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Sawah Technology (3Paper) Principles: *Sawah* hypothesis (1) the platform for scientific technology evolution and *Sawah* hypothesis (2) the platform for sustainable intensification in watershed agroforestry (Africa SATOYAMA System)*

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Summary

Sawah is Malay-Indonesian terms to describe man-made enclosed rice fields to facilitate water control. Essential component of standard *sawah* system is farmers' fields' demarcation by quality bunds (ridges or levees) based on topography, hydrology and soils. The basic facilities are (1) bunding with appropriate height, width with compaction/surface sealing to control leakage, (2) levelling surface soil within 10cm height difference within one *sawah* plot bunded, (3) water inlet connecting to water sources and water outlet to drain, (4) ordinary surface of sawah is puddled to facilitate levelling for water and weed control.

Sustainable lowland rice production is realized by co-improvement or co-evolution of both (1) varietal improvement through biotechnology and (2) *sawah* system improvement and evolution through ecotechnology of the farmers' rice fields. Compared to biotechnological science, technology and innovation (STI), the eco-technological STI for improvement of rice growing ecology, i.e.,*sawah* system evolution, has been largely neglected in SSA during the last 50 years. Although all three GRs have been available during the past 50 years, they have not been effective at majority of farmers' fields in SSA. Almost all institute-based technologies could not scale up to farmers' fields. Thus, the GR has never been realized. All scientific technologies essentially have limited operational platform conditions. As shown in this paper, farmers' fields have to improve to the evolutional stages of *sawah* higher than 4th for animal cultivation or 5th stages for power-tiller cultivation among the six evolutional stages, i.e., standard *Sawah* plots, which have irrigation/drainage and are surrounded by quality bund to stop water leaking and the inside of *sawah* plot has leveling quality of ±5cm (*Sawah* Hypothesis 1: Scientific platform). The size of one *sawah* plot has to be big enough area, >100-200m^2, to make possible water management of rice cultivation area that can preserve livelihood of each farmer, which can be estimated

to be about 1 ha or more. This sawah size is also important to manage by one family with smooth operation of animal plow or powertillers cultivation. The advanced irrigated and drainaged large *sawah* plots have >0.3-1ha with quality bund and leveling quality of ±2.5cm in a large sawah plot using laser lever tractor (Stage 6 th). The rudimentary stages of *sawah* plots are bushy non *sawah* both upland and lowland open rice fields (Stage 1 st), lowland ridge planted rice, i.e., no leveling, with land demarcation bunds and with or without irrigation (Stage 2nd) , lowland micro rudimentary *sawah* plots smaller than 30-50m^2 with poor bunds and with or without irrigation (Stage 3rd). The intermediate stage *sawah* systems between the 2nd , 3rd and the 4th are also common in many irrigation schemes in Nigeria, Mali and Tanzania. The characteristics of the intermediate *sawah* systems are ①The cultivation of livestock utilization is common, thus ②bunded demarcated land use plot’s shape is long and narrow, typically 100m long and 5m width, and ③ micro *sawah* plots or ridge planting inside of the bunded demarcated land use plots.

As we described in the separate paper, **‘*Sawah* technology (4paper, 4ppt) Practices and Potential of Irrigated Sawah System Development by Farmers Self-help Efforts**, the *sawah* technology will make possible ‘Site specific farmers’ personal irrigated *sawah* system development and *sawah* based rice farming by farmers’ self-support efforts’. If *sawah* system and *sawah* mamagement skills can reach to the standards levels, the *sawah* can improve irrigation and fertilizer efficiency, and thus can cope with water shortages & excess and poor nutrient supplies (especially N & P as well as Si, Ca, Mg and K). It can also neutralize acidity and/or alkalinity, thus improve micronutrient supplies. With this, the improved HYVs can perform better and we will be able to realize Green Revolution in Africa. Through the control of water and puddling, weeds can be also controlled. The lowland *sawah* system can thus sustain rice yields higher than 4 t/ha through macro-scale natural geological fertilization and micro-scale mechanisms to enhance the supply of various nutrients (*Sawah* hypthesis 2: Intensive sustainability platform). For optimum results, appropriate lowlands must be selected and developed at least to standards quality of *sawah* system, and soil and water of *sawah* systems must be managed properly. If we can also apply improved agronomic practices such as System Rice Intensification (SRI) or others under the advanced *sawah* system platform, paddy yields can exceed 10 t/ha. However without advanced *sawah* foundation, such improved agronomic practices are useless and innovations are impossible.

What is the core strategy to realize the rice green revolution in Sub Saharan Africa (SSA)? There are 6 on-going major strategies to realize rice revolution in SSA. **(1) Biotechnology priority, such as upland NERICA, targeting current bushy open non-consolidated farmlands.** This is the mistaken strategy that good variety can solve major low productivity problems even in current bushy open non-consolidated farmlands in SSA. **The (2nd) is the introduction of Asian green revolution (GR) technology.** Among the three GRs, high-yielding varieties (HYV) was core with irrigation/drainage and fertilizer/agrochemical input in Asia. This strategy is only effective on the irrigated *sawah* fields of quality infrastructure consolidation. However among the estimated potential irrigated rice land, *sawah,* 50 million ha, only 2 million ha, less than 5%, are irrigated including micro *sawah* plots. Thus this strategy has no priority currently. As we described as *Sawah* Hypothesis (I), the success of the Asian green revolution was based on the prehistory that the *sawah* systems had been developed by farmers before GRs arrived in 1960s during last hundreds and thousands years. The same thing is true to the British Agricultural revolution in 18th century, which was realized based on the long continued enclosure movement during 15th to 18th centuries. Unfortunately SSA has no such history. The 500 years of history of slave trade and colonial rule had been disturbed such nation building ground works. **The (3rd) is the introduction of advanced agronomy and hybrid seeds for super high yield.** This strategy has only reasonable cost performance in the fields with advanced sawah of quality infrastructure consolidation in the region and countries no more frontiers space for new sawah development such as System Rice Intensification technology (SRI) in Madagascar and Asian countries. **The (4th) is contractors based irrigated sawah system development using ODA funds such as World Bank, African Development Bank and other donors.** Since farmers, extension officers, engineers, scientists and policy makers in SSA have no or very limited knowledge, experience, and skills on irrigated sawah based rice cultivation, investment cost for development, management, rehabilitation and training costs are all expensive compare to Asian countries. Both environmental and social degradation are often serious, such as land grab, land conflict, and corruption as well as lowland submergence by dam, topsoil erosion, and forest destruction. ODA projects are also likely to destroy autonomy of African government. **The (5th) is Irrigated *Sawah* System Development by Private Big Business Enterprise.** The private business based irrigated *sawah* system developments are more efficient than ODA based projects. However still similar environmental and social degradations have to consider. The investment and technology gap between SSA farmers and big business enterprises are too big to fill. In addition, the private big business farms will enclose a big good lowlands of the nation, i.e., land grab. Numerous small farmers who are the most important national resource will be excluded from autonomous rice cultivation and empowerment. **The (6th) is our *sawah* technology strategy for endogenous *sawah* system development and *sawah* based rice farming with sustainable mechanization.** As described in this paper, SSA needs *sawah* system development for rice green revolution. In order to realize this target, SSA needs the innovative technology for breaking through the two big barriers of both area and time, i.e. 50 million ha of irrigated *sawah* system development by 2050, within several decades, not historical several hundred years like Asia and British, before the explosion of population bomb. Among the 6 strategy, only our S strategy will make possible these two targets above.

Introduction

In 1935, Dr. Gonjiro Inazuka, a rice breeder at Iwate Prefectural Experimental Station, Japan, successfully bred the NORIN-10 variety of wheat. This was collected in 1948 after World War II by scientists of US-occupied forces in Japan. In 1953, the variety was transferred to Dr. N. Borlaug at Chapingo, Mexico. By 1957, Dr. Borlaug used the NORIN-10 to quickly breed and released 14 high-yielding wheat varieties. This was the start of the dramatically successful green revolution innovation (GR) and the start of the Consultative Group of International Agricultural Research (CG) centers in the 1960s and '70s (Evenson and Gollin 2003, Hesser 2006, Hardin 2008, Renkow and Byerlee 2010). The NORIN-10 was the first crop variety in which the characteristics of a semi-dwarf gene, *sd1* to realize high yield, were identified. The Miracle rice of IR-8 was bred by IRRI through the application of the same concept which developed by Dr. Inazuka. We now know that all high-yielding varieties (HYVs) of wheat, maize and rice of the *Gramineae* family have the same *sd1* gene (Ashikali et al. 2002, Matsuoka 2004). Thus Dr. Gonjiro Inazuka is actually the "grandfather" of the GR.

The green revolution from semi-dwarf gene (sd1) crops from Japan originally was named for increased food production in Asia and Latin America, but in parallel with that, it also contributed to the increase in wheat production in Europe and the United States of America in the same time. The yield of wheat and core increased dramatically since 1950 as shown in Figure.10 in this paper, the green revolution of advanced European countries (Nishio 1998, Borojevic and Borojevic 2005).

As described in ***Sawah* Technology (2)Background,** we can summarize major contributors of Science, Technology, and Innovation (STI) in Asian/Latin American’s first GR as follows, i.e., **Dr. Inazuka for the development of GR technology in 1935, Dr. Borlaug for GR innovation in 1957 and Dr. Matsuoka and Ashikari for scientific foundation of GR in 2002.** Since the dramatic success in Latin America and tropical Asia in the 1960s and '70s, the similar variety-oriented research for GRs has been intensively and extensively conducted in sub-Saharan Africa (SSA). Probably in response to the view that the failure to realize a GR was due to the absence of appropriate varieties for the continent (Sanchez 2002), the Africa Rice Center (AfricaRice) developed the new rice cultivar for Africa (NERICA). The NERICA technology has indeed been hoped to be very promising (FAO 2007). In 2005, the Millennium Village Project (MVP) was established in 14 hunger and poverty hotspots cutting across diverse agro-ecological zones in SSA. This was in fulfilment of one of the recommendations in accordance with the Millennium Development Goals (MDGs) of the UN. Despite all these interventions, the GR is yet to be realized in SSA. Hence, SSA remains the only region where the population continues to grow while per capita agricultural production has 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 realizing a GR in SSA remains unclear (Otsuka 2006, Otsuka and Kalirajan 2006, Orr et al. 2008, Wopereis et al. 2008) except for our strategy, i.e., **GR through Sawah Technology and Irrigated Sawah System Evolution**.

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 large-scale activities targeted toward 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 biotechnology, as was the case in tropical Asia 50 years ago. However, now their advocacy for HYVs emphasizes the need for natural resources management (NRM)-oriented modifications.

As described in this paper, however, a more realistic approach to sustainable agricultural production is by balanced application at farmers' fields of both (1) varietal improvement through biotechnology, and (2) improvement, ie., evolution of *sawah* (man-made rice ecological environment) through ecotechnology. We believe at the present condition that the core technology to contribute to GR in Africa is rather ecotechnology, such as the *sawah* technology. CARD also now looks shifted from variety strategy to somewhat more weight on ecological improvement than past. This became clear at the TICAD V, Yokohama, Japan, in June 2013.

Quite recent FAOSTAT(2017-2018) as shown in ***Sawah* Technology (1) Statistics**, data during 2007-2016, which indicates that Madagascar, Mali, Cote d'Ivore, Benin, Mauritania and Senegal, as well as Kebbi state in Nigeria, which is described in this companion paper of sawah technology(4), have now almost realized the GR. Although we have to examine the reliability of their statistics and still the impact to all SSA is not big through these countries or areas, if we examined the *sawah* system quality or stage of sawah system evolution, these countries or areas may have reached to **'standards stage of *sawah* evlolution'** as shown in the next chapter of this paper and in the separate paper of '***Sawah* Technology (2) Background'**, which may have reach to the similar evolutionary stage of Asian rice farming, i.e., standard level of sawah system. This facts support the *Sawah* hypothesis 1, i.e, GR through *sawah* system evolution of farmers' rice fields.

Compared to the biotechnological research and varietal improvement, ecotechnological research and *sawah* improvement/evolution have been largely neglected in SSA during the last 50 years. Although there is a research concept to improve natural resource management (NRM), no clear research concept to improve and to evolve the lowland soil and water management system in Africa. The *sawah* hypotheses 1 and 2 and *sawah* technology described in this paper are such missing concepts and technology to improve natural resources in the majority of African rice farmers' fields. For over 30 years (1986–2016), we have been using various research funds to engage in basic and action research in collaborations with mainly national teams, such as Ghana Soil Research Institute (SRI-CSIR) and Crops Research Institute (CRI-CSIR), the National Center for Agricultural Mechanization (NCAM), the National Cereals Research Institute (NCRI), and the University of Nigeria, Nsukka (UNN) as well as the University of Agriculture, Abeokuta in Nigeria.

Sawah Technology research started in 1983-88 under IITA's Wetland Research Project (Juo and Lowe 1985, Wakatsuki et al 1988). This project has been succeeded by Hirose Project at IITA during 1992-2008 (Hirose and Wakatsuki 2002, IITA 2008) and JICA/CRI-CSIR Ghana *Sawah* project during 1994-2001(Wakatsuki et al 2002). During the JICA/CRI *sawah* project, the collaboration with Africa Rice Center for sawah technology development had started (Wakatsuki et al 2001a and 2001b), then materialized through Center Commissioned External Review (CCER) in 2006 (Khush, Wakatsuki and Adole 2006). Based on these preliminary collaborations, *Sawah* Technology transfer and dissemination through Africa Rice Center's SMART-IV(*Sawah*, market access and rice technology in inland valleys) program started and is on-going successfully during 2009 to 2019, which is supported financially by International Cooperation Division of Ministry of Agriculture, Forestry, and Fisheries (MAFF), Japan (Africa Rice 2013, 2014a, 2014b, 2015, 2016, Mohapatra 2016). The first step was SMART-IV kickoff workshop at AfricaRice headquarters at Benin (Wakatsuki 2010, Buri 2010), then workshop and on-the-job training of SMART-IV staffs of Benin and Togo at Kumasi, Ghana (Buri et al 2011, SMART 2010-2014 and 2016). Working with farmers to improve control in inland valleys using *Sawah* Technology, AfricaRice 2012 Annual Report published in 2013. High Scalability of *Sawah* Technology in Sub Sahara Africa, AfricaRice 2013 Annual Report published in 2014. Scaling up of *Sawah* Technology in Benin and Togo, AfricaRice 2014 Annual Report published in 2015. *Sawah* technology for rehabilitating the rice sector in post-conflict countries of Liberia and Sierra Leone, AfricaRice 2015 and 2016 Annual Reports published in 2016 and 2018. In 2017 AfricaRice published the manual of this technology (Defoer et al. 2017). However, it is not the name of *Sawah* Technology but is changed to the abbreviated Smart-valleys approach and it is described as AfricaRice's proprietary technology

After a long stagnation, in the last forty years finally the appearance of the agricultural revolution of SSA different from Asia (the center is the rice revolution) began to appear now. After continued long-term basic and action research in 1986 through 2016, our *sawah* research team could establish basic technology sets. This is the "site–specific, personal irrigated *sawah* systems development and sawah based rice farming by farmers' self-support efforts (i.e., Sawah Technology)" in diverse inland valley agro-ecologies as primary targeted rice ecology in Ghana and Nigeria. We believe that the core technology to contribute to the GR in Africa is the *sawah* technology. During 2011-2016 our *sawah* team demonstrated and trained *sawah* technology successfully at the huge Niger river's flood plains and inland deltas in collaboration with Kebbi state Fadama III and ADP staff in Nigeria. Two power tillers could develop or make evolve 20 ha of the pump-based irrigated standard *sawah* systems with 5-8 t/ha of paddy yield during April 2011 to May 2014. By the end May 2014, Kebbi farmers bought additional 22 sets of powertillers by their own budget and developed 326 ha of sawah and produced 2100 tons of paddy (Kebbi Rice revolution, Dakingari 2013 and Yeldu 2014, World Bank 2016). Thus 2015-16, Nigerian government, especially Kebbi state government, have started the dissemination and implementation project (Kebbi Rice revolution and ESTRASERIF, Expansion strategy for sustainable sawah eco-technology for rice farming) to scale-up the past successful results in nationwide. Kebbi state government had bought 1000 sets of power tillers and started to distribute farmers for new 10000 ha of *sawah* development and rice cultivation. Our *sawah* technology has just arrived at the stage of conducting large-scale implementation to the nation wide scale up of the past successful results. This Kebbi rice revolution as described in ***Sawah* Technology (4) Practices** will be the first step to implement the *sawah* technology in all over the Nigeria in order to realize rice GR, and this is expected to extend to Ghana, Togo and Benin as well as to the entire West Africa and SSA. Sawah based rice farming in SSA has entered the stage of rapid evolution and development.

