the concept of watershed eco-technology and watershed agroforestry. The soils formed and nutrients released during rock weathering and soil formation processes in upland are accumulated in lowland through geological fertilization processes, such as soil erosion and sedimentation as well as surface and ground water movements or colluvial processes. 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 contribute to the increase in supply of nutrients, such as Si, Ca, Mg, K and sulfate.

Table 3. Summary of Multi Functionality of Sawah Systems

I. Intensive, diverse and sustainable nature of productivity

(1) Weed control through water control and enhancement of nutrient supply

(2) Ecosystem Nitrogen fixation : 20 to 200kgN/ha/year

(3) To increase Phosphate availability: concerted effect on N fixation

(4) pH neutralizng ecosystems: to increase micro nutrient availability

(5) Watershed Geological fertilization: water, nutrients and topsoil from upland

(6) Various sawah based farming system option.

(7) Fish and rice, Goose and sawah, Birds and sawah, Forest and Sawah

II. To combat Global warming and other environmental problems

(1) Carbon sequestration through control of oxygen supply. Methane emission under submerged condition. Nitrous oxide emission under aerobic rice

(2) Watershed agroforestry, SATOYAMA, to generate forest at upland

(3) Sawah systems as to control flooding & soil erosion and to generate electricity

(4) Denitrification of nitrate polluted water

III. To create cultural landscape and social collaboration

(1) Terraced sawah systems as beautiful cultural landscape

(2) Fare water distribution systems for collaboration and fare society

This is ecological engineering basis for sustainability of intensive lowland *sawah*-based rice farming.

The *sawah* system is also characterized by micro-scale mechanisms which help to ensure sustainability of the system under intensive rice production. The *sawah* system can be managed as multi-functional constructed wetland. Submerged water can control weeds. Under submerged conditions, P availability is increased through the reduction of ferric iron and both acid and alkaline soil conditions are neutralized or mitigated. Hence, micronutrients availability is also increased. These mechanisms promote not only rice growth but also the growth of various aquatic algae and other aerobic and anaerobic microbes, which increase N fixation in the system through increase in photosynthesis. This is the basis for referring to *sawah* systems as functional wetlands. Puddling softens the soil and this is needed to encourage collaboration of diverse microbes consortia through the various nanowire' interactions in *sawah* soils.

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