Asian African Collaboration for Sustainable African Green Revolution through *Sawah* and *Satoyama* Eco-technology to Combat Global Food and Ecology Crisis in 2025

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Abstract

The Green Revolution (GR) has yet taken place in Sub Saharan Africa (SSA). On the other hand, now Asia is a global center of economic growth thanks to the green revolution that started in 1970s. However, because of this economic development, serious food crises are anticipated in near future by 2025. On the other hand, SSA has vast lowlands and wetlands, 250 million ha, almost double of those in Asia. Contrary to Asia, unfortunately SSA has no tradition and technology for lowland agriculture, such as *sawah* based irrigated lowland rice farming in Indonesia. The potential irrigable lowland is estimated to 20-50 million ha in SSA. Majority of these lowlands are yet developed, because of lacking innovative technology, training, dissemination, and scientific research. The paper described that Asian, especially ESAFS and African collaboration for the promotion of lowland agriculture in SSA will be very important to solve global food and ecology crises in near future.

Keywords: Asian African collaboration, Eco-technology, Rice green revolution, *Sawah* eco-technology, *Sawah* hypothesis 1 and 2, Sub Saharan Africa, Watershed agroforestry, Wetlands

Introduction

Although food crops are very diverse in SSA, per capita total production of major food crops has been stagnating <200kg in SSA as seen in Figure 1 (FAOSTAT 2012). In tropical Asia, because of the green revolution, the figures increased from 200kg in 1961-1965 to 300kg in 1996-2000 (Figure 2).

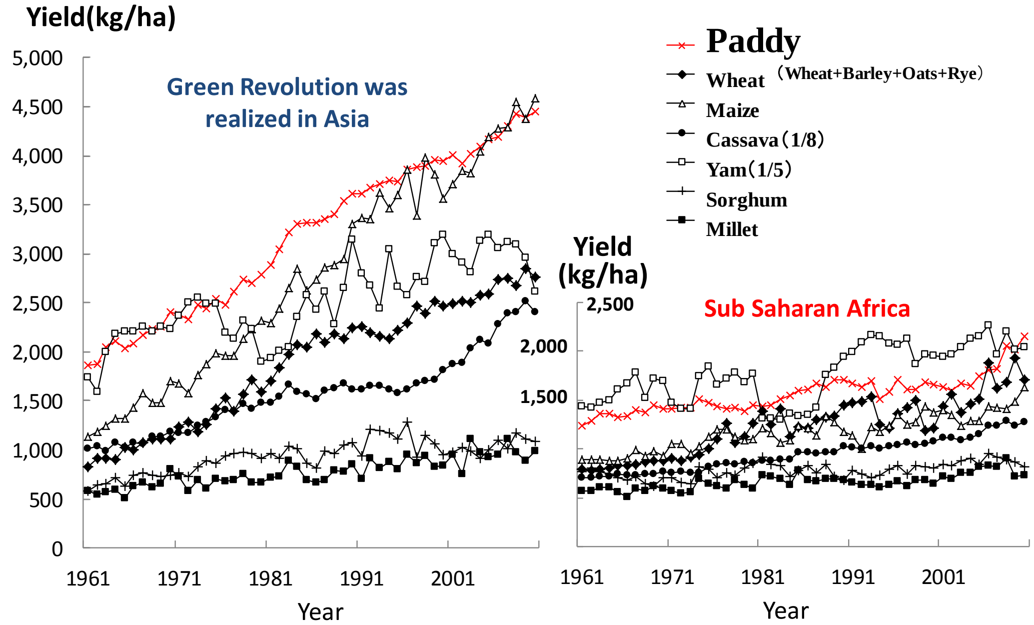


Fig.1. Comparative yield trends of five major cereals as well as yam and cassava between Asia and Sub Saharan Africa (SSA) during 1961-2010 show that SSA has no indication of green revolution (FAOSTA 2012). Kg weight data of yam and cassava were divided by 5 and 8 respectively to calculate cereals equivalent because of high water contetnts and low protein as well as nutrient minerals.