What is *Sawah*, Paddy and Irrigation?

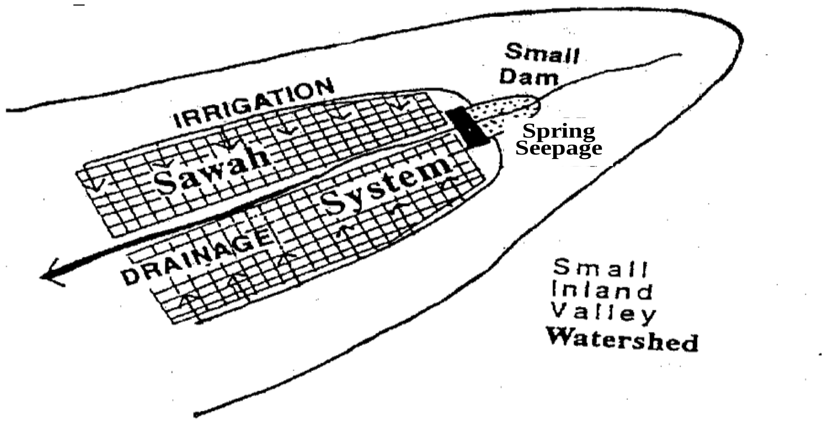


Figure 1. Sawah system with irrigation and drainage facilities for control of water in an inland valley watershed

Quality of Sawah determines the performance of various agronomic practices . The quality of a sawah can be determined mainly by the quality of leveling. If height difference in a plot of Sawah is within 5cm, excellent, within 10cm, good, within 20cm marginal to get the targeted yield 4t/ha, if more than 30cm, paddy yield will be less than 3t/hahe.

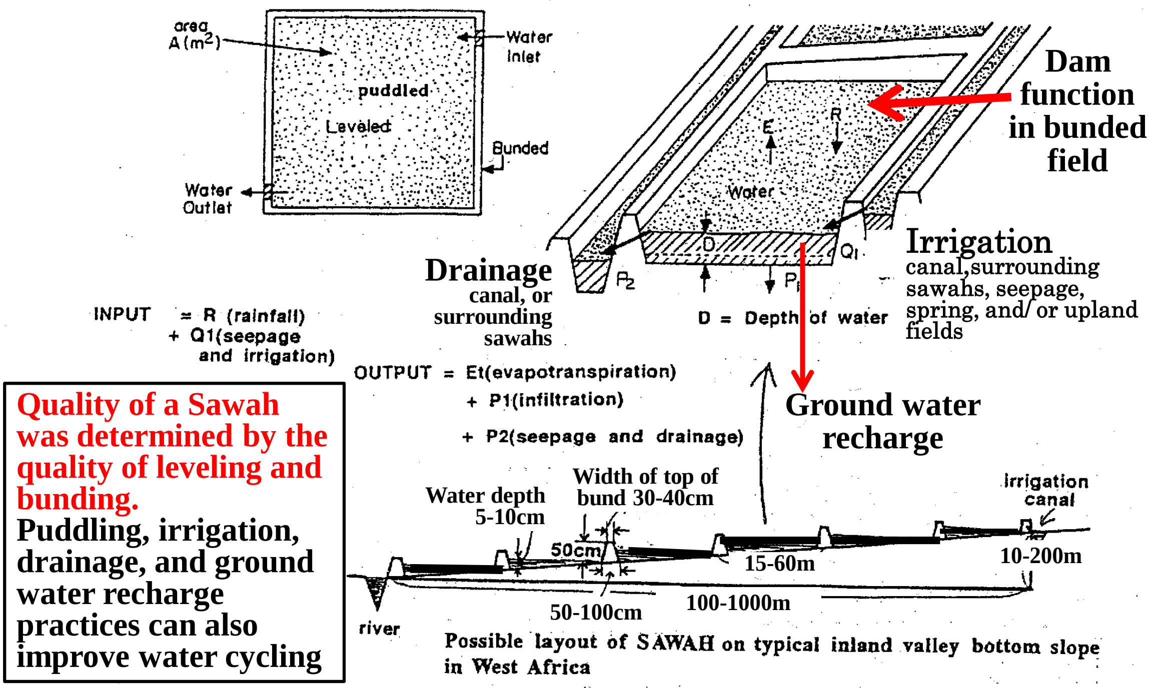


Figure 2. Sawah: A bunded, leveled, and puddled rice field with inlet of irrigation and outlet to drainage, thus control water and weeds as well as manage nutrients

The English term, "paddy," originates from Indonesia, and means rice plant or rice grain with husk, such as paddy yield and paddy production. The term "*sawah*" is also of Indonesian origin, and refers to a bunded, puddled and leveled rice field with water inlet and outlet to improve water control, especially control of water depth and flow in rice fields, and thus soil fertility (Wakatsuki et al. 1998). Historically SSA farmers, except for Madagascar and a part of UR Tanzania, have no sawah based rice cultivation skills, there is no *sawah* concept and word of *sawah*. The English paddy field means all kinds of rice production fields in SSA, it does not distinguish all 6 stages of sawah fields as shown in the Photographs 5. Under this circumstance, in order to promote the development of the sawah system platform, we proposed to use the term of sawah. Since it is the starting point of scientific research to use clearly defined technical term. The *sawah* technology can improve irrigation and fertilizer efficiency, and with the *sawah* technology the improved varieties can perform well to realize a GR in SSA. Suffice it to say that the *sawah* technology is the prerequisite platform condition to apply the three GR technologies successfully (*Sawah* hypothesis 1). As shown in Figure 1 and 2, a *sawah* system is composed of *sawah* fields and irrigation/drainage facilities in a lowland. The lowland *sawah* can also sustain rice yields higher than 4 t/ha through macro-scale natural geological fertilization from upland and micro-scale mechanisms to enhance various nutrients' supplies as described later in Fig 6 (*Sawah* hypothesis 2), if appropriate lowlands are selected, developed to standard *sawah* and the soil and water can be managed properly.

Most of the paddy fields in Asian countries correspond to the definition of the term standard *sawah*. Therefore, the paddy fields are almost equivalent to standard *sawah* for Asian scientists. However in West Africa and SSA, the term paddy refers to just a rice field, including upland, lowland, and irrigated rice fields. In order to avoid confusion and to stress the focal point for realizing the long-awaited rice GR through the improvement of the rice ecological environment using ecotechnology, the term *sawah* is proposed to use as a scientific foundation to describe the improved man-made rice-growing environment and the rice plants growing in it (Wakatsuki et al 1988 and 1998).

Photograph 1. Google Earth image showing micro rudimentary sawah system, evolutionary stage II, in which three green revolution technology can not be applied effectively. As shown of 50m scale marker, each micro sawah plot has an area of 5-30m^2 only. These are large schale Irrigated rice schemes of Kura, Kano State, upper photo and Kadawa, Kano State, lower pohoto, Northern Nigeria,.

Another frequent source of misunderstanding in Africa is the term "irrigated rice." In Asia, the meaning of this term is clear, as the *sawah* was developed by local farmers over the past hundreds or thousands of years as described later in Figures 7 and 8, before the recent advent of irrigation projects (after the 1970s) by Asian governments. However, in West Africa and SSA, since both irrigation and *sawah* are new and the concept of *sawah* has been lacking, there have been many irrigation systems without standard *sawah* system as shown below of the Google earth image (Photograph 1, which is the biggest rice irrigation project of northern Nigeria) or one of the oldest rice irrigated project site of Edozhigi, Kaduna river flood plain, Niger state. These are also described in **Sawah Technology (2) Background and Sawah Syestm Evolution.** The poor performance of past irrigation projects in SSA (Fujiie et al 2011) can be explained by lacking the *sawah* concept and *sawah* system management skills in rice scientists, engineers, extension officers and farmers. Standards *Sawah* systems are few in majority of African rice farmers including huge rice irrigation schemes, especially in Nigeria as shown in the Photograph 1 above.

In a standard *sawah* plot, the water inlet and outlet should be installed at the bunds with gates that connect with the irrigation and drainage (Fig. 2, upper part). Proper knowledge and practical skills — especially of sloping pattern and hydrology in a watershed — of the field is needed to do this. In an extensive watershed, the interval of bunding is guided by the slope (lower part of Fig. 2). The aim should be to maintain an interval that will permit standard leveling (within 10cm height difference in a sawah plot) of the puddled soil for optimum water control. The quality of a sawah can be determined by the quality of leveling. If height difference in a plot of Sawah is within 5cm, excellent, within 10cm, standards, 10-20cm marginal to get the targeted yield 4t/ha, if more than 30cm, paddy yield will be less than 3t/ha (Fig. 2, Matsushita 2013).

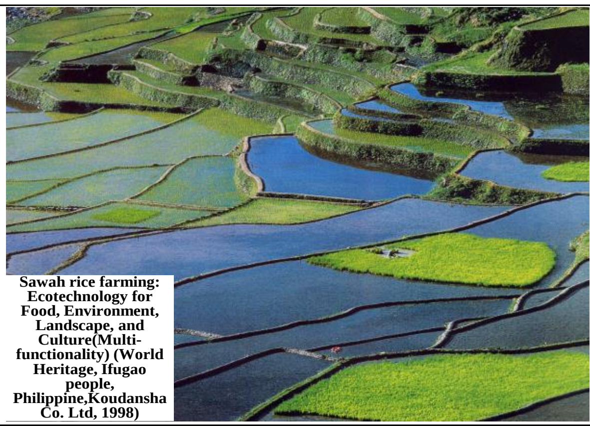
Six stages of Sawah system evolution in Asia and Africa

Basic infrastructures and skills necessary for *Sawah* based rice farming are common in the world, nothing special in Asia. Although all standard sawah plots have common structures to control water of rice fields (i.e, bunded to control sideway water flow, leveled topsoil with irrigation inlet and drainage outlet of water, and normally topsoil was puddled to control weed and excessive percolation water loss), there are diverse evolutionary stages of *sawah* systems in the world depending on the diversity of topography, soils, hydrology, climate, socio-

Forest Destruction by Shifting Upland Paddy Cultivation in Guinea Highland: Upland rice can not be sustainable without sawah or soil conservation measures (Guinea highland, 2002)

Sawahs of Madagascar may have thousand years of history with the migration of "old" Maly-Indonesian. Sawah systems are the base of "System Rice Intensification (SRI)" (from 2009 JICA trainee of Mr. Lantonirina Gilles)

Sawah was developed using hundreds years by Chinese Farmers (Otsuka 2004)



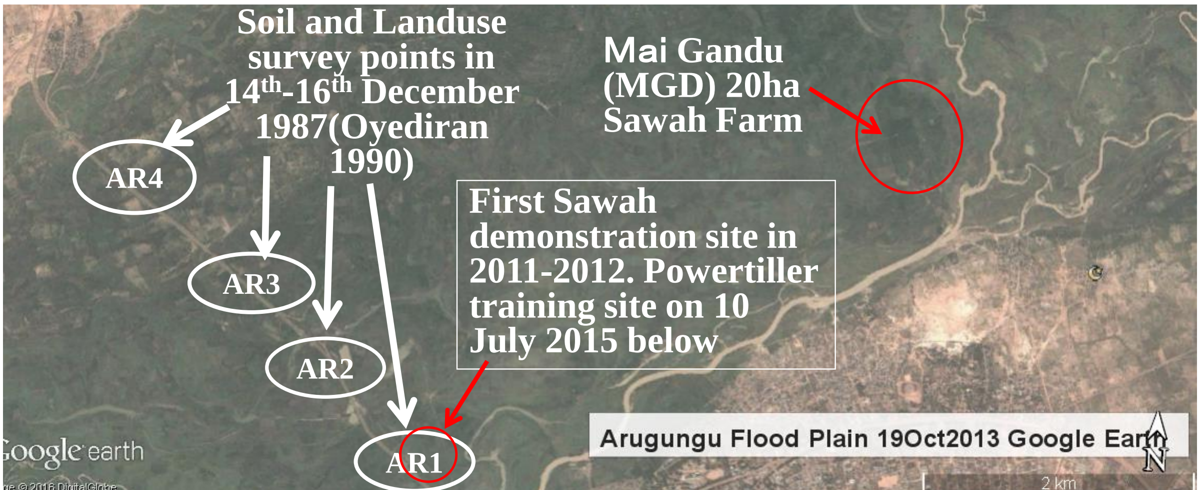
Sawah rice farming: Ecotechnology for Food, Environment, Landscape, and Culture(Multi-functionality) (World Heritage, Ifugao people, Philippine,Koudansha Co. Ltd, 1998)

Photograph 2. Standard quality Sawah systems in China, Philippines, and Madagascar and non-sawah system in Guinea highland, West Africa

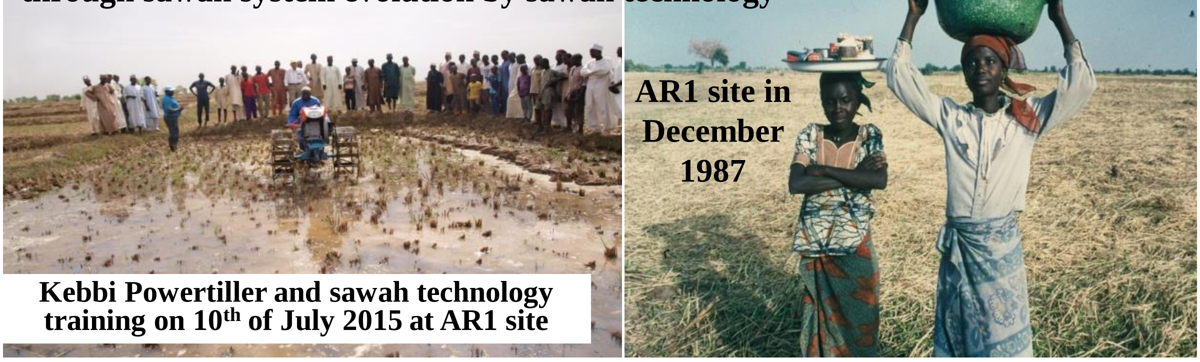
Figure 1 a. Lowland paddy field at Sokawe, Kumasi, Ghana Three Green Revolution technologies can't apply

Figure 1b. 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)

Photograph 3. Traditional rice cultivation on non-sawah open bush lowland and sawah system developed by farmers using sawah technology, Ashanti, Ghana



Photograph 4. Arugung in 1987 and 2015. Starting site of Kebbi rice revolution through sawah system evolution by sawah technology



6 Stages of Sawah System Evolution (I)

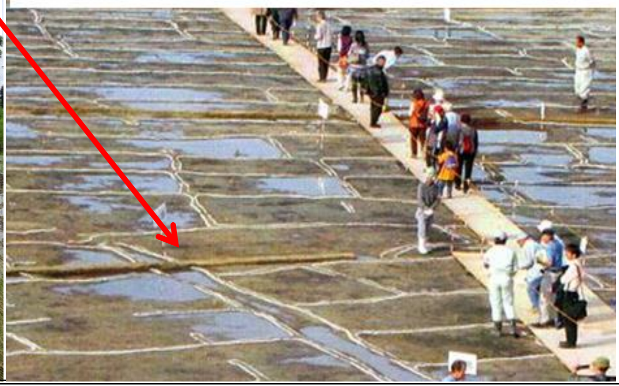
Green Revolution is possible only after the 4th Evolutional Stage

1st (L) stage : Lowland non sawah rice cultivation, Inland Valley, Sierra Leone, 1987

Evolutionary Satge 1 or 0 (Upland rice and Fonio cultivation at Guinea)

3rd stage: Irrigated micro rudimentary sawah. 2nd stage: ridge planted rice in Inland valley, Nupe, Nigeria

Irrigated Rudimentary Micro Sawah plots at Nakanishi, archaeological site, Nara, Japan at 2400-2500 years ago
http://www.bell.jp/pancho/k_diary-6/images/image-3/1112-202.jpg



6 Stages of Sawah System Evolution (II)

4th Stage: Standard sawah plots with leveling quality of ±5cm using animal plowing, Indonesia. This has the longest history in Asia

6th Stage: Advanced and large sawah plot of >1ha with leveling quality of ±2.5cm using laser leveler tractor (Kubota Co)

5th stage : Standard sawah plots with leveling quality of ±5cm. Bush inland valley was developed by farmer using powertiller

Transplanting on the 6th stage sawah. Direct sawing is possible with high performance

Photograph 5. Six Stages of Sawah System Evolution. Three green revolution technologies will be only effective in the 4th to 6th Stages of Sawah Systems

economy and history in each region of the world. *Sawah* system's evolutional stages will co-evolve with the evolution of agricultural tools, machinery and methods. Photograph 4 shows *sawah* system evolution on the flood plain at Arugungu, Kebbi state between 1986 (Oyediran 1990) and 2015.

