SECTION TWO
SCIENTIFIC PRESENTATIONS

Table of Content

Page

Multi-Functionality of *'Sawah'* Eco-Technology: Why *'Sawah'*-Based Rice Farming is Critical for Africa's Green Revolution

T. Wakatsuki[1], M.M. Buri[2], R. Bam[3], O.I. Oladele[4], S.Y. Ademiluyi[5], I.I.Azogu[5] and C. A. Igwe[6]

[1]*School of Agriculture, Kinki University, Nara 631-8505, Japan ;* [2]*CSIR-Soil Research Institute, Kumasi, Ghana ;* [3]*CSIR-Crops Research Institute, Kumasi, Ghana ;* [4]*North West University, Mafikeng Campus, Mmabatho 2735, South Africa ;* [5]*National Center for Agricultural Mechanization, Ilorin, Nigeria ;* [6]*Department of Soil Science, University of Nigeria, Nsukka 410001, Nigeria.*

Abstract

Sustainable agricultural rice production is realized by balanced application at farmers' fields of both: (i) varietal improvement through biotechnology, and (ii) 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: (a) irrigation, (b) agrochemicals input, and (c) high-yielding varieties (HYV). Although all these three technologies have been available for 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 Institutions results (5-8 t ha^{-1}) and those of farmers (1-3 t ha^{-1}). However, 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 institutions 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 are available, farmers can not control water and majority of African farmers' fields will not be 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: (i) demarcation by bunding based on topography, hydrology and soils, (ii) levelling and puddling to control and conserve soil and water, and (iii) water inlet to get water (through various irrigation facilities) and water outlet to drain excess water. These are the basic characteristics of *sawah* fields. *Sawah* eco-technolgy which can improve irrigation and fertilizer efficiency, will thus 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 the GR in Africa can be realized. Thus for the three GR technologies to be successful, the *sawah* ecotechnology is a prerequisite. Lowland *sawah* can also sustain rice yield higher than 4t ha^{-1} through macro-scale natural geological fertilization and other 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 such improved agronomic practices as System of Rice Intensification or others are further applied using the *sawah* systems, paddy yield can exceed 10t ha^{-1}. After continued long-term basic and action researches during 1986-2010, *sawah* research programs have finally established basic technology sets for the system. This is the "site specific personal irrigated *sawah* systems development and management by farmers' self-support efforts" (*sawah* eco-technology) in diverse inland valley agro-ecologies at forest and transitional zones in Ghana and at derived and core Savannah zones in Nigeria. 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* eco-technology in the whole of Ghana and Nigeria in order to realize rice GR in both countries. It is expected to extend to Togo and Benin as well as 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^{-1} (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 (TICAD 4) held in May 2008 at Yokohama, Japan. Similar to the UN MVPs, AGRA and CARD have big scale activities for a 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: (i) varietal improvement through biotechnology, and (ii) the improvement of rice ecological environment through eco-technology. It is our believe therefore that the core technology to contribute to GR in Africa is eco-technology and an example is the *sawah* eco-technology.

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 exist 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 our involvement in the on-going long-term research, has been able to verify the importance of water control through the *sawah* system. At farmers' level, our *sawah* research programs finally have 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 and transitional zones in Ghana and derived and core Savanna zones in Nigeria. In 2011, the sawah team demonstrated *sawah* eco-technology successfuly on the huge flood plains in collaboration with Kebbi state Fadama III and ADP staff, Nigeria. One power tiller could develop 7 ha of the pump based irrigated sawah systems with over 7t ha^{-1} of paddy yield during April to September (6 months).

The *Sawah* eco-technology has now arrived at 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.

What is 'Sawah', Paddy and Irrigation?

The English term, paddy, originated 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, improved varieties can perform better to realize GR in Africa. Suffice it to say that the *sawah* eco-technology is the prerequisite condition for the successful application of the three GR technologies. As shown in Figure 1, a *sawah* system is composed of *sawah* fields and irrigation/drainage facilities in a small inland valley watershed. The lowland *sawah* can also sustain rice yield higher than 4t ha^{-1} 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.