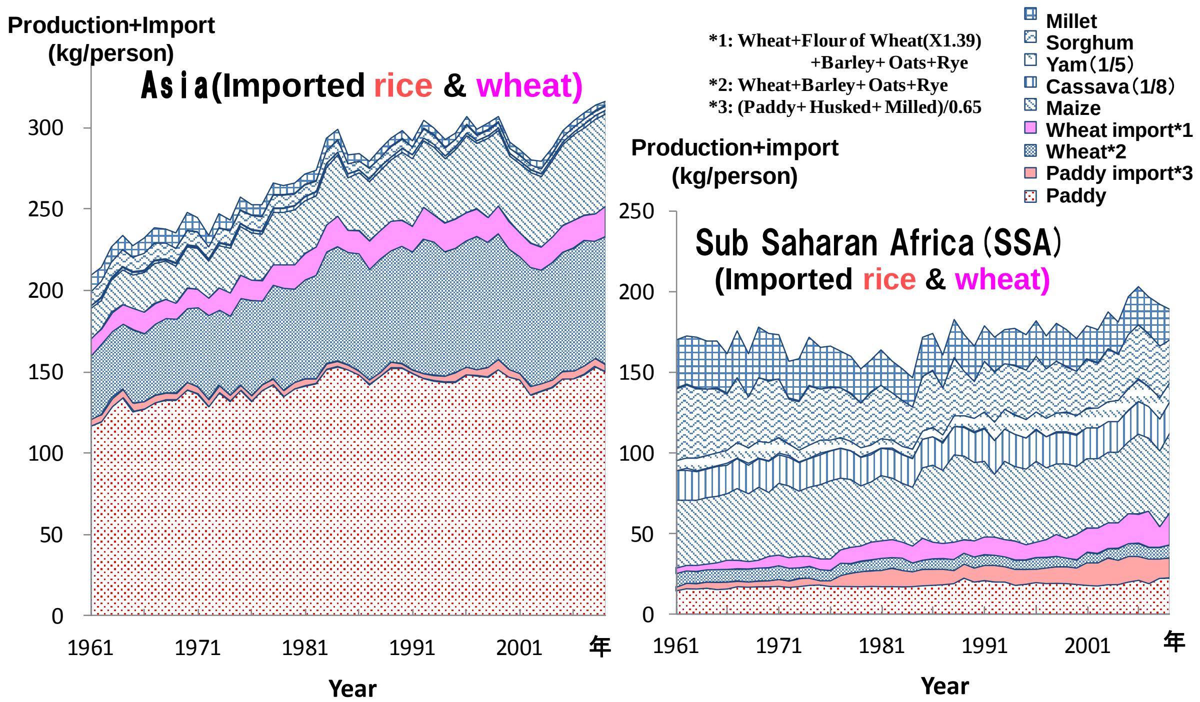


Figure 2. Per capita cereal equivalent food consumption (production+import) in Sub Saharan Africa (SSA) and Asia during last 50 years. Both SSA & Asia had produced ±200kg of per capita cereal equivalent food in 1960s. 50 years after, Asia increased about 300kg, but SSA is less than 200 kg. Both Millet (73%) & Sorghum(70%) productions were decreased. But Cassava (108%) & Maize (120%) increased, especially Rice(140%) & Yam(167%) considerably. The consumption of rice dramatically increased (186%). Thus the importation of rice was increased 383%. Although wheat importation also increased 428%, SSA has very high potential ecology for rice production.

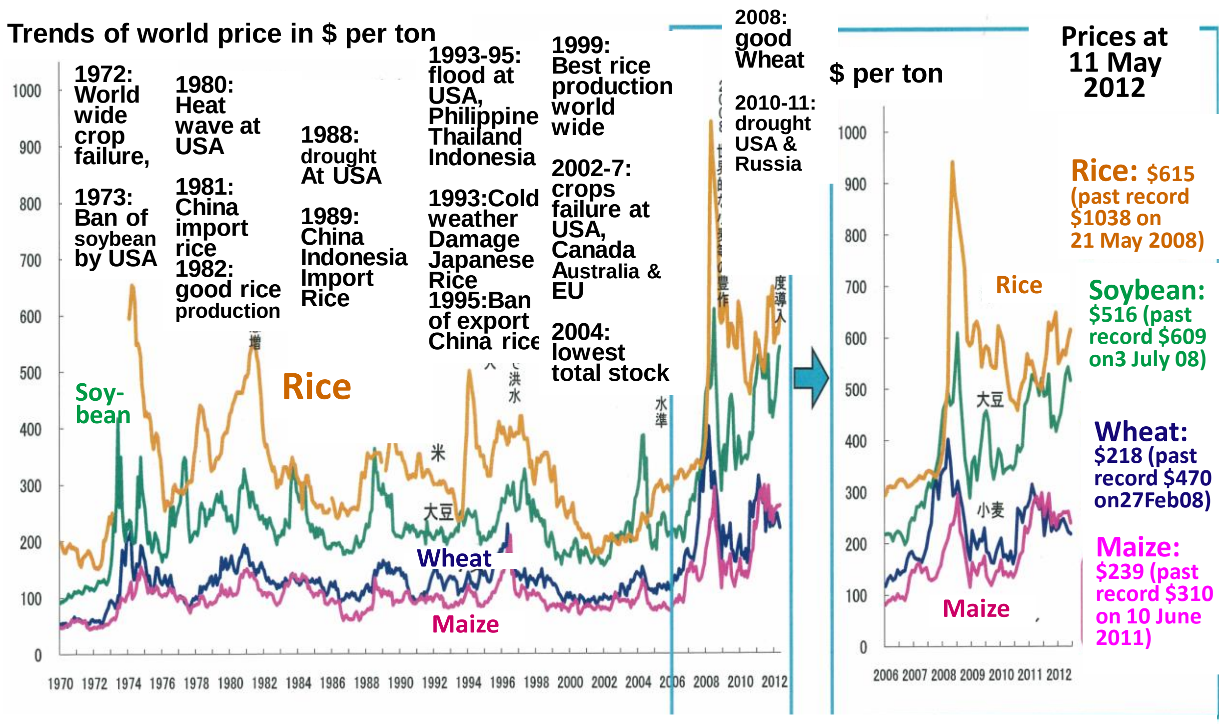


Figure 3. Trends of world trading prices of Rice at Thai (milled 2nd class FOB) and of Soybean, Wheat and Maize at Chicago commodity exchange during 1961-2012 (Ministry of Agriculture, Forestry and Fishery, MAFF, Japan 2012).