In order to realize GR in Africa, it may be enough to distinguish six evolutionary stages of sawah systems as seen in the following photographs 2 to 5. **The 1st stage is non-sawah system in either upland (U) or lowland (L). The 2nd** stage is ridge planted rice with irrigation or non-irrigation typically in flood plain. **The 3rd stage** is micro rudimentary sawah system with the size 5 to 30m^2 with irrigation or non-irrigation. These system are typically observed in inland valleys in Nupe land, Niger state, Nigeria. As shown the right side of the Nupe's micro sawah system, very interestingly, this stage of sawah seems to equivalent to Japanese archaeological sawah stage which appeared 2500 years ago at the time irrigated sawah based rice farming had started through the technology transfer from Chinese and Korean immigrants. However, even major irrigation schemes still have this system in current Nigeria as shown above Google earth images (Photograp 1)**.** The three green revolution technologies can not be used efficiently in these 1st, 2nd and 3rd stages. Mainly because water control is difficult in these three evolutionary stages of Sawah. If available agricultural tools are only hoe and cutlass, sawah systems can not evolve beyond these three stages even under irrigation.

If animal plow is available, the sawah system can evolve to the **4th stage**, which has been typically seen in Asia before starting mechanization in 2010s. This stage has standard sawah plots with leveling quality of ±5cm in a sawah plot through animal assisted plowing, puddling and leveling. **The 5th stage** has also standard sawah plots with leveling quality of ±5cm using powertiller or bulldozer. **The 6th stage** is advanced and large sawah plot of >1ha with leveling quality of ±2.5cm using laser leveler tractor. Only the rice fields higher than **4th stage**, the three green revolution technologies and more advanced agronomy technology can be used efficiently

Possible similarity of *Sawah* system development, British Enclosure for Agricultural Revolution and the Characteristics of Modern Sciences

As shown in Figure 3 (Salgado 2012), medieval manors were characterized with a set of open fields and rural community. The period of the modernization progresses were also the ages of enclosure, that is, the arable

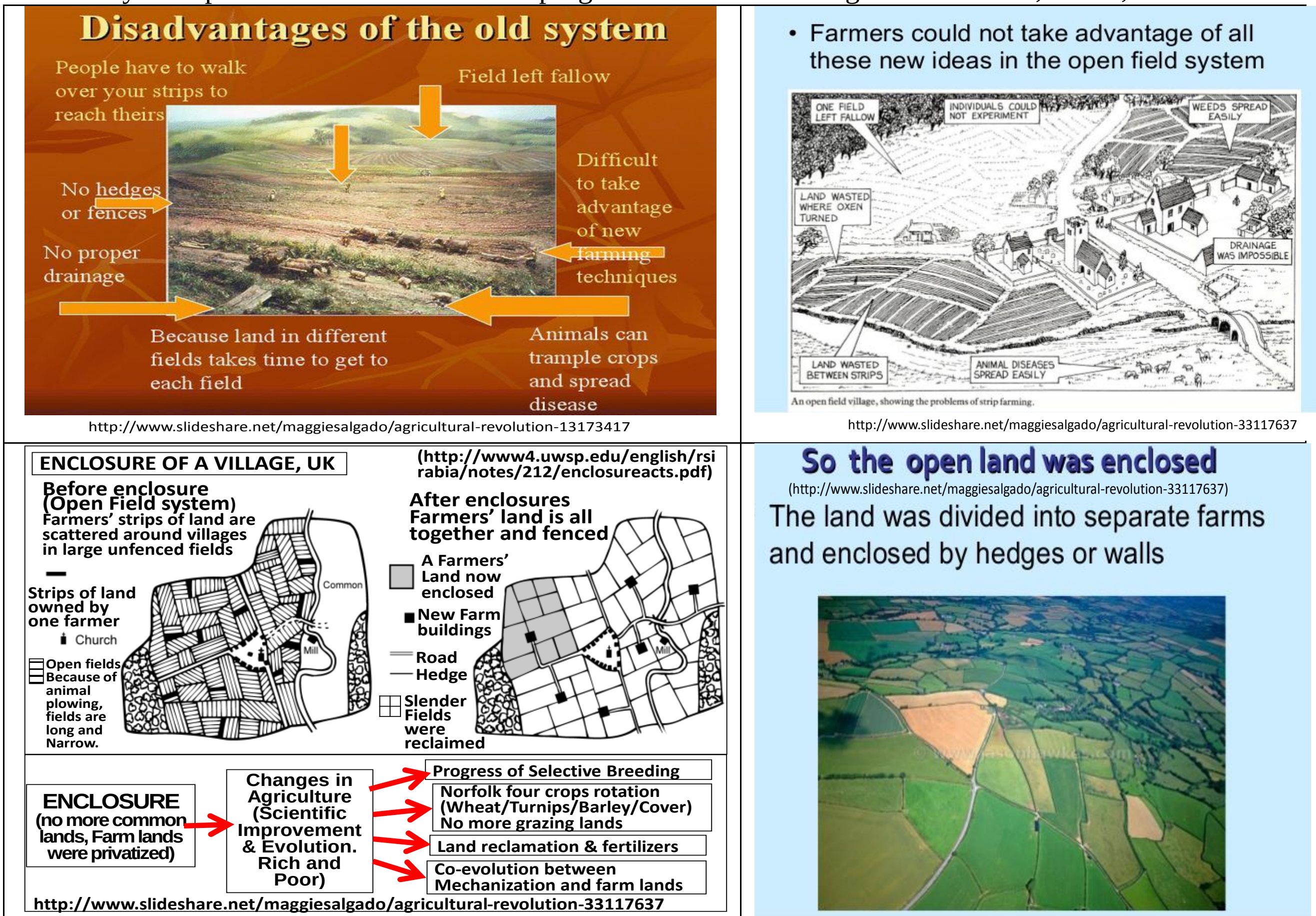
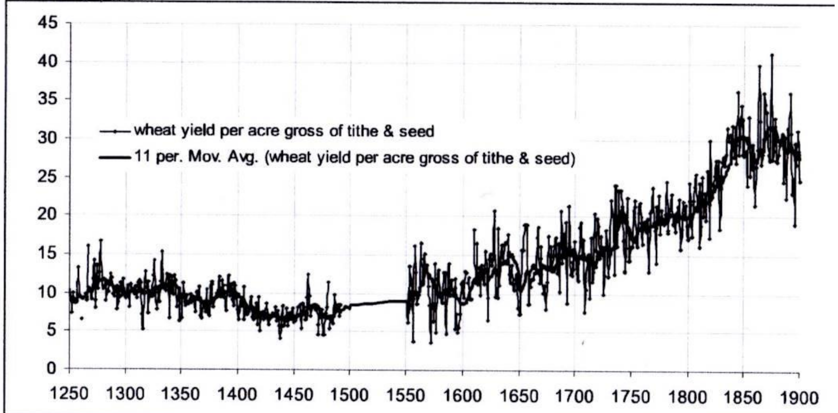


Figure 3. British Enclosure and Agricultural Revolution, Possible relation to Sawah System Platform

English Agricultural output and labour productivity, 1250-1850: Some preliminary estimate by A. Apostolider, S. Broadberry, B. Campbell, M. Overton, B. van Leeuwen, 26 Nov 2008 (http://www.basvanleeuwen.net/bestanden/agriclongrun1250to1850.pdf)

FIGURE 4: Weighted national average wheat yields per acre, gross of tithe and seed (bushels)



Enclosure in UK during 15-18th centuries Created Basic platform for scientific technology, Agricultural Revolution, then Industrial revolution

Table 1. Wheat, Rye, Barly, Oats

	A. Yield per acre gross of seed (bushels)					B. Seed sown per acre (bushels)				
	Wheat	Rye	Barley	Oats	Pulses	Wheat	Rye	Barley	Oats	Pulses
1250-1299	11.27	13.73	14.41	10.91	8.93	2.56	3.02	4.16	3.67	2.90
1300-1349	10.77	13.31	13.36	10.21	8.77	2.53	2.95	3.90	3.61	2.63
1350-1399	9.96	12.00	13.67	11.12	8.43	2.49	2.79	3.92	3.63	2.57
1400-1449	8.28	13.01	12.20	9.52	7.71	2.39	2.55	3.75	2.97	2.30
1450-1499	8.94	16.75	12.74	8.42	6.57	2.45	2.79	4.18	2.48	2.08
1550-1599	10.38	11.71	12.40	11.87	10.62	2.50	2.50	4.00	4.00	3.00
1600-1649	12.95	18.78	15.16	14.97	11.62	2.50	2.50	4.00	4.00	3.00
1650-1699	13.86	16.69	16.48	14.82	11.39	2.50	2.50	4.00	4.00	3.00
1700-1749	16.36	17.32	19.38	16.27	13.23	2.57	2.50	4.30	4.00	3.00
1750-1799	19.54	20.37	25.38	24.90	17.19	2.27	2.50	3.50	4.00	3.00
1800-1849	25.56	22.02	29.70	32.37	20.35	2.41	2.50	3.80	4.00	2.50
1850-1899	29.19	28.68	27.08	35.36	18.80	2.50	2.50	3.27	4.00	2.50

lands were enclosed with stone walls, bunds, or hedges, then reclaimed the enclosed lands. The first enclosure mainly on the 16th century was called that "Sheep eat men (Thomas More's Utopia)", because the landowner evicted the tenant farmers to expand pastureland for sheep rising. Whereas the second enclosure around 1700-1850 dramatically increased agricultural production as seen in Figure 4. As shown in the enclosed farmlands enabled reasonable land use plan and infrastructure development such as drainage improvement, the reduction of the waste land, conservation of land degradations originated from cultivation, pests and weed management, promotion of selective breeding, new farming techniques and the mechanization. Furthermore, various scientific farming techniques were innovated (evolved) through field experiments which were only became possible in enclosed lands. However, since the enclosures and infrastructure development needed investments, the rich capitalists who were able to carry out enclosure became increasingly rich and the tenant and the small farmers that were not able to enclose decreased agriculture income, lost their land and became wage labors at urban areas. Consequently, the gap between rich and poor was increased. The wage labors were important for the **Industrial Revolution** and the development of the **Capitalistic society**.

Scientific technology is defined as the whole of knowledges, experiences, skills and practices which can be systematically and reasonably classified and categorized, thus which can be transferred between human beings through learning, education and training. Enclosure was land demarcation, classification and rezoning practices. Modern Western world has only been materialized through the establishment of modern sciences (S. Nakayama, H. Butterfield). It may not be a rare coincidence that active period of contributors to establish modern science, such as Nicolaus Copernicus (1472-1543), Johannes Kepler (1571-1630), Galileo Galilei (1564-1642), René Descartes (1596-1650), Robert Boyle (1627-91), Isaac Newton (1642-1727), Antoine-Laurent de Lavoisier (1743-94), James Watt (1736-1819) and Justus Freiherr von Liebig (1803-73) had been overlapped with the period of Enclosure.

Sawah Hypothesis (1) Scientific platform for three Green Revolution Technology

There has been a considerable paddy yield gap between those of the African Research Institute (5–8 t/ha) and those of farmers (1–2 t/ha) for the past 50 years. During this period, three major components of GR technologies, (improved seeds, fertilizers and other agrochemicals, and irrigation) have been researched 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 photograph and Figures 3, 5-6 below explain the reason. All scientific technologies have some limited operational conditions, platform, in the field. A high-skill 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 (*see* the Google photograph, photographs 1- 5, and Figures 3, 4-5) and as described above on leveling quality. A good demarcation and leveling not only helps to control water and conserve soils but also encourages the expression of the beneficial physical and biochemical interactions going on in either upland or lowland soil. As shown in the Google photographs, the necessity for field demarcation and appropriate leveling is not only lowland but upland as well. Thus the Sawah Hypothesis (1) is equivalent to the British Enclosure. Although the quality of demarcation and leveling at upland is not the same at lowland. Lowland demarcation and leveling are more critical than upland because of the difference of the power of water flow. The control of water in farmers' fields, for example, need standard *sawah* systems. The majority of African farmers' fields are not ready to accept most of the scientific technologies developed at research institutes such as the IITA and AfricaRice (Figure 6). The *sawah* system and sawah technology is the prerequisite platform condition for applying the three Green Revolution technologies (*Sawah* hypothesis 1).

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

Figure B. 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)

Sawah System Development by Sawah Technology

Farmers' Paddy Fields: Diverse and mixed up environmental conditions: mixed farming systems, crops, varieties, and weeds. No clear field demarcations.

1. The improvement of field conditions are difficult. Water cannot be controlled, therefore no soil conservation possible.

2. Land right of the field has overlapping with diverse people and communities. Conflicts with nomads and fishermen No incentive to improve land.

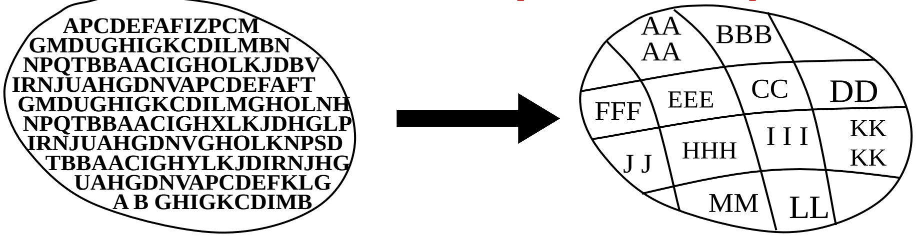
3. Post-harvest technology can not apply.

Sawah Fields: Lands are demarcated by bund based on topography, hydrology and soils, which makes diverse sawahs but homogeneous condition of each sawah.

1. Water can be controlled. Soil is conserved. Therefore field conditions are improve through the accumulation of every year.

2. Land can be surveyed and registration become possible, then private ownership is promoted, which makes incentives to improve land.

3. Market competitive standardized paddy production becomes possible



Green revolution (GR) technologies of fertilizer, irrigation, and high-yielding varieties (HYV) are not effective in the bushy open fields

Sawah is similar to British enclosured land, which realized Agricultural revolution. This is foundation for scientific technologies of GR

Fig 5. Sawah hypothesis (1): Farmers' Sawah should come the first to realize Green Revolution. Farmers fields have to be classified and demarcated ecotechnologically. Then scientific technologies can be applied effectively.