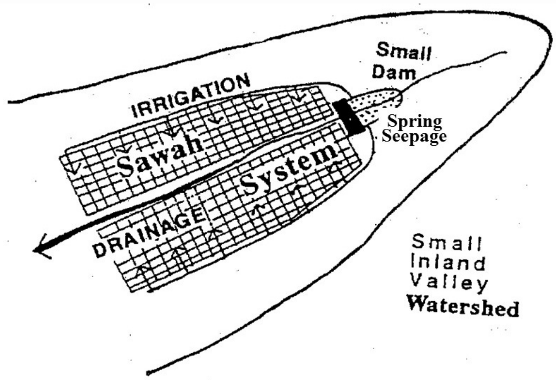

Figure 1. Sawah system with irrigation and drainage facilities for control of water in an inland valley watershed

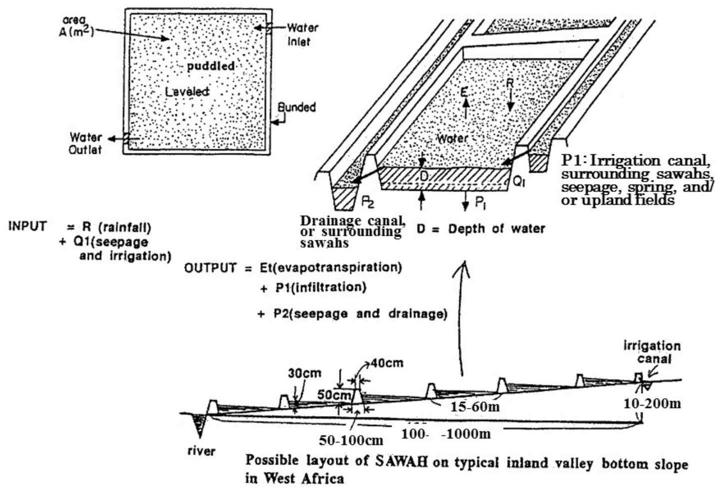

Figure 2. Sawah: A leveled, bunded, and puddled rice field with inlets and outlet to control water

Another frequent source of misunderstading in West Africa is the term irrigated rice. In Asia, the meaning of this term is clear, as *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 Institution(5-8 t ha^{-1}) and those of farmers (1-3 t ha^{-1}) 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 air photograph and the Figure 3 can explain 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 bunds. Good demarcation 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. As shown in the Google air photograph, necessity of fields' demarcation is not only on lowland but upland as well.

To control water in farmers' fields, 'sawah' systems are needed. Majority of African farmers' fields are not ready to accept most of the scientific technologies developed at research institutes like IITA and AfricaRice. 'Sawah' eco-technology is the prerequisite condition for applying the three Green Revolution technologies (ref: 'Sawah' hypothesis 1). To increase rice production, both "varietal improvement" through breeding studies using bio-technology and "improvement of ecological environments of farmers' fields through '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. There is therefore the need to accelerate 'sawah' development in Africa.