Note : Prices of wheat, Maize, and Soybean are prices at both the first and the last Friday of each month. Rice price is at both the first and the last Wednesday of each month. Note FOB, Free On Board at Bangkok port.

This is the fundamental cause of the current difference on sustainable economic growth and take-off between SSA and Asia. However if we look over the near future, 2013-2025, and beyond, the rapid economic expansion of Asia may result in decrease of both area of good productive farm land and population of good farmers, which will decrease food production in Asia. Economic growth will also increase the amount of consumptions of food crops by animals to produce more meat. The increase of biofuels production will be anticipated too. Although Asian population increase will not be considerable during 2010-2025, 4.2 billion in 2010 and 4.7 billion in 2025, African population will increase rapidly, 1.0 billion in 2010 and 1.4 billion in 2025 (United Nations 2013). All these factors suggest serious food crises may come near future by 2025. Recent rapid increases of market prices of all major cereals during 2008-2012 (Figure 3) will almost confirm the above argument. Thus we have to ready to combat this big task. I believe Asian and African collaboration will be very important to solve this global issue.

Sawah Hypthesis 1 for Green Revolution in Sub-Saharan Africa

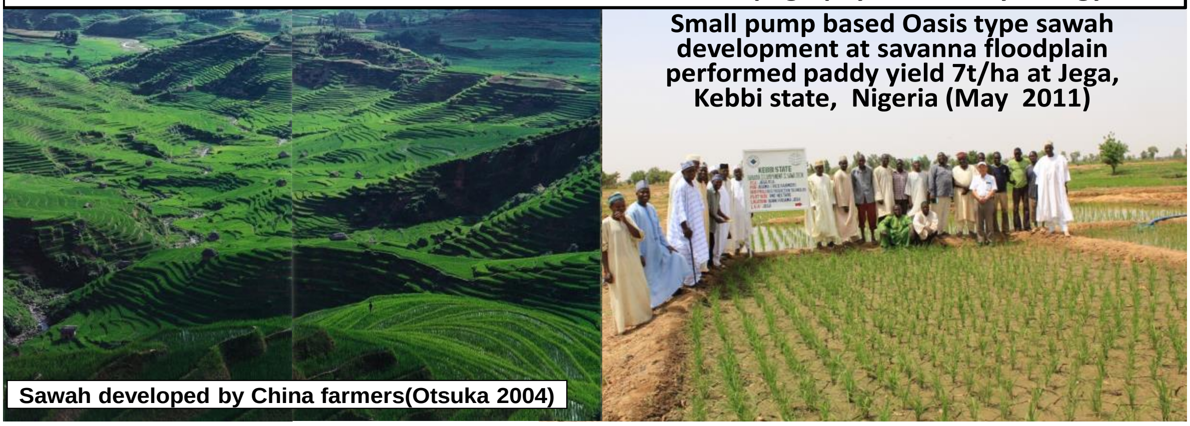
(1) *Sawah* Hypothesis 1: *Sawah* as a platform for scientific technology application

(2) Eco-technology and Bio-technology

(3) What is Sawah?: concept and technical term

Last 40 years in Africa, almost all agricultural research results could not scale up to farmers' fields, including three core technologies of Green Revolution (GR), i.e., ①improved high yielding varieties, ②fertilizers for soil management and agrochemicals for pest management and ③irrigation and drainage for water management (Figure 4). The Google photograph of Figure 5 explains the reason. African farmers' fields cannot accept scientific technologies developed at research institutes, such as International Institute of Tropical Agriculture (IITA) and Africa Rice Center (AfricaRice). In order to apply GR technology, farmers' fields have to be demarcated ecotechnologically based on topography, soil and hydrology, such a sawah system **(Sawah hypothesis 1)**, which makes possible soil and water management (Wakatsuki et al 1998, Hirose and Wakatsuki 2002, Oladele et al 2010, Abe et al 2011).

Figure 4. Sawah Hypothesis 1 : Platform to apply scientific technologies. Farmers bushy rice fields have to be classified and demarcated based on topography, soil and hydrology.



To increase rice production, both “varietal improvement” and “improvement of ecological environments” are equally important. The two technologies are complementary to each other. However, “sawah” research to improve farmers’ ecological environments has been largely neglected in Africa because of lacking the concept and technical term (Table 1 and 2, Wakatsuki 2013a and 2013b, Wakatsuki et al 2013a, 2013b, and 2013c).