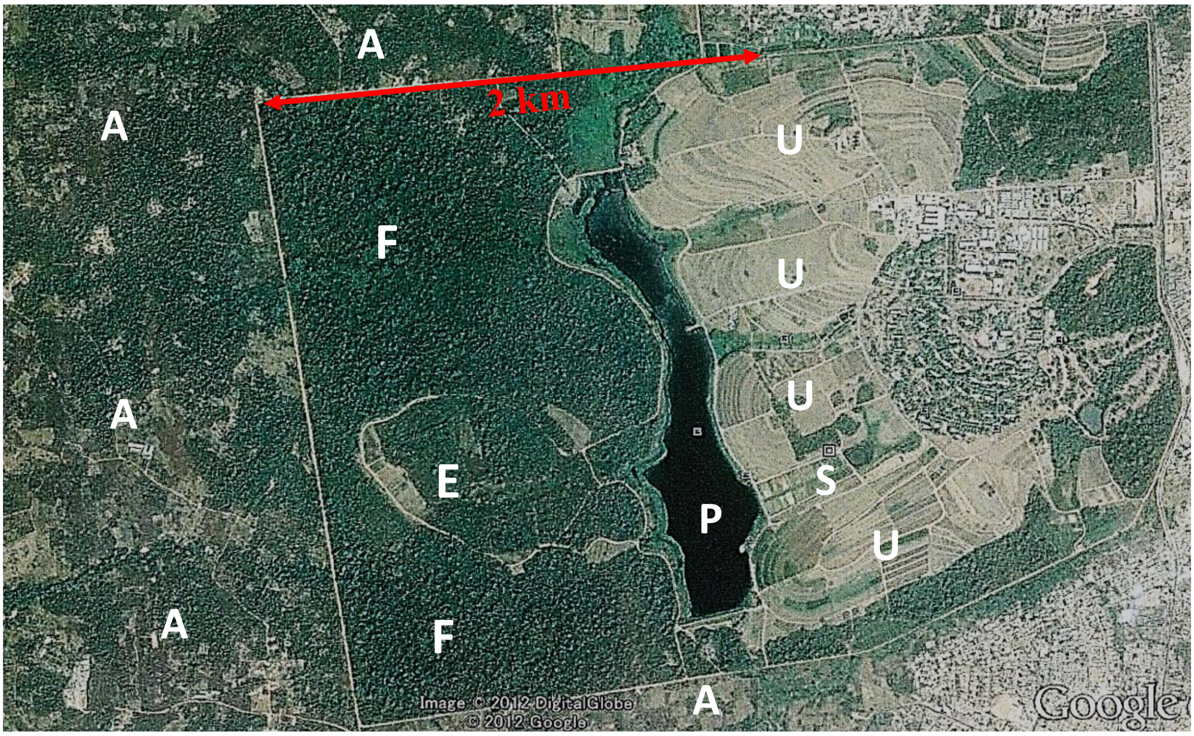


Fig.6. Sawah Hypothesis (1). Prerequisite platform to apply green revolution technologies exist in fenced 1000ha of IITA's research fields, but no such infrastructures farmers' fields. A: Farmers fields with the same soils, topography and hydrology. U: demarcated upland fields along contours. S: Sawah fields at valley bottom. P: Pond for irrigation. F: Regenerated forest, E: Erosion experiment site by Prof. R. Lal and his team in 1970-80s

To increase rice production, "varietal improvement" by breeding studies using biotechnology and "improvement/evolution of ecological environments of farmers' fields" by *sawah* studies using ecotechnologies are equally important. The two technologies are complementary to each other. Biology and ecology (environment) are the two basic components of agriculture. As shown below, we must accelerate standard *sawah* system development in Africa. Our first *sawah* hypothesis for realizing a GR in Africa is that farmers' standard *sawah* development should come first. We explain here that the core technology for a GR in SSA is *sawah* ecotechnology (Fig. 7) (Wakatsuki et al. 1998, 2001, 2005, 2009; Hirose and Wakatsuki 2002, Wakatsuki and Masunaga 2005, Oladele et al. 2010, Abe and Wakatsuki 2011, Igwe and Wakatsuki 2012). This '**Sawah technology (3) Principles**' paper and its companion '**Sawah technology (4) Practices and potential**' paper at the first international sawah workshop (Wakatsuki et al. 2011, Wakatsuki et al 2013) also explain four key skills necessary for the *sawah* ecotechnology to achieve a GR in SSA. These four are (1) site selection and sawah system design, (2) power tiller based efficient and low cost sawah development, (3) sawah based rice farming, and (4) farmers socio- economic empowerment measures, which are described in the separe paper of **sawah technology (4) Practices and potential.**

The rice GR includes three core technologies – (1) irrigation and drainage, (2) fertilizers and agrochemicals, and (3) the use of HYVs. Although these three technologies have been available for the past 40 years, 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)** (Fig. 5, 6 and 7), which is equivalent to the British enclosure (Fig. 3). Essential components with regard to land development are (1) demarcation by bunding based on topography, hydrology, and soils, (2) leveling and puddling to control water and weeds and conserve soil, and (3) water inlets to get water (using various irrigation facilities) and water outlets to drain excess water. These are the characteristics of *sawah* fields.

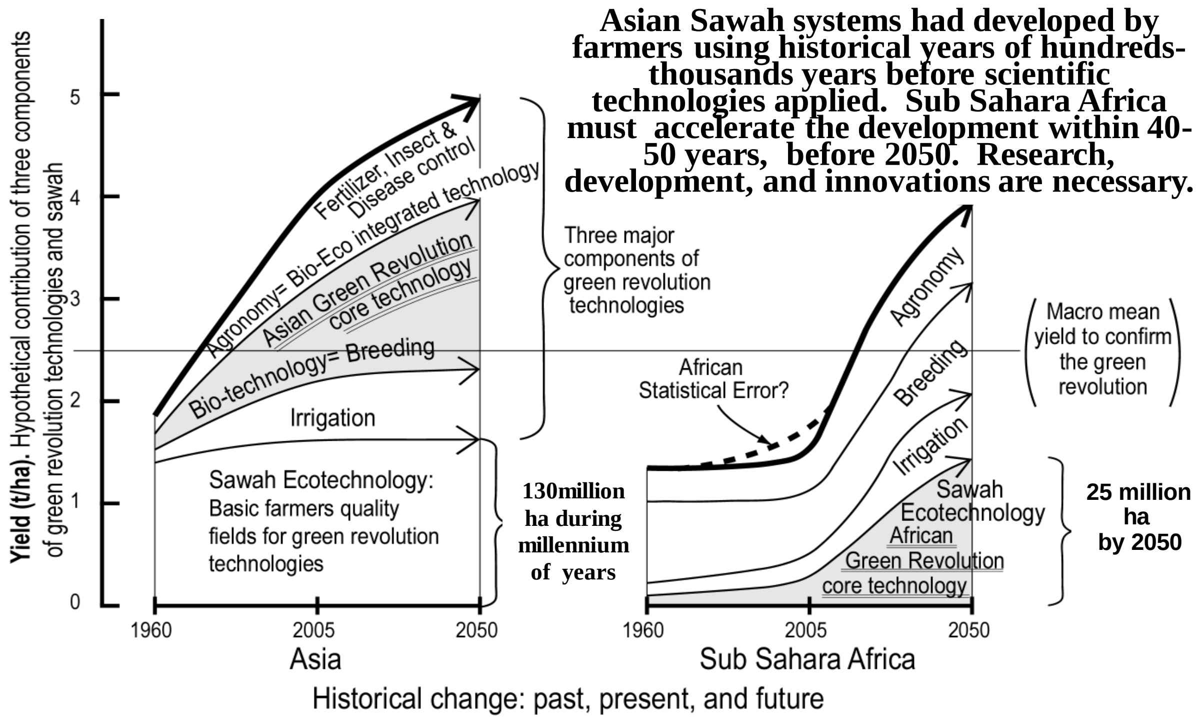


Fig. 7 : Sawah hypothesis (1) for Africa Green Revolution: hypothetical contribution of three green revolution technologies & sawah system development during 1960-2050. Bold lines during 1960-2005 are mean rice yield by FAOSTAT 2006. Bold lines during 2005-2050 are the estimation by the authors.

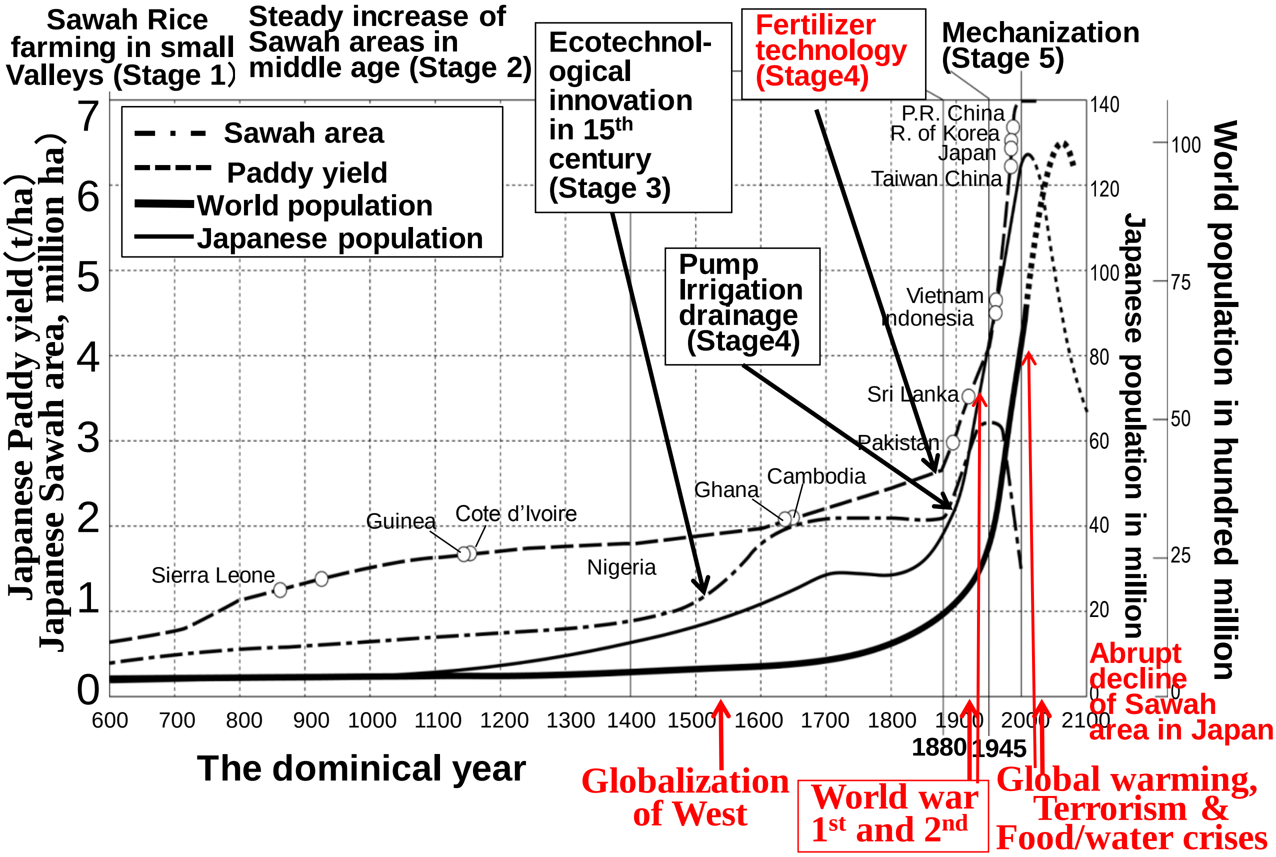


Figure 8. Historical path of Japanese and world population, Sawah area, and paddy yield in comparison with Asia and Africa at 2001/2005 of FAOSTAT data. (Takase & Kawano 1969, Honma 1998, JICA 2003, Kito 2007, Wakatsuki 2013b)

As shown in Figure 7 and 8, Asian *sawah* systems were developed over the past hundreds and thousands of years by farmers' self-support efforts, long before the advent of GR technologies. These are the basic infrastructures needed for the application of HYVs, fertilizer and government-assisted irrigation technologies. However, such infrastructures are very limited in SSA. For various social and historical reasons, the endogenous developments of these basic land and infrastructure have been disturbed in SSA mainly maybe by the globalization of the West, slave trade and colonization which started in 15^{th} centuries (Hirose & Wakatsuki 2002). Because of rapid population increase we must now accelerate the development of standard *sawah* systems to realize a Green Revolution. As shown in Figure 8, before green revolution, there were long continued efforts to expand lowland sawah areas in the history of Japanese rice cultivation during the 6^{th} to 20^{th} centuries**.** The same is true for the other Asian countries although various difference due to the degrees of disturbances by the globalization of the West (Fig 8). The Figure 8 also shows the historical trends of paddy yield, sawah area and population of historical path in Japan in comparison with paddy yields in major Asian and African countries. The historical trends of world population are also shown in Fig.8.

Because of the sawah platform had been developed and sawah based farming been practiced, Japan's green revolution realized immediately after the introduction of fertilizer technology of the West at the end of 19^{th} century. Then the rapid expansion of Sawah area was followed based on pump irrigation and drainage, with the rapid population increase, which was finally unfortunately exploded as the world war the II. Although world war the II was the biggest human disaster in our history, very fortunately colonized major Asian countries could get independence in 1950s and then African countries could follow in 1960s.

As seen in Fig 8 for the trend of Japan, however, only 10-20 years after world war the II, because of the expansion of the economy, through science and technology innovation based industrialization and urbanization, agriculture was declined and thus the sawah area had decreased rapidly. After the Japanese population maximum reached in 2008, decline and aging population is the major problem now. On the other hand, majority of Asian and SSA especially are expecting rapid population explosion and maximum within decades with possible world crises on global warming, terrorism, food and water shortage.

If we make close look at the stages of lowland sawah development in Japan in Fig. 8, we can distinguish five stages, i.e, (Stage 1) : BC10^{th} to 7^{th} century : Sawah development in various lowlands, which have hydrology of easy water control, such as small inland valley streams and springs (Stage 2) : 7^{th} to 15^{th} century: Steady increase of sawah development in bigger lowland and bigger river water sources (Satge 3) : 15^{th} to 19^{th}: Major ecotechnological breakthrough to control major flood plain of major rivers (Stage 4) : 19^{th} to 1960s: Introduction of scientific fertilizer technology of the West. Pump irrigation and drainage made possible to develop big swamps, typically delta, (Stage 5): 1960s to date: Mechanization and major sawah reclamation for efficient mechanized operation.

In Sub Saharan Africa, we can now available all basic technologies used at all the five stages. Only major lacking is farmers' skills on sawah technology and sawah system infrastructure. Therefore if African farmers master the skills of sawah technology, lowland development and irrigation projects will be accelerated to achieve rice green revolution, hopefully by 2025.

Beyond Realizing African Green Revolution: Theoretical Consideration of Sawah Hypothesis (1) and Ultrahigh Sustainable Rice Yields Level Achievable in the Near Future by 2050.

Figure 9 shows the three major factors of productivity growth using production functions by Kalaitzandonakes et al 1994). The total productivity can be arranged into following major three factors, i.e., ①elimination of inefficiency, ②Scale adjustment, i.e., expansion to appropriate scale of farm land and management scale, and ③advancement of technology. Please note, it is an example of an extension by one of the authors (T. Wakatsuki) to add sawah hypothesis 1 as a cause of inefficiency elimination. The progress from A → B, or C → D are agricultural revolution by Paradim /Regime shift, which is the agricultural intensification (Boserup 1965). Even if inputs such as labor, output never increase, Geertz (1963) described shows the period of agricultural involution typically observed on sawah based rice farming in Indonesia during 1900-1960, just before the green revolution. This maybe describe as internal development or sustainable agriculture. If we observe the Fig 10, Japan's sawah based rice farming during 1700-1850 was the similar involution period. The position of Boserup(1965), Geertz(1963) and Marthus(1798) were cited based on the paper by Ellis et al (2013).

These theories, however, did never reflect the rapid increase in productivity by modern science, such as the green revolution of 1960 – 2014.

Among these three factors, with regard to the realization of the green revolution (GR) in Africa, the Asian GR was high yielding varieties (HYV) developed by international agricultural research centers, such as IRRI (International Rice Research Institute) and CYMMET (International Wheat and Maize Research Institute). Due to too dramatic success, it seems that it was too overburdened with the advancement of technology such as variety improvement by biotechnology, which is only one of technologies of the factor ③. The two curves showing by F1 and F2 in the figure are two production functions. The production function is describing general relationship between productivity (P), such as output (Y) or yield (Y), and various inputs when farmers produce rice by inputting labors and materials (L) to a certain farm lands (R). It is generalized that F1 shows what is due to the current farming system and F2 shows when it reaches high level production function due to technological progress (Kalaitzandonakes 1994, Watanabe 2010, Arahata 2014, and Sekine & Umemoto 2015).

The first factor ①elimination of inefficiency is to reach the frontier of the production function F through the elimination of base line causes of inefficiency (Arahata 2014). In British enclosure during 1500-1850 removed such technical inefficiency to reach the level such production function which made the foundation of the Agricultural Revolution (Kerridge 1967, Overton 1996). The enclosure made change the common shared lands through the eliminated the medieval open scattered small strips unfenced (no demarcated) field system to privately owned fenced/hedged straightly grouped larger lands, which formed the platform to change the long continued medieval agriculture and made begin various scientific improvement and innovation. Norfolk four crops rotation, wheat-turnips-barley-clover, has developed and been widely disseminated to improve soil productivity to convert the grazing land into a good crops farm lands, accelerate selective breeding, mechanization and chemical fertilizer application. Looking at the current status of SSA, under the current multilayered shared land right use system, irrigated sawah system development by either government or farmers' self-support efforts has been frequently challenged through the destruction of bunds, canals, dykes, weirs and surface levelling of sawah systems by nomads' cattle in dry season, and fisher men's traps. These are inhibiting the sustainable development and management of irrigated sawah systems.