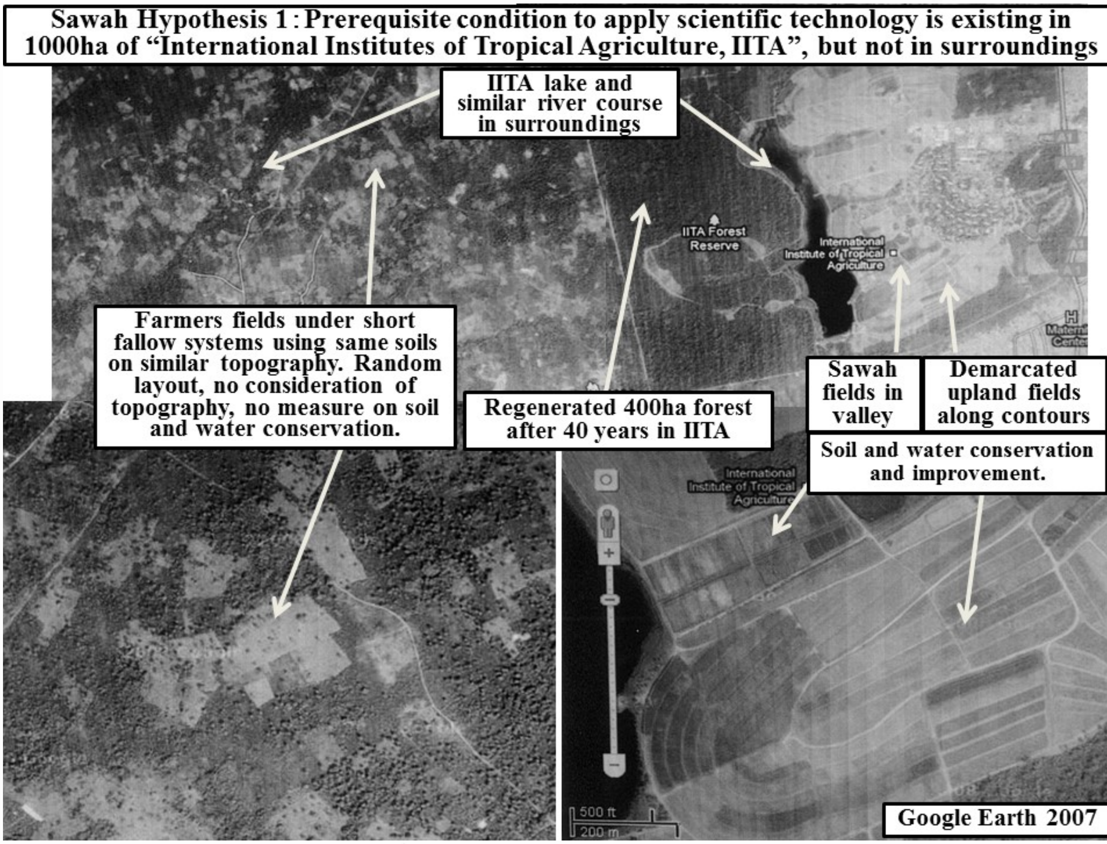

Fig. 3

The '*sawah*' hypothesis for realising GR in Africa is that farmers' '*sawah*' should come first. This paper explains why the core technology for GR in SSA is '*sawah*' eco-technology as outlined by 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, and Abe and Wakatsuki 2011 and illustrated in Figure 4. The paper also explains five key technologies necessary under the '*sawah*' approach to achieve a GR in SSA. The rice GR must include three core technologies: (i) irrigation, (ii) fertilizers and agrochemicals, and (iii) use of HYV. In order to apply these scientific technologies, farmers' fields must be developed into '*sawah*' or other similar alternatives typically in the lowlands that can conserve soil and control water. Essential components with regard to land development are (i) demarcation by bunding based on topography, hydrology, and soils, (ii) puddling and levelling to control and conserve soil and water, and (iii) water inlets to get water (using various irrigation facilities) and water out-lets to drain any 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 in SSA (Hirose and Wakatsuki 2002).