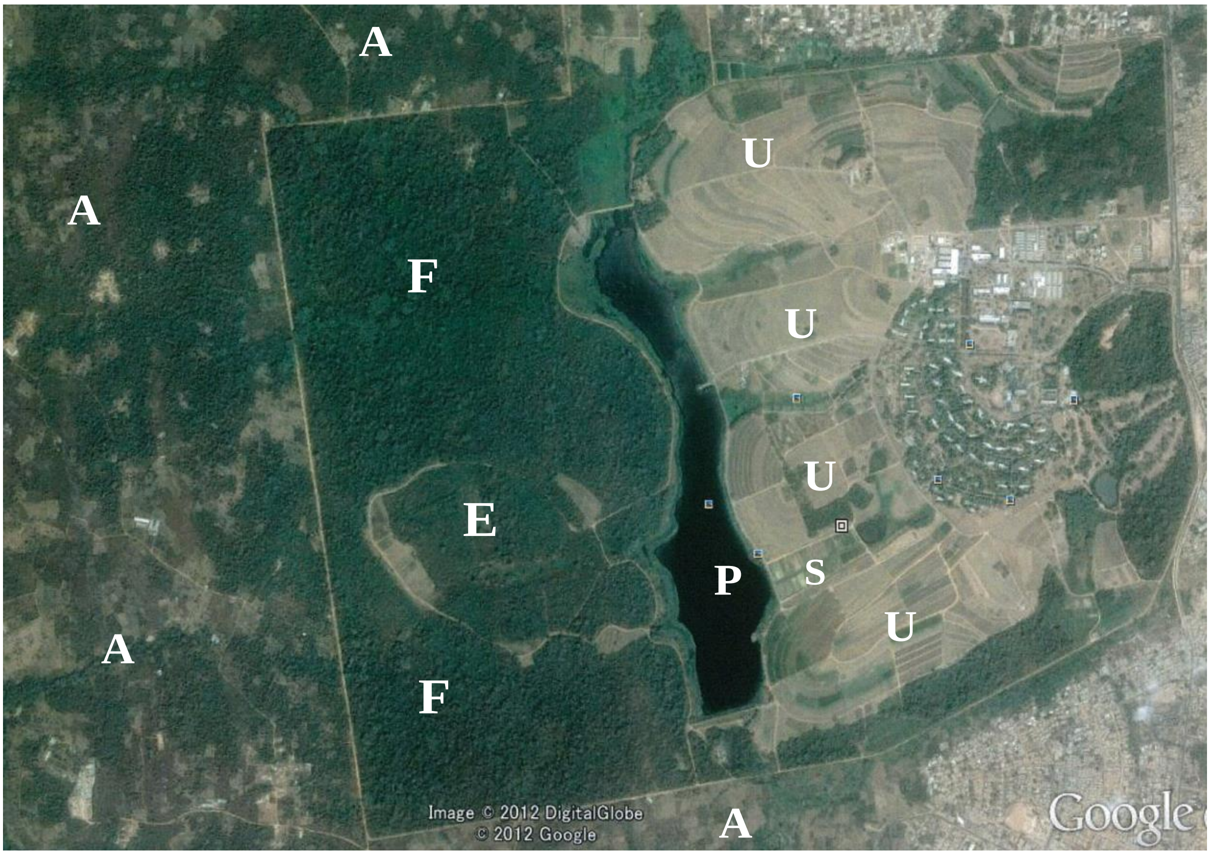


Figure 5. Sawah Hypthesis 1. Prerequisite platform conditions to apply scientific technologies exist in 1000 ha of fenced IITA’s research fields. But there are no such platforms or infrastructures in surrounding farmers’ fields. **A:** Farmers fields under random layout short fallow systems which have the same soils on similar topography and hydrology. **U:** demarcated upland fields along contours. **S:** about 4ha of irrigated Sawah fields at valley bottom. **P:** 100ha of IITA’s pond for irrigation. Similar rivers are available outsides. **F:** Regenerated 400 ha of forest after 40 years of conservation. **E:** Soil erosion experimental plots operated by Prof. R. Lal and his team in 1970-80s.

Table 1. No proper English/French and local language in West Africa and SSA to describe eco-technological concept and term to improve farmers’rice fields, Sawah or SUIDEN (in Japanese)

Suiden(Japanese) =SAWAH(Malay-Indonesian)

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

Table 2. Research, technology development, innovation and dissemination in the area of eco-technology are just emerging, although it philosophy is to study the past to learn new things, i.e., learning from history「温故知新」 Agriculture needs Good Environments and Good Varieties. Both Biotechnology and Ecotechnology have to be researched, developed and innovated in good balance

Bio-technology:

To improve varieties through breeding, i.e., Genetic improvement. Target is DNA improvement.
Operational platform is Cell of organisms

Eco-technology:

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.