The sawah hypothesis 1 mentioned in this paper is precisely the ① elimination of these inefficiencies. As shown in Photographs 1-5 as well as Fig 5-7, it is obvious that majority of current rice fields are difficult to control water in SSA even under irrigation. These are also somewhat similar to the British's medieval open

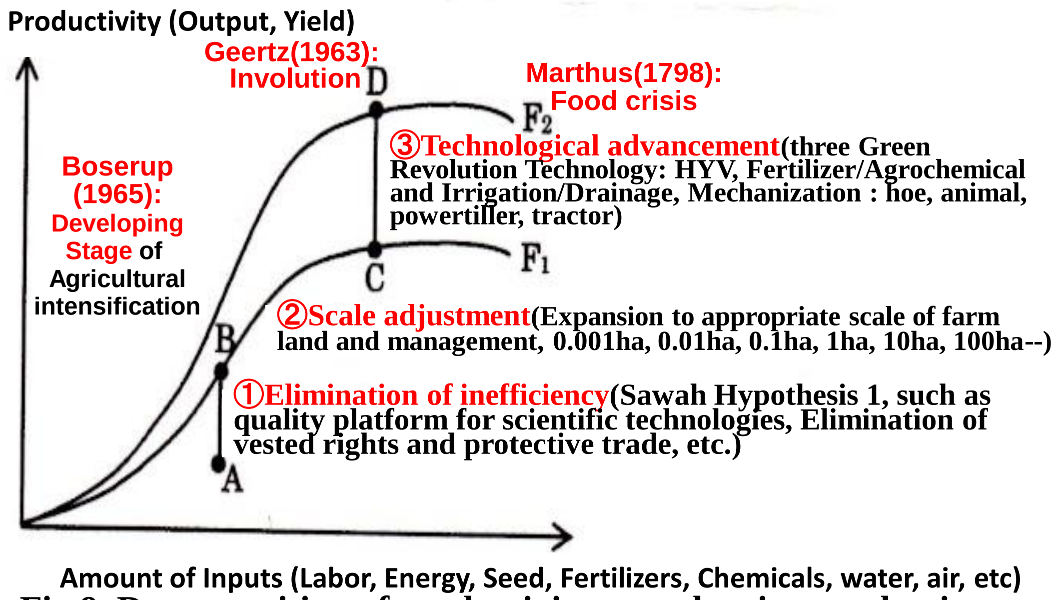


Fig 9. Decomposition of productivity growth using production functions. Total productivity=①Technological advancement +②Scale adjustment+③Elimination of inefficiency

Productivity Growth and Competitiveness, In Maurey E Bredahl、Philip C Abbott、and Michael C Reed、edited "Competitiveness in International Food Markets, p169-187", Westview Press., 1994. Inclusion of Sawah hypothesis 1, Boserup(1965), Geertz(1963) and Marthus(1798) were done by T. Wakatsuki. Cited from 関根久子・梅本雅、2015、小麦収量水準格差の形成要因—日本とドイツの比較分析、中央農研研究報告、24号:31-54、Bull. NARO.Agric.Res.Center、 scattered small strips unfenced (no demarcated) field systems. Majority of rice farmers' lands in SSA have not reach the frontier of the production function F1. Thus three green revolution technologies of high yielding varieties, fertilizer/agrochemicals, and irrigation/drainage are never effective. As the ① elimination of inefficiency, in the case of SSA, measures concerning the quality of agricultural land similar to enclosure and Sawah system, the necessity of infrastructure platform, i.e., quality standard irrigated sawah system, is the main issues. However, in the most other parts of the world where had already experienced the first agricultural revolution such as the green revolution, the main issue may be eliminating institutional inefficiencies such as stopping trade protection and encouraging free trade. In countries where priority have been given to industrial revolution rather than agriculture promotion like Japan in 1971-2016 and the current Asian countries since the period of high growth, aging and lack of personnel, the productivity may not reach to the frontier of the production function (point B of F1 curve).

Looking back on the history after the independence of SSA since 1960, erroneous policies of "let's not have feet on the ground" were taken, which means that the industrial revolution the 1st without considering the agricultural revolution. This adverse effect remains in society as a whole, as a disregard of agriculture seen in young people and society in general.

The second factor is ②Scale adjustment in Figure 9. If it expands to farmland of the proper scale, farm management of the appropriate scale becomes possible and cost reduction becomes possible. When reaching point B on the front line of the production function F1, productivity can be increased from point B to point C by rice cultivation with a farm of an appropriate scale. In the *Yayoi* period of Japan, 2400-2500 years ago and the current SSA (see the Photograph 1 and 5), the number of agricultural lands of 1 ha is divided to 1,000-400 sections of micro rudimentary sawah of 10-25 m^2, and water management and soil management are also impossible. Therefore, it is agriculture in an extremely close position at the origin of the coordinate axes of the production function F1. Therefore yield, remains low. Even if the scale of the sawah plots is increased, the quality of the sawah field is low (topographically irrigation and drainage is not easy, leakage from bunds of sawah plots, insufficient leveling of sawah soil surface, rice planted on ridge, water leakage from sandy sawah soils, etc.), cost reduction will not be realized. Also, if it is too large, it takes time to irrigate and drain, making it difficult to manage water control. In current Japan, after 2013, the scale expansion and the expansion of the area of one sawah field are in progress, but as in the U.S. and European agriculture, one unit of farm land of 10 to several 10 ha and total farm land 100-1000 ha of one farmer's management is not the proper scale, probably appropriate area of one sawah plot is 0.5 - several ha and total farm land of 10 - several 10 ha of one farmer's management scale. It will be clarified in about 10 years. In Japan, maintenance and improvement of farmland of this appropriate scale and management of sawah field farmers, i.e, the ② scale adjustment and expansion has been stagnated for last 50 years due to the controversial policy to discourage rice production, since 1970. As a result, productivity also stagnated, as seen in Figure 10.

The third factor ③Technological advancement is not the major problem in current SSA. If the other two factors can be satisfied similar to the level of Asin farmers' level, it will be no problem to reach national mean yield higher than 4t/ha. Then all over the world including SSA can come to the starting line of international competition for rice value chain market.

Standards quality of sawah system effectively utilizes water, nutrients and fertile topsoil gathered in the lowlands of the watershed area as will be described later as Sawah hypothesis 2. Weeds can be controlled by water management of appropriate flooding and drainage and appropriate puddling. Since geo-topographical and ecological nutrient supply amount to lowland sawah fields is higher than those of upland rice and wheat, the sustainable yield has been higher during 1700-1900 (Figure 10), almost double before 1900, i.e., before the popularization of modern agricultural technology, such as chemical fertilizers became common (Sawah Hypothesis 2, Figure 14 in next paragraph). The supporting data on the superiority of lowland sawah system in comparison with upland rice are also clear in Figure 11. The historical changes in the rice yield in Japan and the historical yield of wheat in the UK were compared and shown between 1700 and 2014 in Figure 10. The yield data in the UK shows 10 years moving mean data in Fig. 4. Figure 10 also shows the changes in the average yields of major rice countries in Asia and SSA during 1961-2014.

As shown in Figure 10, as already mentioned, after Japan, the rice yields of Asian countries, China, Viet Nam, Indonesia, Bangladesh, Philippines, and India, have been increasing rapidly since 1961 by the green revolution technology. After 2000, top group countries have been increasing their national mean paddy yields, such the countries of Madagascar and Mali which have higher ratio of standard irrigated sawah based rice farming than the other countries in SSA. Madagascar and Mali are now in 2014 similar national paddy yields to Thailand. The country's average yield is increasing, such as Ghana, Tanzania, Ivory Coast, etc., coupling with the progress of sawah system development and improvement. On the other hand, the yield increase of Nigeria and Sierra Leone is delayed because of majority of sawah system development in these countries as a whole are behind standard level of sawah system development. This can be understood from the Photographs 1, 2, and 5 as well as Figure 12 for Google earth comparison of UK, Japan and Sierra Leone as well as Fig. 13 and 14 for Google earth on 2009/2016 and old photographs taken in 1987 on our 1st on-farm research sites at Makeni area, Sierra Leone.

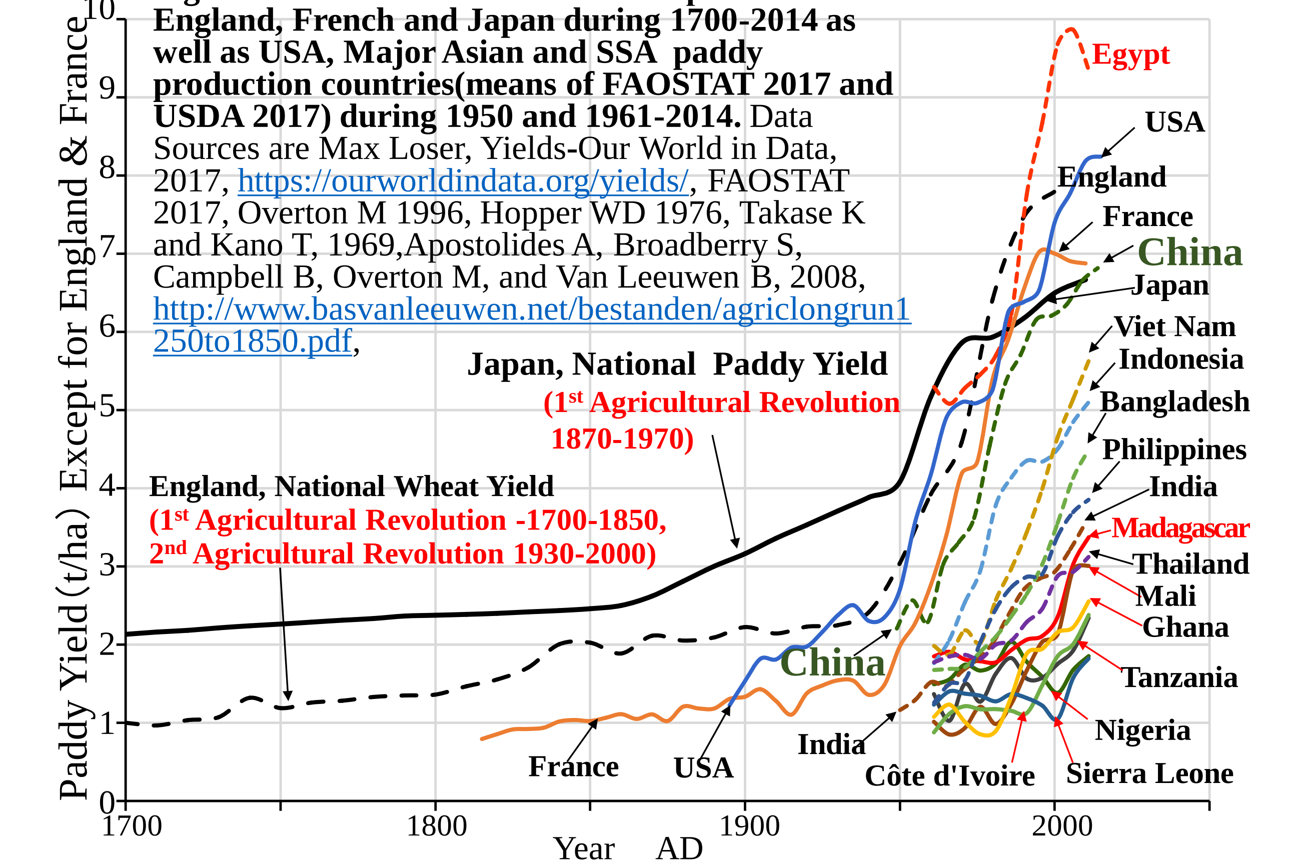


Fig. 10. Historical Trend of Core Crops' Yields of England, French and Japan during 1700-2014 as well as USA, Major Asian and SSA paddy production countries(means of FAOSTAT 2017 and USDA 2017) during 1950 and 1961-2014. Data Sources are Max Loser, Yields-Our World in Data, 2017, https://ourworldindata.org/yields/, FAOSTAT 2017, Overton M 1996, Hopper WD 1976, Takase K and Kano T, 1969,Apostolides A, Broadberry S, Campbell B, Overton M, and Van Leeuwen B, 2008, http://www.basvanleeuwen.net/bestanden/agriclongrun1250to1850.pdf,

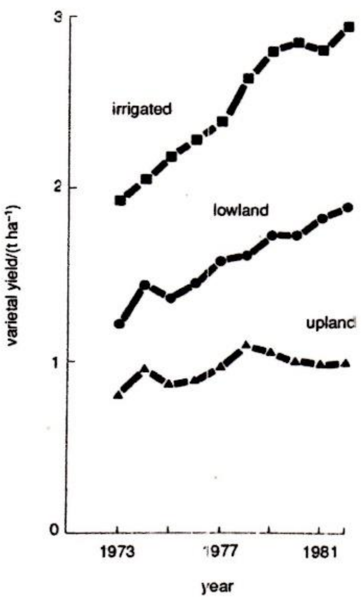


Fig.11 Yield trends for irrigated, lowland and rainfed upland rice crops in the Philippines (L.T. Evans, 1986).

It is very interesting to compare the historical paddy yields of Japan and wheat yields of UK during 1700-2014. Since lowland sawah system has eco-technological advancement, paddy yields had been higher, almost double, during 1700-1960 (Sawah Hypothesis 2). These periods are including the 1st agricultural revolution period of UK during 1700-1850 by enclosure and Norfolk Four Crops rotation. Japan's 1st agricultural revolution period was during 1870-1970 including a drop by World War the 2nd. Since Japan had semi dwarf varieties of both

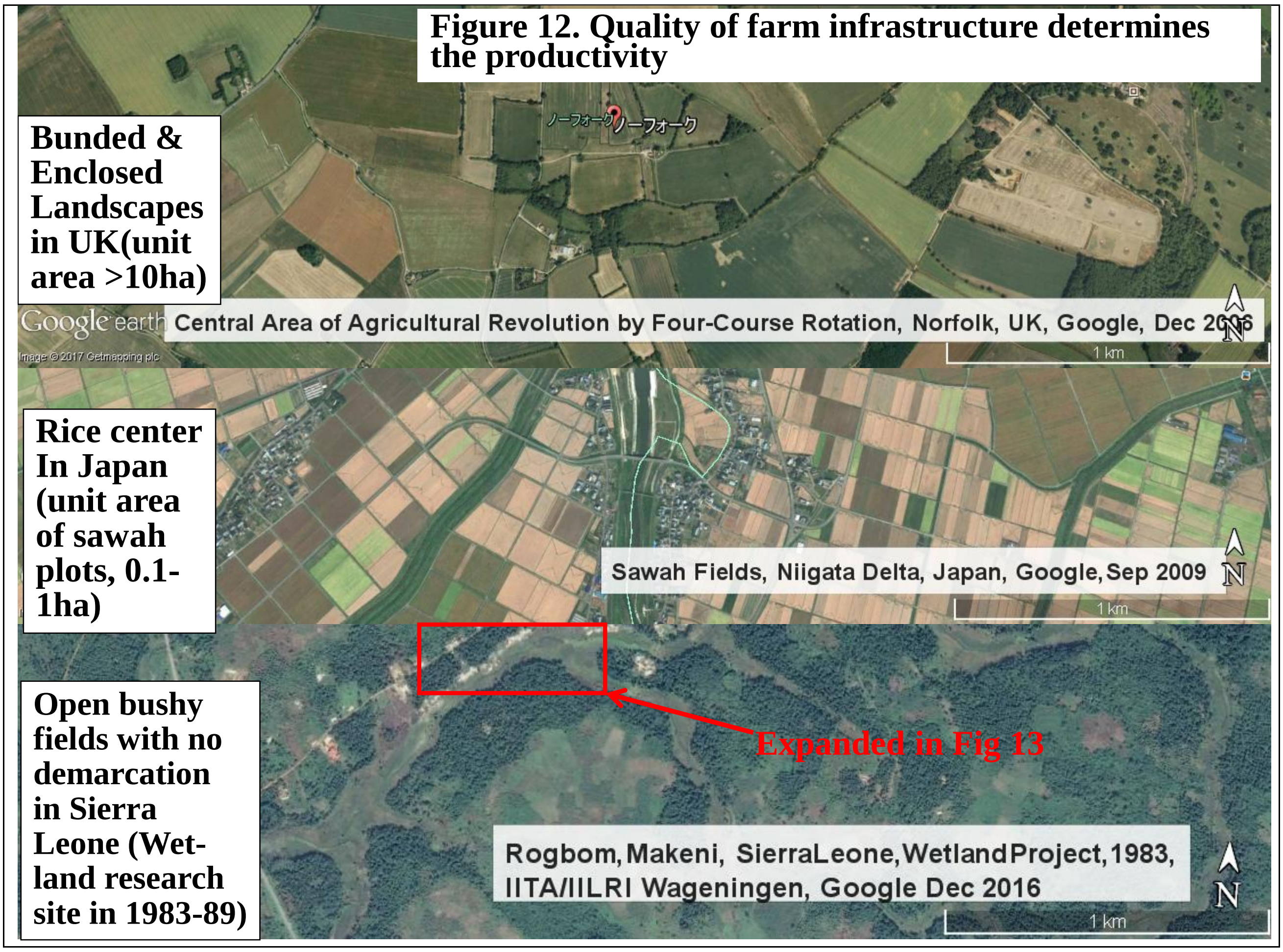


Figure 12. Quality of farm infrastructure determines the productivity

Fig. 13. Upper is Google earth on 2016. This is expanded the area of the red marked area of the Fig.12.Two photographs were taken on 1987, showing ground nuts and cassava cultivation after non-sawah rice cultivation.