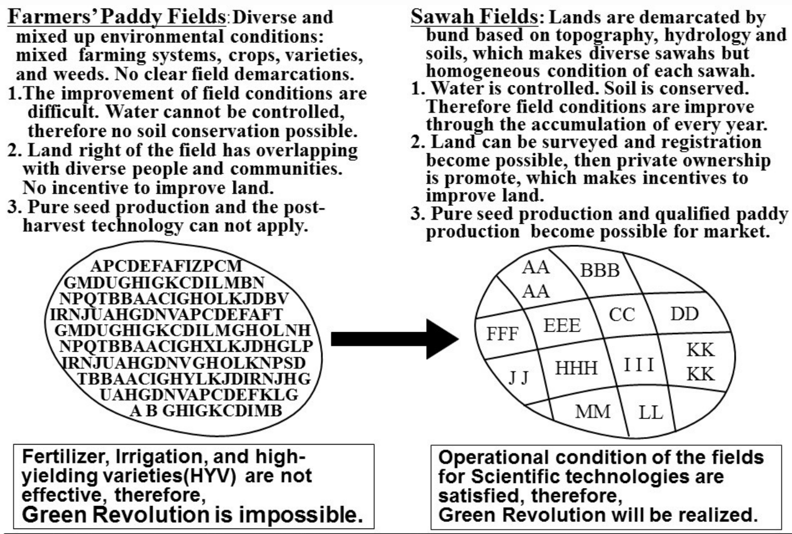

Fig.4. Sawah hypothesis (1): Farmers' Sawah should come first to realize Green Revolution. Farmers fields have to be classified and demarcated ecotechnologically. Then scientific technology can be applied.

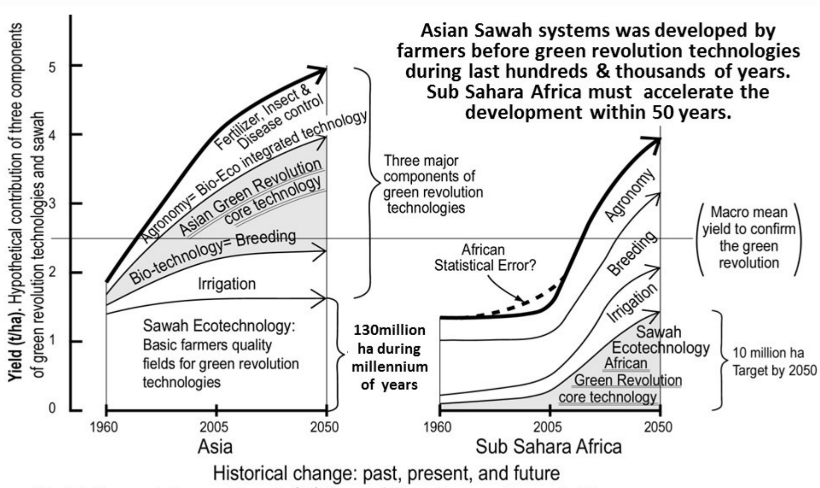

Fig.5. Sawah hypothesis(1) for Africa Green Revolution:
Hypothetical contribution of three green revolution technologies & sawah system development during 1960-2050. Bold lines during 1960-2005 are mean rice yield by FAOSTAT (2006). Bold lines during 2005-2050 are the estimation by the authors.

As shown in Figure 4, Asian 'sawah' systems were developed by farmers' self-support efforts before GR technologies were introduced. These are the basic infrastructures needed before applying High Yielding Varieties (HYV), Fertilizer and government assisted irrigation technologies. Thus Sub Saharan Africa has to accelerate the 'sawah' system development to realize GR through the provision of such structures.

'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 Agro-forestry" (Wakatsuki and Masunaga 2005). The soils formed and the nutrients released during rock weathering and soil formation processes in upland areas are transported and deposited 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 SO_4. 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 6 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^{-1} without any chemical fertilizer application (Hirose and Wakatsuki 2002; Wakatsuki et al., 2009). Furthermore, lowland '*sawah*' systems can support rice cultivation continuously for decades or centuries without any fallow period. In contrast, upland slash and burn rice fields hardly ever sustain paddy yields in excess of 1 t ha^{-1} without fertilizer. In addition to this lower yields; upland paddy fields require a fallow period to restore soil fertility, typically for 2 years of cultivation, 8 - 15 years of fallow may be required. 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^{-1} but less than 0.2t ha^{-1}. In a'l, 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.