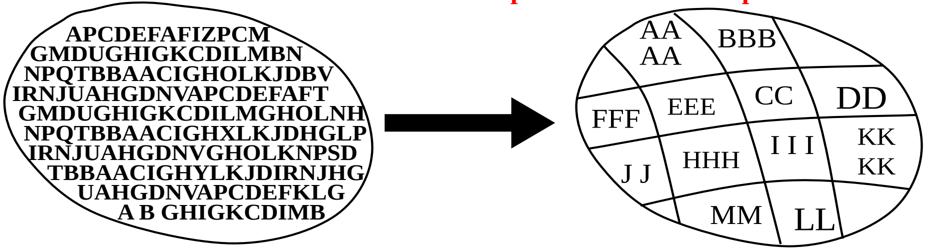
Photograph 1.Lowland paddy field at Sokawe, Kumasi, Ghana Three Green Revolution technologies can't apply

Photograph 2. Once Sawah system was developed, yield can reach at least 4t/ha. If improved but labor intensive rice agronomy can practice, such as System Rice Intensification (SRI), yield reach to 10t/ha (Sokwae, Ghana)

Although three GR technologies have been available for the past 40years, they have not been effective in farmers' fields in SSA (Photograph 1). 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 1, Photograph 2, Figure 6-8). Essential components with regard to land development are (1) demarcation by bunding based on topography, hydrology, and soils, (2) puddling and leveling to control and conserve soil and water, and (3) water inlets to get water (using various irrigation facilities) and water out-lets to drain excess water. These are the characteristics of *sawah* fields. For various social and historical reasons since the 1500s due to the globalization of the West, these basic land and infrastructure developments to make the scientific technologies necessary for a green revolution possible have been disturbed in SSA (Hirose and Wakatsuki 2002).

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. No incentive to improve land.
3. Market competitive 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 is 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 promote, which makes incentives to improve land.
3. Market competitive standardized paddy production become possible.



Fertilizer, Irrigation, and high-yielding varieties(HYV) are not effective, therefore, Green Revolution is impossible.

Sawah is a platform to apply scientific technologies . Thus, Green Revolution will be realized.

Fig 6. Sawah hypothesis (1): Farmers' Sawah should come first to realize Green Revolution. Farmers fields have to be classified and demarcated ecotechnologically. Then scientific technologies can be applied effectively.

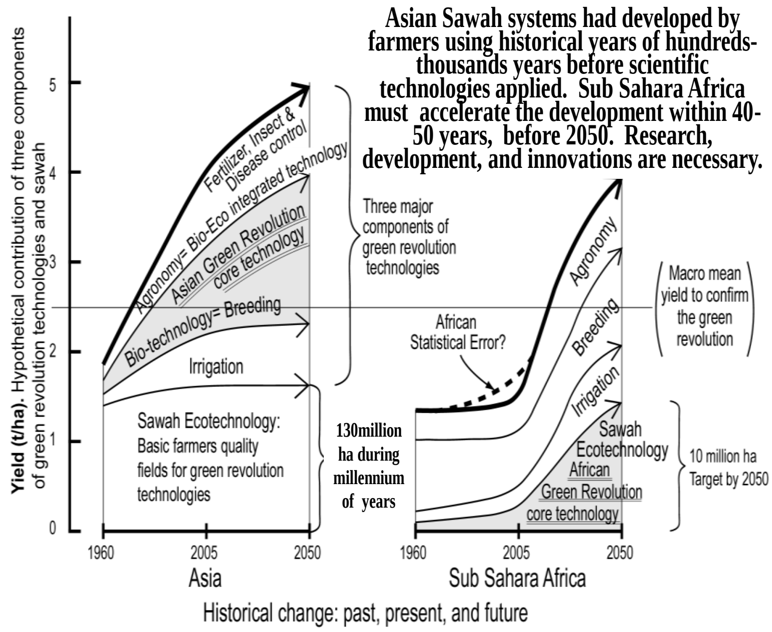


Fig. 7: Sawah hypothesis (1) for Africa Green Revolution: hypothetical contribution of three green revolution technologies & sawah system development during 1960-2050. Bold lines during 1960-2005 are mean rice yield by FAOSTAT 2006. Bold lines during 2005-2050 are the estimation by the authors.

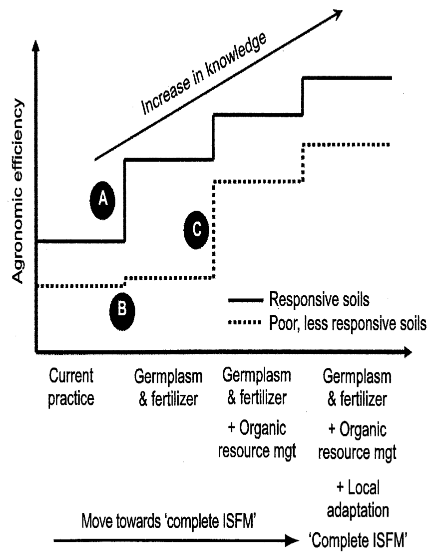


Figure 8. Concept of Integrated Soil Fertility Management(ISFM) by Vanlguwe, Bationo, Sanginga et al, (2010) can not work without proper platform like sawah

As shown in Fig.9, before green revolution, there were long continued efforts to expand lowland sawah systems in the history of Japanese rice cultivation during the 6th to 20th centuries**.** The same apply to the other ESAFS countries although various difference due to the degrees of disturbance by the globalization of the West, which started in 15th centuries (Hirose & Wakatsuki 2002).