Fig.14. Upper is Google earth on 2016 of inland valley of Matam village area, showing sawah system. This village was also under Wetland research of IITA. Lower two photographs were taken on 1987 showing discharge meter of IITA and non-sawah rice.

rice and wheat, chemical fertilizer and sawah system improvement were the major driver of this revolution. Although wheat yields of UK had been stagnated during 1840 to 1940, damatic yield increase has started and been continued during 1940 to the date, 2014. It was almost 4 times, 2t/ha to 8 t/ha. This trend is almost similar to the green revolution of Asia because of the major driver was again semi-dwarf wheat originated from Japan's Norin 10 and Akakomugi (Borojevic 2005). As seen in Figure 10, Lapan's paddy yield became much lower than the yields in Europe and the United States. In contrast to US and European countries, all factors to increase paddy productivities habe been stagnated, especially for scale adjustment and expansion for last 50 years due to the controversial policy to discourage rice production, since 1970. As a result, productivity also stagnated, as seen in Figure 10. This indicates that the advancement (improvement of yield) of agricultural technology can be realized by cooperative work with biotechnology for variety improvement/evolution and improvement of rice growing ecology, i.e., eco-technology for evolution of *sawah* fields (Figure 9). As a matter of course, the essence of agricultural technology is an integrated use technology of variety and growing ecology.

If we make comprehensive assessment of the above and following data, figures and photographs, ie., ① stagnation of the grain yield in Japan after 1975, ②the increase in the wheat yield in the UK, and ③the high degree of intensive sustainability of the sawah system (Sawah Hypothesis 2) described in the next paragraph, it will be possible to have the yield level of Japanese No.1 farmer, 12-13t/ha, and No.1 prefecture, 11-12 t/ha during 1951-1968(paddy yeild base, Monya 1989), if we will continue relevant scienctifc improvement of both bio-technology and eco-technology. Asian countries will be able to achieve the similar results as well. To this end, it is necessary to normalize current agricultural research which is prejudiced in breeding research to balanced agricultural research of Bio-tech Eco-tech, including more balanced sawah system research, for example, FOEAS (Fujimori 2012). In addition, all the national best farmers during the national rice competitive years, 1951-1968, had been improved their *sawah* system infrastructure on its own efforts. They tried to improve and devise their *sawah* system and *sawah* based rice farming suitable for their local environment and keep improving. Our *sawah* technology also places great emphasis on farmers' self-help efforts and ingenuity. Agricultural research that makes use of farmers' ingenuity is important.

If this yield level can be realized, no food crisis will occur even with 10 billion people on Earth. As can be seen from the fact that in Africa, even the present Egypt also achieves a paddy yield of 9 t / ha, if the irrigated sawah system suitable for Africa can be developed, since the sunshine in Africa is blessed more than Asia, somewhat lower soil fertility can be covered enough.

Sawah **Hypothesis 2 for Intensive Sustainability and to Combat Global Warming**

The sustainable yield in upland rice and non-sawah fields in Africa is 1 ton per hectare (2 tons even if fertilized), but if standard sawah fields are developed in lowlands, As shown in Fig 8 and 11, there is about twice as much difference as 2 tons without fertilization (4 tons if fertilized). The yield difference between UK wheat and Japanese paddy rice shown in Fig. 10 before the establishment of modern agriculture until about 1700-1900 is also about twice as large. It is necessary to restore the soil fertility by fallow in upload rice, and it is necessary to secure extra 5 ha of farm land usually to sustain 1 ha upland rice cultivation as shown in Table 2. However, due to the use of macroscale mechanisms in watershed level and micro-scale ecotechnological mechanisms described in Figure 15, fallow is unnecessary and it is possible to cultivate continuously in units of 1000 years. Therefore, sawah system have sustainable productivity more than 10 times that of upland fields. 1ha sawah field allows more than 10 ha of upland fields and forest conservation (Table 2). The functions of sawah fields in the global environment and biodiversity conservation should be emphasized more and more in the future. From a global perspective, sustainable sawah system development in Africa could save the earth society around the year 2050. It could be one of the strategies to realize the "2030 Agenda for Sustainable Development" recently adopted by the United Nations.

The upper part of Figure 15 illustrates the concept of watershed ecotechnology, or "Watershed Agroforestry"

(Wakatsuki and Masunaga 2005). This system is equivalent to Japanese term of SATOYAMA system. The soils formed and the nutrients released during rock weathering and soil formation processes in upland areas gravitate to and accumulate in lowland areas through geological fertilization processes. These processes include soil erosion and sedimentation, surface and ground water movement, and the 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 waters also contribute to an increase in the supply of such nutrients as Si, Ca, Mg, K, and sulfate. This contribution provides an ecological engineering basis for the 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).

Sawah hypothesis 2: The sustainable productivity of 1 ha of lowland Sawahs are over 10 ha of upland fields, i.e., yield difference(>2) x Soil fertility recovery(>5)

Reason (1) Watereshed geological fertilization to lowland sawah: fertile topsoil production in forests, sedimentation in lowlands and accumulation of nutrient rich water, which are promoted by lowland sawah systems. It is also important to control appropriate soil erosion and formation of mountain topsoil.

Reason (2) Sawah system is an ecological factory, it can artificially strengthen and control nutrients such as N, P, K, Si, etc. It is also the platform to control various redox microorganisms to develop carbon sequestration.

Reason (3) Sawah system has dam and groundwater recharge function to improve water cycling. Thus promote intensive sustainability through forest and biodiversity conservation

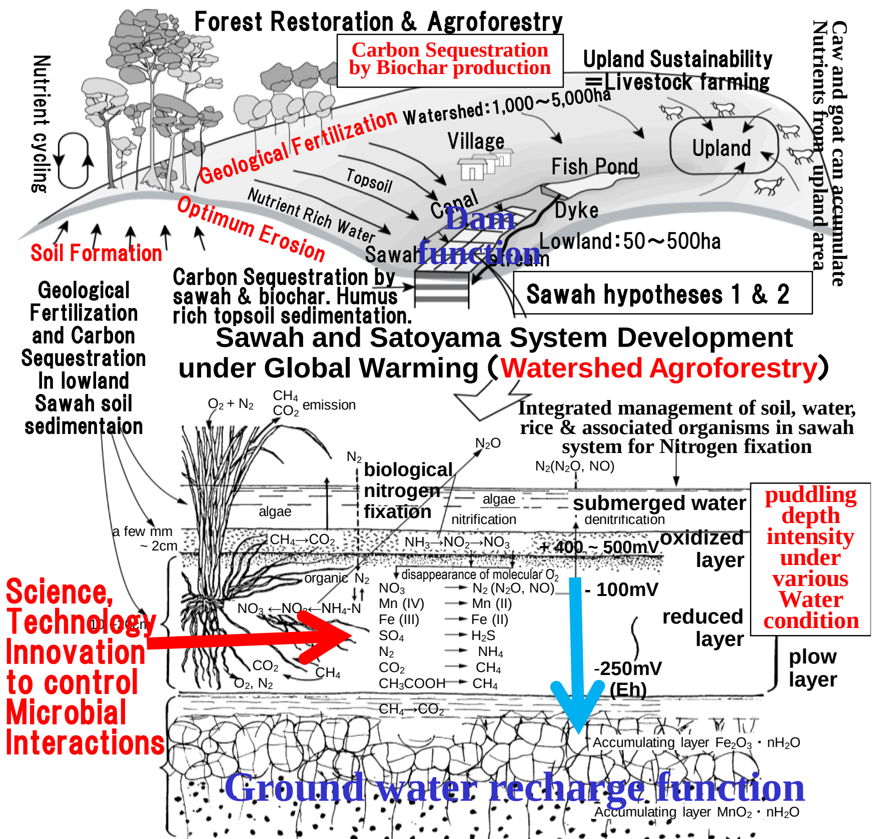


Fig 15. Sawah hypothesis (2): The platform for Sustainable Intensification through Watershed Eco-Technology for Watershed Agroforestry and African SATOYAMA

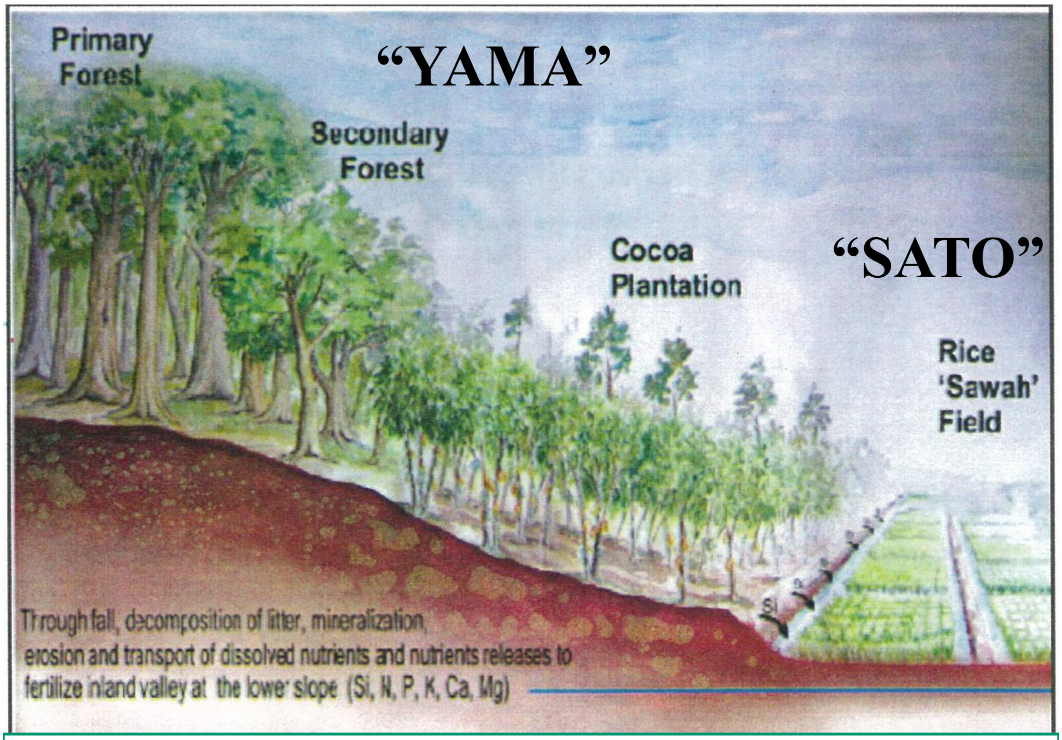


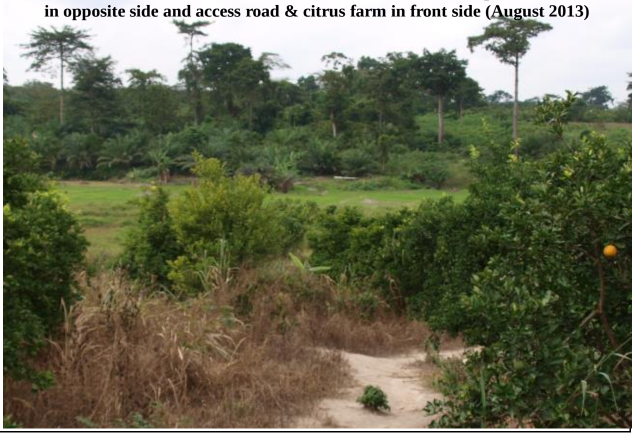
Figure 16. One Example of Africa SATO-YAMA Concept Map by Dr. Owusu, FoRIG, Ghana which is a watershed agro-forestry applicable to Cocoa belt region in West Africa.

Kumasi, Gold valley Site, Non Sawah and Cacao farm

Mt, Oscar's Sawah rice and Cacao farm, at Afari, Kumasi, Ghana

Kumasi, Tawiah Site, Terraced sawah and Cacao and citrus farm

Kumasi, SRI assisted Baniekrom Site, lowland sawah, oilpalm, Cacao in opposite side and access road & citrus farm in front side (August 2013)



Photograph 6 : Examples of Africa Watershed Agroforestry. Lowland sawah with upland Cacao farm, and Citrus farm.Mankranso area, Kumasi, Ghana

Table 2. Sawah hypothesis (2) : Sustainable Productivity of high quality lowland Sawah is more than 10 times than Upland Field

1ha sawah is equivalent to 10-15ha of upland

	Upland		Lowland(Sawah)
Area (%)	95 %		5 %
Productivity (t/ha)	1-3 (1 ≦ **)		3-6 (2**)
Required area for sustainable1 ha cropping*	5 ha	:	1 ha

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

**In Case of No fertilization

The lower half of Figure 15 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 (Kyuma 2004, Nielsen et al 2010). Recently other direct microbe interaction on anaearobic oxidation in the consortia of methane-oxidizing archaea and sulpahe-reducing bacteria common environment in Sawah soil (McGlynn eta al 2015). Science and technology on puddling/non-puddling and microbe interaction is yet researched in Sawah soils. Some leading organic sawah farmers innovated new technology of special shallow (about 5cm) and intensive puddling of well levelled sawah soils under optimum flooding depth of water to control of weeds without herbicides (Matsushita 2013). This innovative technology has to be research scientifically and improve.

As shown in Fig. 15 and 16 as well as photographs 6 above, lowland sawah systems can integrate with various upland tree based systems. As shown in four photographsabove, cocoa plantation in lower slope of watershed is particularly promising in a watershed of forest transitional zone in Ghana. Citrus plantation is also good combination of land use.

Table 3 compare the conceptual target, operational platform and science between eco-technology and biotechnology. Figure 17 as well as 3 -7 shows without scientific platform like Sawah, integrated soil and water management science and technology never work. Figure 18 shows that the use of biotechnologically improved rice varieties alone cannot bring about the expected results in SSA. There is a need for a *sawah*-based ecotechnology to complement biotechnology in the region. Some of the different approaches of biotechnology and ecotechnology to solving agronomic problems are itemized in Table 4.

Table 3. Comparison of target and operational platform of biotechnology and ecotechnology

Bio-technology/Science/Innovation:

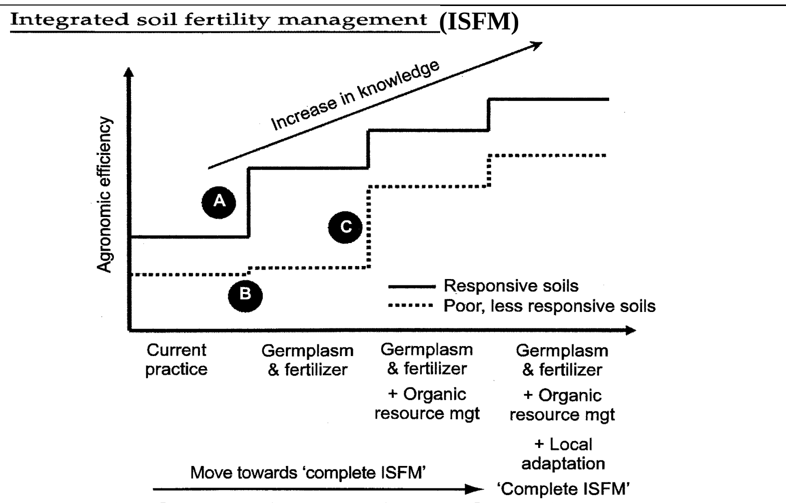
To improve varieties through breeding, i.e., Genetic improvement. Target is DNA improvement.

Operational platform is Cell of organisms

Eco-technology/Science/Innovation:

To improve growing ecology through sawah research, i.e., Improvement of water cycling and soil condition.

Target is soil and water. Operational platform is sawah in watersheds.