It is therefore important to determine 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 intensively used lowland '*sawah*' systems through nutrient cycling and geological fertilization processes (watershed agro-forestry or African SATO-YAMA system). SATO means villagers' habitat and YAMA means multipurpose forests managed by villagers. As a result of the sustainability of intensive lowland '*sawah*' systems, degraded upland fields can be converted to multipurpose forests. Thus as shown in Figure 6, '*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).

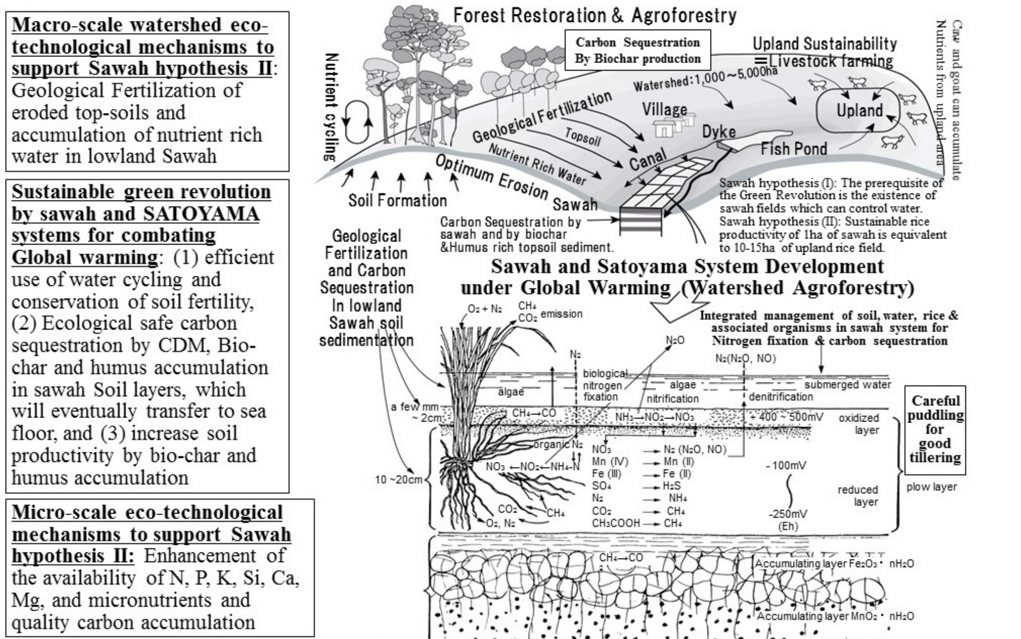

Fig.6. Sawah hypothesis (II): Watershed Agro-forestry for Sustainable Intensive Rice cultivation and to combat global warming

Comparison between biotechnology and 'sawah' eco-technology options for rice production.

Figure 6 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 eco-technology to complement biotechnology in the region. Some of the different approaches of biotechnology and eco-technology to solving agronomic problems are itemised in Table 2. '*Sawah*' eco-technolgy can improve irrigation and fertilizer efficiency. Thus it can improve on water availability, 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*' eco-technology is the prerequisite condition to apply the three GR technologies successfully. Lowland '*sawah*' can also sustain rice yield higher than 4t ha^{-1} 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.