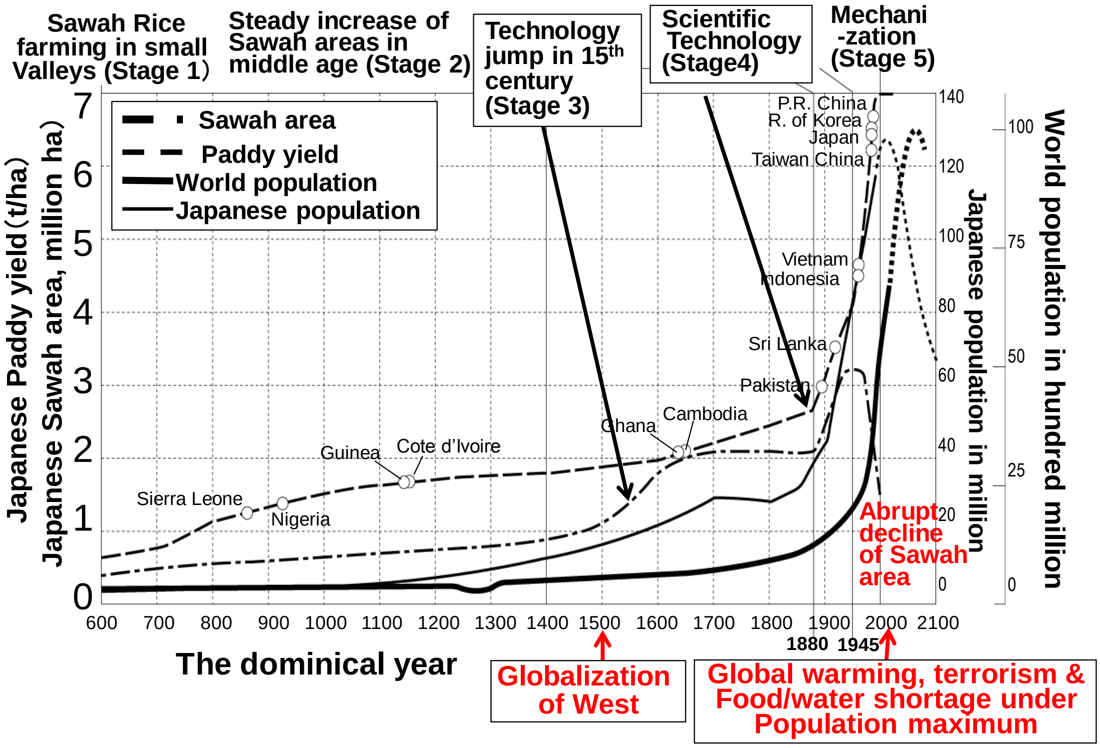


Figure 9. Historical path of Japanese and world population, Sawah area, and paddy yield in comparison with Asia and Africa at 2001/2005 of FAOSTAT data. (Takase & Kawano 1969, Honma 1998, JICA 2003, Kito 2007, Wakatsuki 2013b)

The Fig.9 shows the trends of paddy yield, sawah area and population of historical path in Japan in comparison with paddy yields in major ESAFS and African countries. 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 at the end of 19th century. Then the rapid expansion of Sawah area was followed, with the rapid population increase, which was finally exploded as the world war the first and the second. However, only 10-20 years after world war the II, because of the expansion of the economy, industrialization, and urbanization, the sawah area had decreased rapidly. After the Japanese population maximum in 2008, decline and aging population is the major problem. On the other hand, majority of ESAFS and SSA are expecting rapid population explosion and maximum within decades with possible world crises on global warming, terrorism, food and water shortage.

Potential and Challenge of *Sawah* based rice farming in SSA

Among the 250 million ha of lowlands in SSA, about 10% (20 million ha) are estimated to be appropriate sites for sustainable irrigated *sawah* system development, of which 9-20 million ha are in small inland valleys, 8-15million ha in floodplains, 4-9 million ha in coastal deltas, and 1-5 million ha in inland basins as shown in Table 3. Major challenges on sustainable Sawah development in Africa are shown in Table 4, how to manage low fertility soils, Figure 9 & 10 , how to manage scarce water in vast land of SSA, Table 5, how to manage scarce budget and

Table 6, how to train and innovate sawah eco-technology to huge population of African farmers. Major innovative challenge is speed up of sawah development. i.e., Asia had historical time for Sawah platform development as seen in Figure 9, but SSA had to accelerate as shown in Fig 7 and 9. All these challenges need ESAFS contribution for Asian and African collaboration in near future.