(Vanlguwe,Bationo, Sanginga et al., 2010)

Figure 17. Concept of Integrated Soil Fertility Management can not work without proper platform like sawah

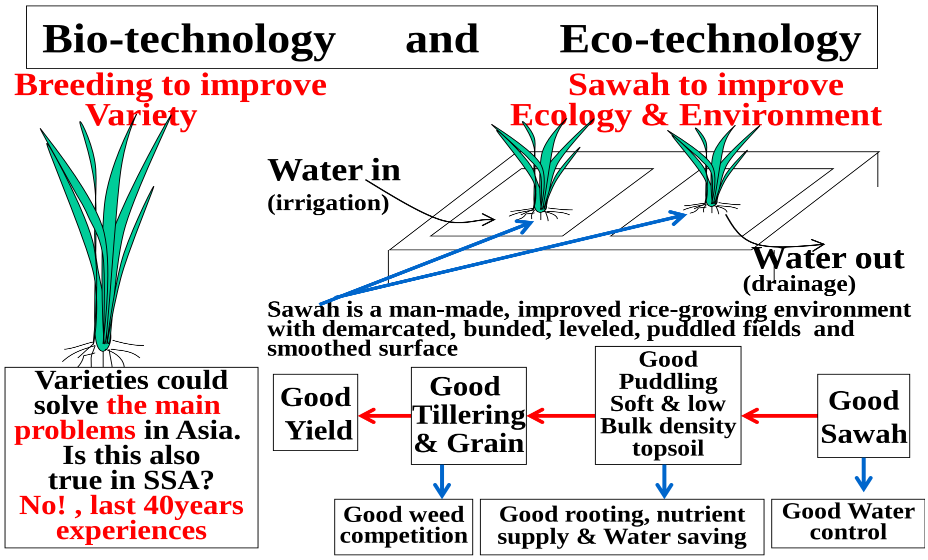


Fig 18. Rice (variety) and environment (Sawah) improvement. Both Bio & Eco-technologies must be developed in appropriate balance

Table 4. Biotechnology and Sawah Eco-technology Options and Complementation for Rice Production

(1) Water shortage and Flood damage

Bitoech: Genes of deep rooting, C4-nature, Osmotic and flood tolerance

Ecotech: Sawah based water harvest in watersheds. Bunding, leveling, puddling, with various irrigation and drainage. Flood control systems, aerobic rice.

(2) Poor nutrition, acidity and alkalinity

Biotech: Gene of N fixation, P and various micronutrient transporters.

Ecotech: Sawah based method to increase N fixation and P, Si, K, and Zn etc. availabilities. Geological fertilization and watershed agroforestry (Satoyama systems). Mixed, organic and natural farmings

(3) Weed, Pest and disease control

Biotech: Genes of various resistance, rapid growth, C4 nature

Ecotech: Sawah based weed management through water control and line transplanting. Good leveling. Sawah based silica and other nutrients supply to enhance immune mechanisms of rice. Sawah based mixed cropping, Sawah based duck, fish and rice and other rice farming.

(4) Global Warming

Biotech: Ultra high yield varieties

Ecotech: Carbon sequestration by Sawah systems through the control of oxygen supply, use of Biochar, and organic farming. System rice intensification and other ultra high yield agronomic practices

(5) Food quality and Biodiversity

Biotech: Golden rice, other vitamin rice gene

Ecotech: Fish, duck and rice in sawah systems. Satoyama agroforestry systems

Table 5. Multi Functionality of Sawah Systems

I. Intensive, diverse and sustainable nature of productivity

(1) Weed control

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

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

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

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

(6) Various sawah based farming systems.

(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 and to conserve bio-diversity

(3) Sawah systems as to control flooding by enhance dam function through bund management

(4) Sawah system as ground water recharge system and to soil erosion control

(5) Denitrification of nitrate polluted water

III. To create cultural landscape and social collaboration

(1) Terraced sawah as beautiful cultural landscape

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

As shown in Table 5, *sawah* ecotechnology can improve irrigation and fertilizer efficiency. Thus it can improve water shortages and poor nutrition (especially for N and P supply), and neutralize acidity and alkalinity to improve micronutrient supplies. With this, improved varieties can perform well to realize GR. Sawah system can perform multifunctional wetlands.

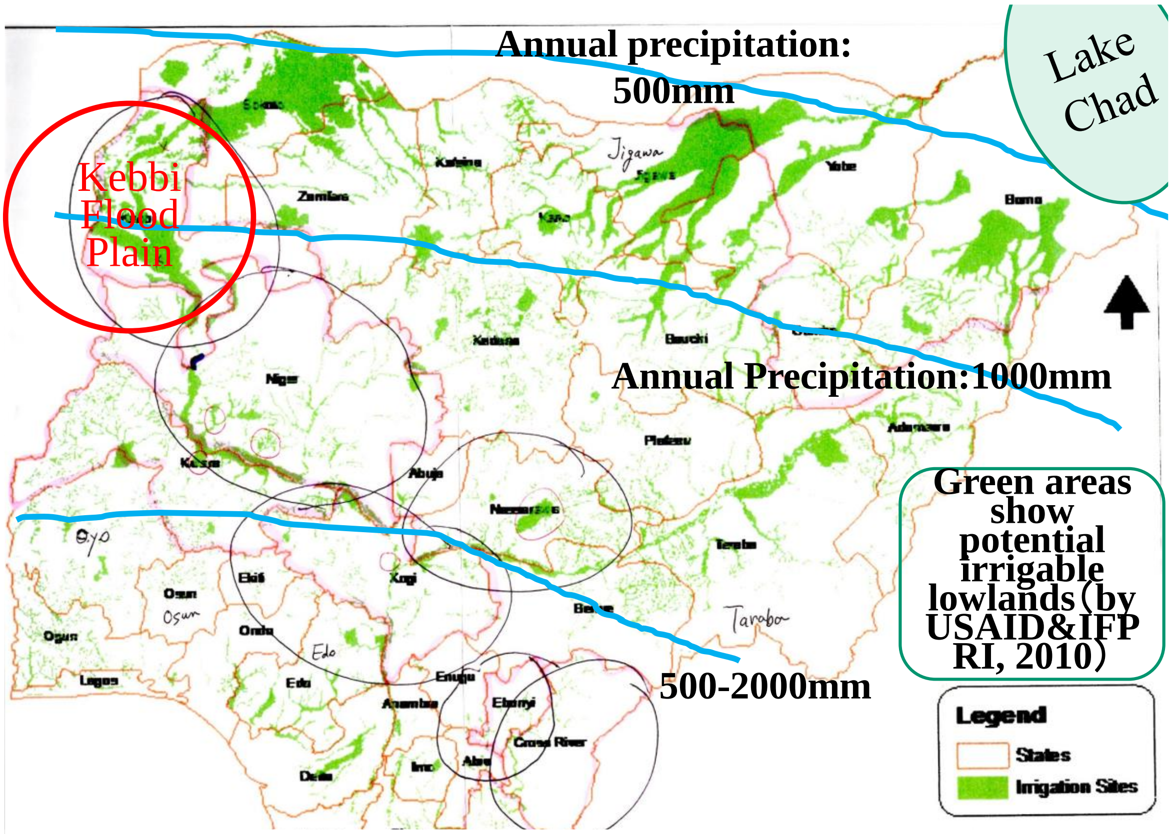


Fig.19. Major lowlands distribution in Nigeria (USAID and IFPRI, 2010)

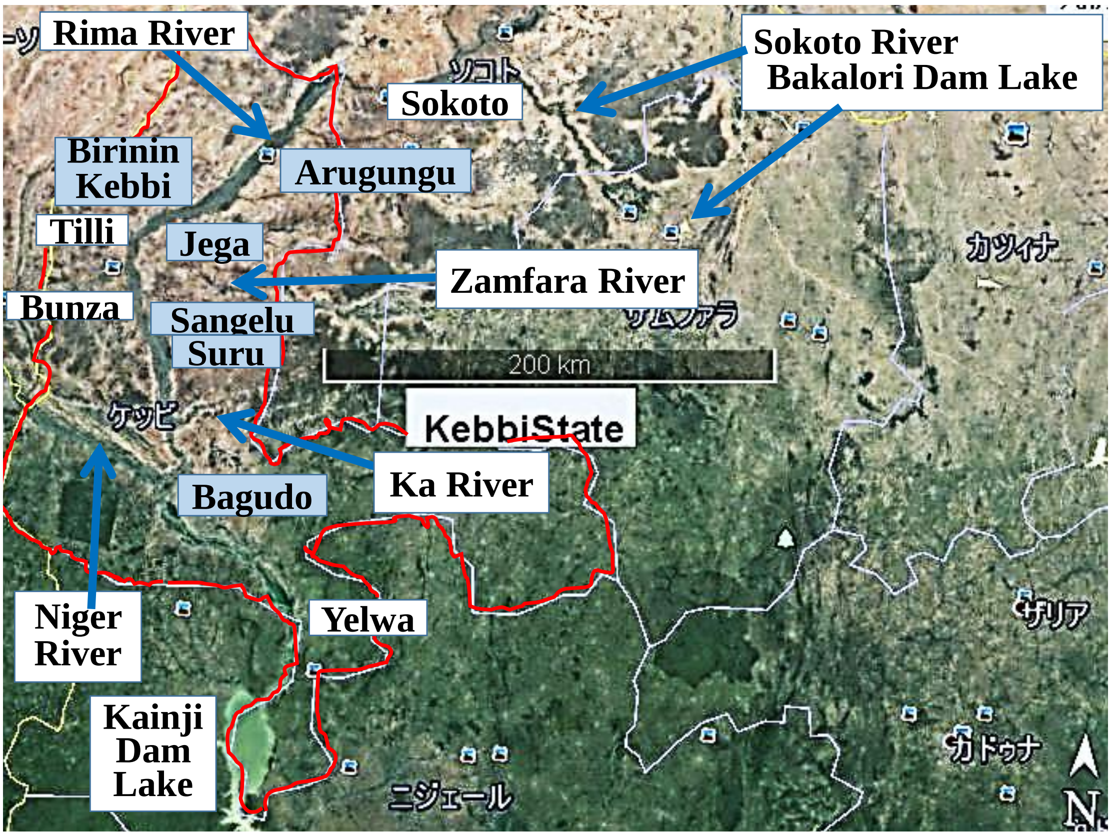


Figure 20. Google Earth of Major Flood plains of Kebbi State, Nigeria. Total Area is estimated 0.4-0.5 million ha. Sawah Technology training and demonstration in collaboration with Fadama III under the World Bank project had done at 6 regions of Argungu, Birinin Kebbi, Jega, Sangelu and Bagudo during 2010-2016.

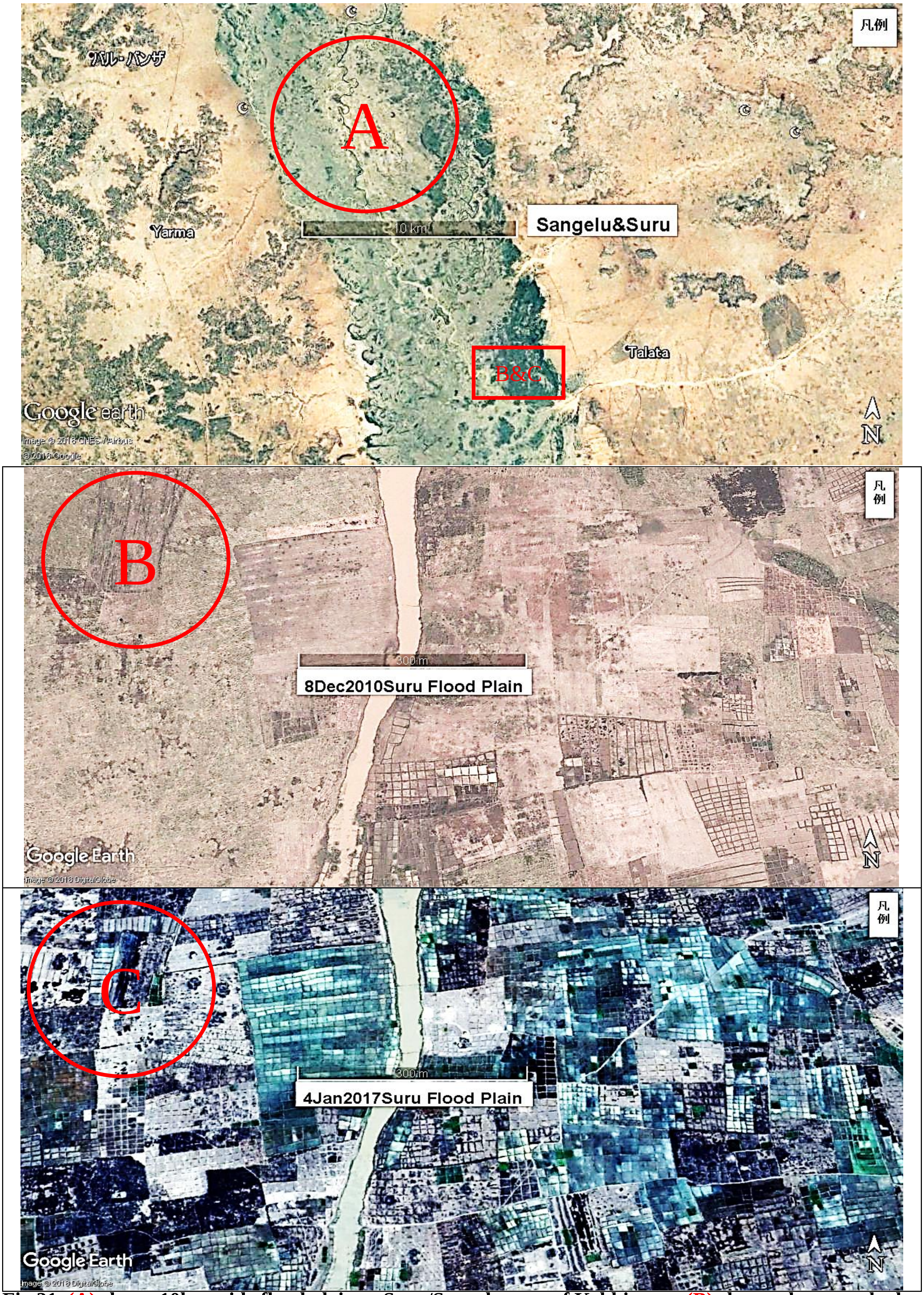


Fig.21. (A) shows 10km wide flood plain at Suru/Sangelu area of Kebbi state. (B) shows photographed in December 2010, before training and (C) shows in January 2017, after sawah technology training. Location of (B) and (C) are the same. Numerous sawah plots were developed by farmers during 2011-2017. Photographed area is about 65ha.

New frontier of Sawah Technology :From Inalnd Valley Ecology to Flood plain and Inland Delats

Sustainable development solutions network of a global initiative for the United Nations published technical report for the post-2015 development agenda as ‘Solutions for Sustainable Agriculture and Food Systems in 2013’. The report described the key paradigm is how to realize ‘Sustainable Agricultural Intensification for African smallholder agriculture’ using better agronomy technologies including (1) water control through irrigation, (2) nutrients management, (3) quality seeds, and (4) mechanization. Sawah eco-technology is a typical such technology as described in separate paper, **‘Practices of Sawah technology (4paper, 4PPt)’**.

Figure 19 shows major irrigation potential area of Nigeria. Very interestingly major flood plains and delta, Inland Delats are distributed in Sudan, Guinea and partly Sahel savannah zones. As described earlier in this paper, Kebbi rice revolution was started at the flood plain in the Sudan savannah zones. Figure 20. Google Earth of Major Flood plains of Kebbi State, Nigeria. Total Area is estimated 0.4-0.5 million ha. Sawah Technology training and demonstration in collaboration with Fadama III under the World Bank project had done at 6 regions of Argungu, Birinin Kebbi, Jega, Sangelu and Bagudo during 2010-2016. Fig.21. (A) shows 10km wide flood plain at Suru/Sangelu area of Kebbi state. (B) shows photographed in December 2010, before training and (C) shows in January 2017, after sawah technology training. Location of (B) and (C) are the same. Numerous sawah plots were developed by farmers during 2011-2017. Photographed area is about 65ha. Small pump irrigated sawah system development by farmers’ self-help efforts has expanded to more than 2000ha in the Suru/Sangelu area in the Figure 20. Similar development has been expanded to all over the Kebbi state. Thus total area of irrigated sawah system developed by farmers will be more than 10 thousand ha during 2011-2017. Estimated cost of this development is about $20million for several thousand tillers (2,000-3,000dollars per set) and tens of thousands of small pumps (200-500 dollars per set), and it was realized in a short time, within 5 years.

Figure 22 shows African characteristic hydrology, i.e, evaporation and ground water contribution are higher than other regions of the earth, such as Asia. To enhance sustainable water use in African agriculture it is necessary to do the research on wide range of use and enhance the multi-functionality of sawah system to fit African specific hydrology. As shown in the Table 5, dam function and ground water recharge function of sawah system need special attention for the sustainable development of the flood plains and inland deltas in Sudan savannah zone.