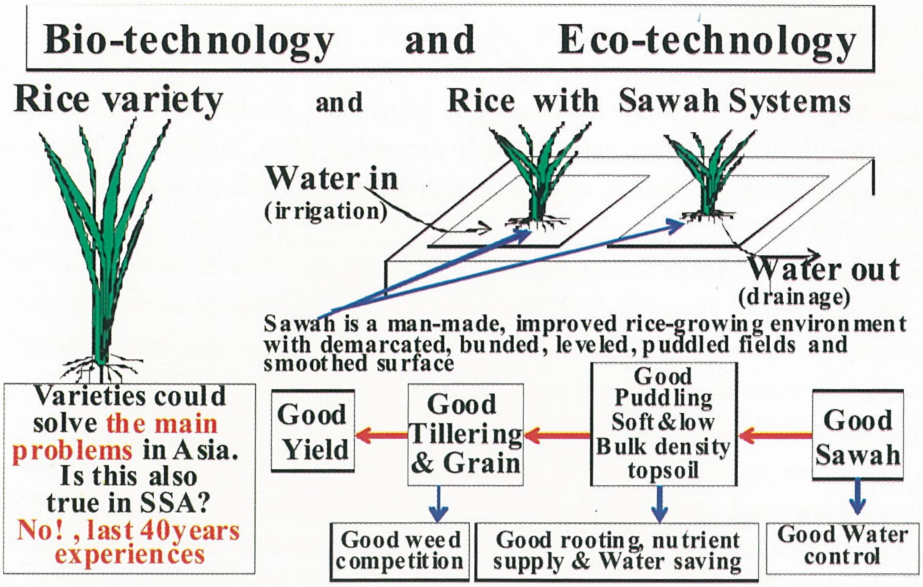

Figure 7. Rice (variety) and environment (Sawah) improvement. Both Bio & Eco-technologies must be developed in good balance

Table 2. Biotechnology and eco-technology differ in their approaches to solving agronomic problems.

Agronomic problem	*Biotechnology*	*Eco-technology*
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 agro forestry; 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; multi-factorial 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

In Table 3, the multi-functionality of 'sawah' systems in a watershed are summarised. Lowland '*sawah*' can produce about 2t ha^{-1} 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^{-1}. 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 increase food production but also to conserve 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 problem through the fixation of carbon in forest and '*sawah*' soils in ecologically sustainable ways.

Table 3: Summary of multi-functionality of sawah systems

A	***Intensive, diverse and sustainable nature of productivity***
i	Weed control by water and enhancement of nutrient supply
ii	Ecosystem nitrogen fixation (20-200kgN $ha^{-1}yr^{-1}$ fixed)
iii	Increases phosphate availability: concerted effect on N fixation
iv	pH neutralizing ecosystems: to increase micro-nutrient availability
v	Watershed geological fertilization: water, nutrients, topsoil from uplands
vi	Various sawah based farming systems options.
vii	Fish and rice; goose and 'sawah'; birds and 'sawah'; forest and 'sawah'.
B	***To combact global warming and other environmental problems***
i	Carbon sequestion through control of O_2 supply; methane emission under submerged conditions; nitrous oxide emission under aerobic rice
ii	Watershed agro-forestry, satoyama, to generate forest at upland
iii	Sawah systems as to control flooding & soil erosion, and to generate electricity
iv	Denitrification of nitrate polluted water
C	***To create cultural landscape and social collaboration***
i	Terraced sawah systems as beautiful cultural landscape
ii	Fare water distribution systems for collaboration and fare society

Conclusions

This paper has shown the concept of watershed eco-technology and watershed agro-forestry. 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 SO_4. This is the 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, phosphorus availability is increased through the reduction of ferric iron while 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 the '*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.

References

Abe S and Wakatsuki T. 2011. '*Sawah*' Eco-technology Triggers Rice Green Revolution in Sub-Saharan Africa. *Outlook on Agric* Vol 40, No 3: 221-227

Agrawal GK, Takeda S, Abe K, Miyano A, Hirochika H, Kitano H, Ashikali M and Matsuoka M. 2004. An Overview of Gibberellin Metabolism Enzyme Gene and Their Related Mutants in Rice. *Plant Physiology* 134: 1642-1653

Ashikali M, Sasaki A, Ueguchi-Tanaka M, Itoh H, Nishimura A, Datta S, Ishiyama K, Saito T, Kobayashi M, Khush SD, Kitano H and Matsuoka M. 2002. Loss of function of a Rice Gibberellin Biosynthetics Gene, GA20 oxidase (GA200x-2), Led to the Rice 'Green Revolution'. *Breeding Sci.* 52: 143-150

Evenson RE and Gollin D. 2003. Assessing the impact of the green revolution, 1960 to 2000. *Science* 300: 758-762