Table 3. Distribution of lowlands and potential irrigated sawah in Sub Saharan Africa, SSA (Windmeijer and Andriesse 1993, Potential irrigated Sawah area estimate by Hirose and Wakatsuki 2002, Wakatsuki et al 2009, Wakatsuki et al 2013b, Wakatsuki 2013b)

Classification	Area (million ha)	Area for potential sawah development
Coastal swamps	17	4-9 millon ha (25-50%)
Inland basins	108	1-5 million ha (1-5%)
Flood plains	30	8-15 million ha(25-50%)
Inland valleys	85	9-20 million ha(10-25%)

Note 1: Although priority target is the inland valley because of easier water control, some flood plains have high priority, such as Sokoto, Kebbi, Yobe and Borno in northern Nigeria where personal pump irrigated sawah is efficient

Note 2: Estimated potential sawah area is 3 million ha and annual paddy production 12 million ton in Nigeria and 20 million ha in SSA . Estimated sawah area came from the relative amount of water cycling in Monsoon Asia, which has 130 million ha sawah. However, if innovative technology will be developed, 5 and 50 million or more ha of Sawah can be developed in Nigeria and SSA, respectively in future. Africa has still immense frontier of irrigated sawah development and rice production.

Table 4. Mean values of fertility properties of top-soils of inland valleys (IVS) and flood plains (FLP) in West Africa in comparison with lowland top-soils of tropical Asia (T. Asia) and Japan

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

*Kawaguchi and Kyuma (529 sites), 1977, Kyuma 2004, ** Bray II.

Source: Hirose and Wakatsuki (268 sites in West African IVS and FLP by Issaka et al 1997 and Buri et al 2000), 1997 and 2002.

Table 4 shows the results of comparison of top-soil fertility between West Africa's rice field and those of southeast Asia and Japan. Although soil fertility is very diverse, general soil fertility of West African lowland is very poor because of prolonged weathering in stable continent of Africa (Hirose and Wakatsuki 2002)..

Can watersheds of SSA sustain Sawah system? High rate of soil erosion and lowland sawah soil formation can be compensated by high rate of soil formation in Asia. However the rates of soil formation, soil erosion and hence lowland soil formation are very low (only 10-20%) in comparison with Asian watersheds (wakatsuki et al 1993)

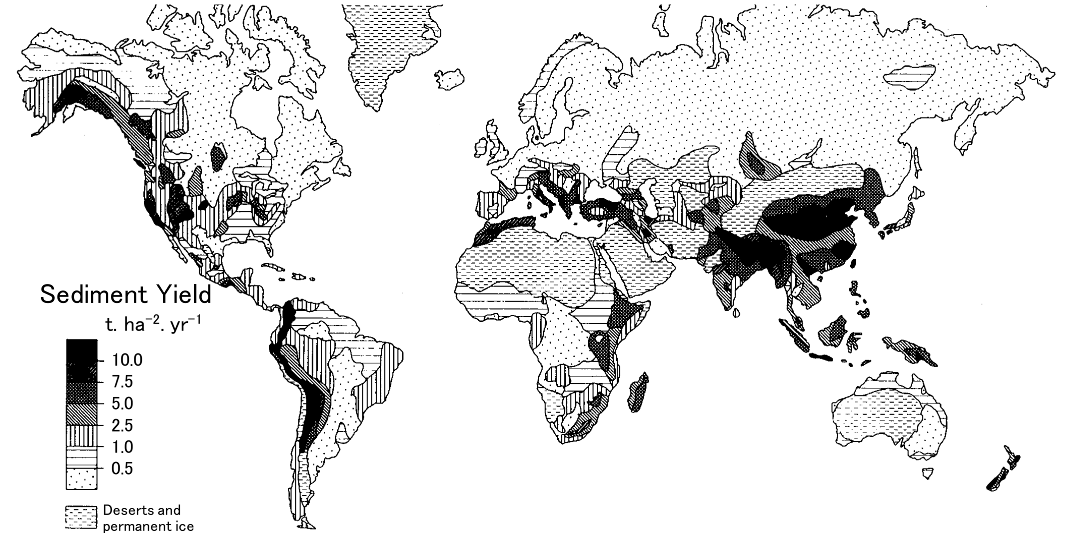
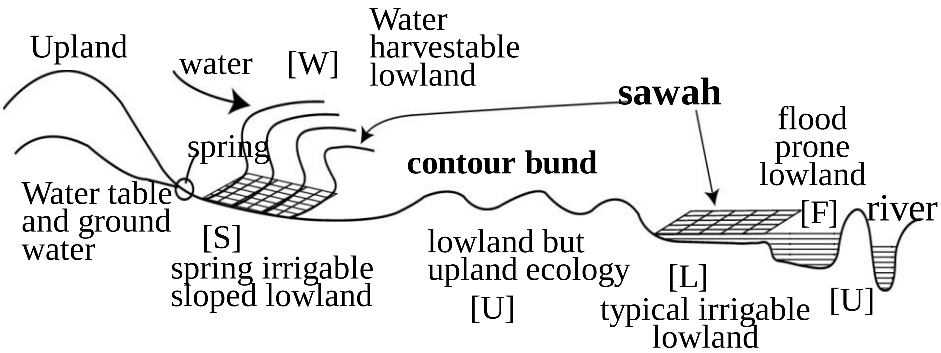