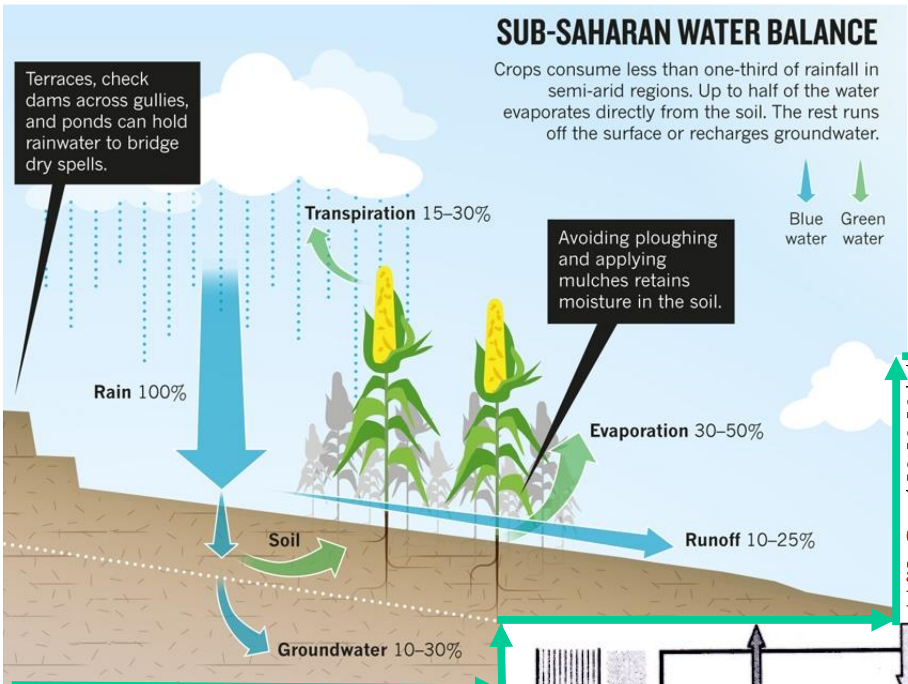
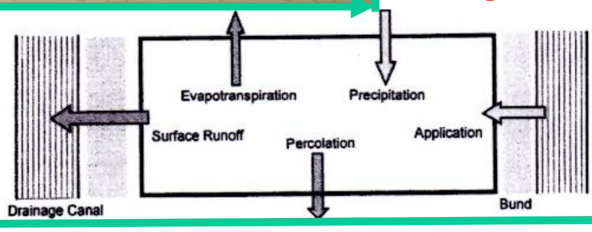


Fig. 22 Upland Strategy for Improve water Cycling by

Rockström & Falkenmark (Nature 2015), which was cited from Molden (ed.) Water for Food, Water for Life (IWMI, 2007)

Lowland Sawah System Strategy for Sustainable Water Cycling enhance ground water recharge



Numerous Sawah plots developed and managed by farmers can enhance water dam function(Figure cited from Advance paddy field engineering, JSIDRE, 1999)

Comparative Evaluation of Six on-going Major Strategies for Rice Revolution in SSA

What is the core strategy to realize the rice green revolution in SSA? Figure 23 shows 6 on-going strategies to realize rice revolution in Sub Saharan Africa (SSA). The figure is indicating yield performances of various improved and traditional rice varieties under both low input and high input as well as both poor water control of bushy open farmlands and good water control of improved farmland infrastructure. The figure is also indicating various advantages, such as higher yield, good water control, and improvement of farmland infrastructure as well as disadvantages, such as lower yield, poor water control, bushy open farmland, various costs of investment, development, maintenance, rehabilitation, training, and labor as well as both environmental and social degradation such as land grab, land conflict and widen the gap between rich and poor, dam damage, forest destruction and topsoil erosion.

A Strategy: Biotechnology priority, such as upland NERICA targeting current bushy open non-consolidated farmlands. As see the line A in the figure, even good high yielding or short season varieties sustainable paddy yield cannot reach >3t/ha even under high input agronomy. So this strategy cannot be core strategy to realize rice revolution. This strategy is assuming the core technology is biotechnology. This is the mistaken strategy that good variety can solve major low productivity problems in SSA. The upland rice priority strategy of AfricaRice might come from the misunderstanding that non-sawah wetland rice cultivations common in West Africa as upland rice cultivations. Following the 3rd Tokyo International Conference on African Development (TICAD III) in 2003, the Japanese government intensified its efforts to support the spread of NERICA rice. However, the strategy for upland NERICA rice dissemination is now at a standstill. If this upland NERICA strategy has been pushed strongly to disseminate using ODA budget like in Uganda and Guinea without proper soil and water conservation measures, such sawah system, soil degradation will be seriously widespread.

Agriculture needs good environments and good varieties. So we have to improve both farmlands by eco-technology and seeds by biotechnology. Both technologies have to be researched, developed and innovated in good balance. The target of biotechnology is to improve varieties through breeding, i.e., genetic improvement, i.e., DNA improvement. Its operational platform is cell of organisms. While the target of eco-technology is to improve growing ecological environment through sawah technology research and farmland infrastructure consolidation, i.e., improvement of water cycling and soil condition. Target is soil and water. The operational platform is lowland sawah, upland farms and forests in watersheds.

B Strategy: Introduction of Asian Green Revolution Technology. As see the line B in the figure, this strategy is only effective on the irrigated sawah fields of quality infrastructure consolidation. Although this strategy is assuming the three green revolution technologies of Asian green revolution, i.e., high yielding varieties, fertilizer/agrochemicals and irrigation, must be successful too, this is the mistaken strategy. As we explained in the Sawah hypothesis (1) that the success of the Asian green revolution was based on the prehistory that the sawah systems had been developed by farmers before green revolution technologies arrived in 1960s during last hundreds and thousands years. The same thing is true to the British Agricultural revolution in 18th century, which was realized based on the long continued enclosure movement during 15th to 18th centuries. As we discussed in this paper, Sawah hypothesis (1) for lowland rice cultivation and the enclosure for upland cultivation are the same prerequisite infrastructure to apply green revolution technologies and to evolve agricultural sciences and technologies. Unfortunately SSA has no such history, because of the globalization of the Western countries during 15th to the independent year of 1960s. The 500 years of slave trade and colonial rule had been disturbed such nation building ground works. Thus SSA needs the innovative technology for breaking through the two big barriers of both area and time, i.e. 50 million ha of irrigated sawah system development by 2050, several centuries to shorten to several decades, before the explosion of population bomb.

C Strategy: Introduction of Advanced Agronomy and Hybrid Seeds Technologies for Super High Yield. As see the line C in the figure, these strategies have only reasonable cost performance in the fields with advanced sawah of quality infrastructure consolidation in the region and countries no more frontiers space for new sawah development such as System rice intensification technology (SRI) in Madagascar and Asian countries. During 1949-1968, Japanese government had been organized national competition of Japan’s No.1 paddy yield farmer, minimum 1000m^2 area of sawah plot. The data were between 11-14ton of paddy per ha (1100-1400kg per 1000m^2), which farming skills were somewhat similar to the SRI farming technology (Mototani 1989, Horie 2005, Tsujimoto 2015). However among the estimated potential irrigated rice land, sawah, 50 million ha, only

2 million ha, less than 5%, are irrigated including micro sawah plots. Thus the C strategy has no priority and can be very limited impact to increase paddy production currently.

In addition to this, we have to consider the amount of input. At the moment SRI may increase the yield double but labor cost might has to increase triple. Hybrid seeds are expensive. Rice farmers in SSA have limited budget to buy expensive hybrid seeds every year. These will be additional heavy burden on majority of rice farmers in SSA.

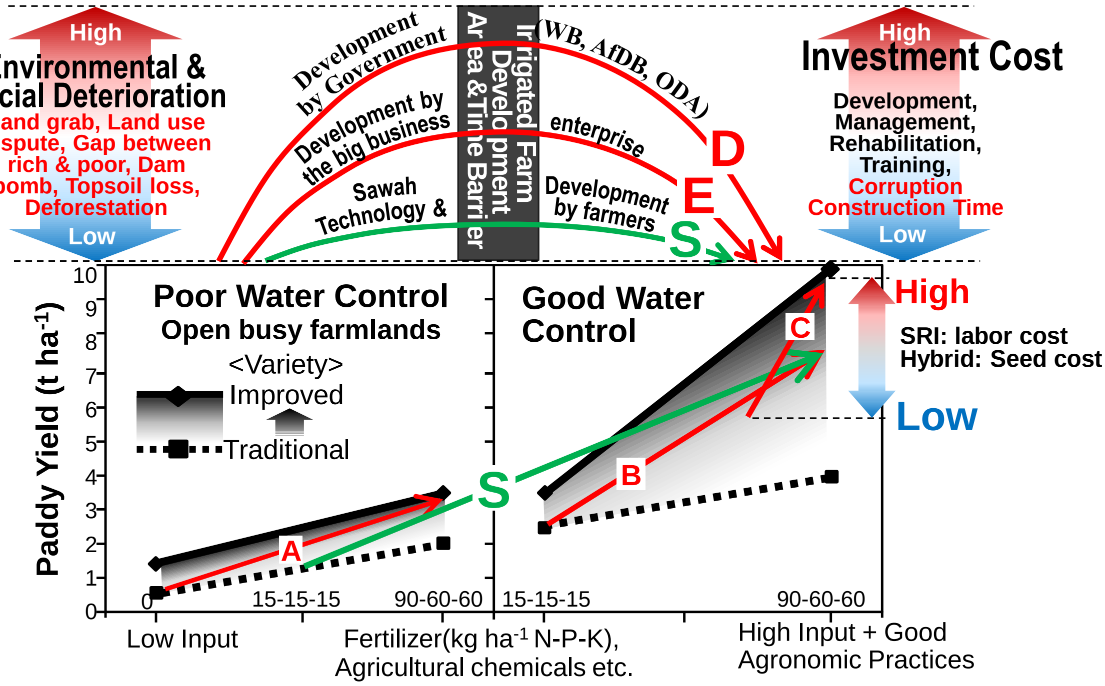


Figure 23. Six Strategies to Increase Paddy Yield and Production in SSA

A type strategy: Upland **NERICA** technology
B type strategy: **Asian Green Revolution technology**
C type strategy: **System Rice Intensification**
D type strategy: **Contractor based ODA** irrigation/drainage development
E type strategy: Irrigation by **private big business enterprises**
S type strategy: Sawah technology with sustainable mechanization

D Strategy: Contractors based Irrigated Sawah System development using ODA funds such as World Bank, African Development Bank and other Donors. As see the curved line D and as shown in Table below, although many rice sector people understanding the importance of irrigation, since farmers, extension officers, engineers, scientists and policy makers in SSA have no or very limited knowledge, experience, and skills on irrigated rice cultivation, both large-scale and small-scale irrigation projects, typically created by contractors under Official Development Assistance (ODA), are very costly because of dependence on heavy engineering works and outside expertise (FAO 1998, Wakatsuki et al. 2001, JICA 2008, MOFA and AfDB 2008, Fujiie 2011). Investment cost for development, management, rehabilitation and training costs are all expensive compare to Asian countries. In addition to the direct investment cost, corruption is widespread. The development operation is used to continue longer than 5 years. During the development period, farmers cannot cultivate rice. Due to the high construction costs, the economic returns remain negative for a long period of time (20–30 years).

Both environmental and social degradation are often serious, such as land grab, land conflict, and expansion income disparities as well as lowland submergence by dam, topsoil erosion, and forest destruction.
ODA projects are likely to destroy autonomy of African government. Project ownership remains with the government (engineers) rather than with the farmers, because farmers cannot develop the systems by themselves. Therefore, neither the development nor the management is sustainable.

E Strategy: Irrigated Sawah System Development by Private Big Business Enterprise. Dr. Adesina (2013), Federal Minister of Agriculture and Rural Development (FMA&RD), Nigeria, declared the new policy that Agriculture should treat as a moneymaking business and not as a charitable development project, which had been often expanded corruption last several decades. The private business based irrigated sawah system developments are more efficient than ODA based project in terms of the investment cost for development, management, rehabilitation and training with the most advanced mechanized farming, like the example of Olam farm at Benue State, Nigeria. Total investment was $110million targeting for 6000ha of irrigated sawah development pumping water from Benue river, which can double cropping, 10,000ha annual cultivation and

Table 6: Comparison of farmers' site-specific personal irrigated sawah system development and sawah based rice farming(Sawah technology) with large- and small-scale contractor (ODA) style developments, and traditional rice cultivation system in various lowlands of Nigeria and Ghana (2014).

	Large-scale development	Small-scale development	Sawah technology	Traditional system
Development cost ($/ha)	**10000–30000**	**10000–30000**	**1000-3000**	**30–60**
Gross revenue ($/ha)†	2000–3000	2000–3000	2000–3000	500–1000
Yield (t/ha)	4–6	4–6	4–6	1–2
Running cost, including machinery ($/ha)	1000–1100	1000–1100	1000–1100	400–500
Farmer participation	Low	Medium–High	High	High
Project ownership	Government	Government	Farmer	Farmer
Adaptation of technology	Long	Medium to short	Medium to short, needs intensive demonstration and on-the-job training (OJT) program	Short
Technology transfer	Difficult	Difficult	Easy	Few technology transfer
Sustainable development	**Low(heavy machinery used by contractors in development)**	**Low to medium**	**High (farmer-based and small power-tiller used in development and management)**	**Medium**
Management	**Difficult**	**Difficult**	**Easy**	**Easy**
Adverse environmental effect	High	Medium	Low	Medium

† Assuming 1 ton paddy is worth US$ 500; one power-tiller costs US $ 3000-4000 in West Africa depending on the brand quality and accessories (2015 values). Selling prices are $1500-$3000 for farmers in Asian countries.

60,000 ton of paddy and 36,000 ton milled rice. Project has started in 2013 (OlamNigeria Home page 2016, Rockefeller foundation 2013). Upon our (T. Wakatsuki, YS Ademiluyi, and PM Kpama) visit to the Olam farm on August 2016, the status of progress may be about 60% of the target. Because of site is on the flood plain of Benue river, some sawah plots were suffered by flood damage last year. The farm equipped with airport for direct seeding and pesticide spraying from airplane. Laser leveler attached tractors are leveling and cultivating. Each one tractor can manage 20-40 ha of sawah plot with 1 to 40 ha size. Combine harvest paddy, then milled at the farm. It is fully mechanized integrated rice farm except for weeding. Because of direct seeding manual weeding is necessary. Several hundred ladies are working to pick weeds by hands.

Although based on the estimated 60% of progress, the cost-effectiveness is better than the ODA based development shown in the Table 2 above. The development cost per ha of irrigated sawah is $110million/6000ha=$18,000/ha including huge mill cost. If double cropping will be realized, the cost will be $110million/10,000ha=$11,000/ha. The total annual milled rice selling price will be 0.6 (milling ratio) x6 x10000x $500(per ton)=$18million. Since the running cost per ha for paddy production per ha is about $1000, the total running cost will be $10million, the annual profit becomes $8million. The investment cost can be recovered in 110/8=13.75 years. This is about the double of the ODA based "charitable development project". However we have to wait the final evaluation still some years after. The completion of the development and the reach of full operation of huge milling machine, 36,000 ton per year.

Although the Olam farm includes out grower farmers training program, the farm is operating the most advanced mechanize rice farming, majority of surrounding rice farmers are operating by hand hoe and non sawah rice farming. Thus the investment and technology gap will not be able to fill. In addition, the private farms will enclose a big good lowlands of the nation, i.e., land grab. Numerous small farmers who are the most important national resource, can be excluded from autonomous rice cultivation and empowerment.

S Strategy: Sawah Technology for Endogenous Sawah System Development and Sawah Based Rice Farming with Sustainable Mechanization. As described in this paper, SSA needs sawah system development for rice green revolution. And SSA needs the innovative technology for breaking through the two big barriers of both area and time, i.e. 50 million ha of irrigated sawah system development by 2050, several centuries to shorten to several decades, before the explosion of population bomb. Among the 6 strategy, only our S strategy will make possible this two targets above. Our companion paper "Sawah Technology (4Paper): Practices of irrigated sawah system development and sawah based rice farming by farmers' self-support efforts" described in details.

Sawah technology offers low-cost irrigation development and water control for sustainable rice intensification with a sustainable paddy yield of more than 4-5t/ha in 5–15 ha, i.e., 20-75 ton of annual paddy production using one power tiller per farmer or farmers' group. This will empower small rice farmers economically, i.e., 20-75 ton of paddy price will be $5000-$30,000 ($250-$400 per ton of paddy), if milled in 0.625% milling ratio and $450-$800 per ton of milled rice, then total selling price will be $5,625-$37,500. While new sawah development cost will be $1000-3000 per ha including powertiller cost, $2000-$4000 per set, and running cost of sawah based rice farming will be 50% of the total selling price. The investment cost of 5ha of sawah will be $5000-$15000 and annual profit will be 20-25ton of paddy, $5000-$10000. This means the investment can recover within 2-3 years, which can compare 10-30years of private business enterprises and ODA based development (D and E strategies). Even though this investment cost is too big and the recovery years of 2-3 is too long to manage for majority of small rice farmers in SSA. Special policy by governments of SSA are necessary.

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