FAO. 2007. Rice situation update as of 31 March 2007. FAO Rice Market Monitor, Vol. X, Issue No. 1. Food and Agricultural Organization of the United Nations.
Available at: http://www.fao.org/es/esc/en/index.html

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

Hardin LS. 2008. Meeting that changed the world, Bellagio 1969: The green revolution, *Nature* 455: 470-471

Hazell P and Wood S. 2008. Drivers of change in global agriculture. Philos. Trans. R. Soc Lond, B. Biol Sci 363: 495-515

Hesser L. 2006. *The man who fed the world, Nobel peace prize laureate Norman Borlaug and his battle to end world hunger*. Durban house Publishing Company. Dallas, 263p, ISBN1-930754-90-6

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

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

Nielsen LP, Risgaard-Petersen N, Fossing H, Christensen PB and Sayama M. 2010. Electric currents couple spatially separated biogeochemical processes in marine sediment. *Nature* Vol. 463 | 25 February 2010 | doi:10.1038/nature08790

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

Oladele OI, Bam RK, Buri MM and Wakatsuki T. 2010. Missing prerequisite for Green Revolution in Africa: Lessons and the challenges of '*Sawah*' rice eco-technology development and dissemination in Nigeria and Ghana. *J. Food Agric Environ* 8: 1014-1018

Orr S, Sumberg J, Erenstein O and Oswald A. 2008. Funding international agricultural research and the need to be noticed: A case study of NERICA rice. *Outlook on Agric* 37: 159-168

Otsuka K and Kalirajan KP. 2006. Rice green revolution in Asia and its transferability to Africa: An introduction. *Dev Econs* 44:107-122

Otsuka K. 2006. Why can't we transform traditional agriculture in sub-Saharan Africa? *Review of Agric Econs* 28:332-337

Renkow M and Byerlee D. 2011. The impact of CHIR research: A review of recent evidence. *Food policy* (in press)

Sanchez P. 2002. Soil fertility and hunger in Africa. Science 295: 2019-2020

Toenniessen G, Adesina A and DeVries J. 2008. Building an Alliance for a Green Revolution in Africa, Ann. *New York Academy of Sci* 1136:233-242

Wakatsuki T and Masuanga T. 2005. Ecological Engineering for Sustainable Food Production and the Restoration of Degraded Watersheds in Tropics of low pH Soils: Focus on West Africa. *Soil Sci. Plant Nutr.* 51:629-636

Wakatsuki T, Buri MM and Oladele OI. 2009. West African green revolution by '*sawah*' eco-technology and the creation of African Satoyama systems, *http://www.humanosphere.cseas.kyoto-u.ac.jp/article.php/workingpaper61*

Wakatsuki T, Buri MM, and Fashola OO. 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, KL and Hardey B. (eds), pp 363-366, IRRI, JIRCAS, NARO, NIAS, NIAES, NIRE, APO, MAFF, Tsukuba, Japan

Wakatsuki T, Buri MM, Obalum SE, Bam R, Oladele OI, Ademiluyi SY and Azogu II. 2011. Farmers' personal irrigated '*sawah*' systems to realize the green revolution and Africa's rice potential, Paper presented at 1st International Conference on Rice for Food, Market, and Development (rice-Africa), Abuja, Nigeria March 3-5, 2011

Wakatsuki T, Otoo E, Andah WEI, Cobbina J, Buri MM 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, Shinmura Y, Otoo E and Olaniyan GO. 1998. African based '*sawah*' systems for the integrated watershed management of small inland valleys in West Africa. *In FAO Water Report No. 17. Institutional and Technical Options in the Development and Management of Small Scale Irrigation.* Rome, pp 45-60

Wopereis MCS, Diagne A, Rodenburg J, Sie M and Somado EA. 2008. Why NERICA is a successful innovation for African farmers: A response to Orr et al from the Africa Rice Center. *Outlook on Agric* 37:169-176