Fig. 10. Rate of Soil erosion in the World (Walling 1983)



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

Lowland sawah development priority

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

***Even huge flood plain, farmers can practices sawah based rice farming using pump, except for 2-3 months flood period**

Fig. 11: Very Diverse Nature of African Lowlands Need on Large Scale Action Research and On The Job training on Site Specific Sawah Development and Sawah Based Rice Farming

The Figures 10 and 11 shows diversity of African lowland under scarce water cycling comparing to the vast land area. Water saving new sawah technology innovation will contribute future food crisis in the World (Table 3). Site selection and efficient water use sawah systems will be very important.

Table 5: Comparison of farmers' site-specific personal irrigated sawah system development and sawah based rice farming(Sawah eco-technology) with large- and small-scale contractor (ODA) style developments, and traditional rice cultivation system in inland valleys of Ghana and Nigeria (2013).

	Large-scale development	**Small-scale development**	**Sawah eco-technology**	**Traditional system**
Development cost ($/ha)	**10000–30000**	**10000–30000**	**1000-3000 (10 yrs ago 3000-7000)**	**30–60**
Gross revenue ($/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)	900–1000	900–1000	900–1000	300–400
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 $ 3000-5000 in West Africa depending on the brand quality and accessories (2012 values). Selling prices are $1500-$3000 for farmers in Asian countries.

Table 5 shows socio-economic consideration. Both large-scale and small-scale irrigation projects, typically created under Official Development Assistance (ODA), have been very costly (Fujiie et al 201), because of no sawah ecotechnological background in SSA, thus total dependence on heavy engineering works and outside expertise (Table 5). 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.

The *sawah* ecotechnology package in Table 6 offers low-cost irrigation and water control for rice intensification with sustainable paddy yield of more than 4t/ha. If we apply improved agronomic practices, such as the System of Rice Intensification (SRI, Tsujimoto et al 2009) with the *sawah* systems, paddy yield can reach more than 10t/ha, although the high yield is the trade-off with labor cost. However, African lowlands are quite diverse and different from Asian lowlands as shown in Figure 10. Therefore careful site-specific *sawah* development and management technologies must be researched, developed, innovated and disseminated through intensive On-The-Job training (OJT). The sawah ecotechnology package (Table 6) was developed based on the long term action research in Nigeria and Ghana during 1986-2012. The technology makes possible farmers' themselves to develop their personal irrigated sawah systems and to produce 20-50 tons of paddies (equivalent to $10,000-25,000) per season using one powertiller ($3000) within three years. The technology was successfully tested at > 50 sites and >100 ha in Ghana and >100 sites and >200 ha in Nigeria. The sawah technology has four components, i.e., (I). Skills for site selection and site specific sawah system design. (II).

Table 6. Four Skills of Sawah Ecotechnology Innovation to Develop Farmers Personnel Irrigated Sawah Systems to Realize Green Revolution in SSA

(1) Site & Time Selection & *Sawah* system design

(a)Rice cultivation >15ha
Farmers strong will to improve technology
(b)Hydrology & quality
(>30 L/s, >5 months/year)
Maximum flow <10ton/s
(c)Topography and soil
Slope ±1%
Not extremely sandy
(d)Privately own the land
or at least Secured rent longer than 5-10 years
(e) *Sawah* system design
Sawah layout
Leveling quality
Bundding quality & Mgt.
Drought and Flood control measueres
(f) Powertiller and trailer trafic road
(g) Water intake, storage, distribution, & drainage
Simple sand bag & wooden dam/Weir dam, barrage
Canal system
Interceptor canal
Pond and fish pond
Pump irrigation small, middle, large
Central drainage

On-the-job training on site-specific *sawah* development & management

Collaboration between farmers & scientists, engineers, and extension office is very important

Farmers know site specific hydrological conditions which are the most important for site election

The successful example of *Sawah* ecotechnology innovations:
(1) Oasis type pump irrigation in floodplain (Sudan savanna zone, Kebbi state)
(2) Spring based irrigation system (all climatic zones)
(3) Overflow dykes on small rivers (Guinea savanna zone, forest transition zone, forest zone)

(2) Efficient & Low cost Sawah Development: Skill & Technology

(a)Skills for bush clearing & de-stumping
(b)Skills for bunding, canal construction and treatment surface roughness
(c)Cost for hired labors, tools, powertiller purchasing and management
>10ha of development/3-5 years using one powertiller
Purchasing $3000-5000/10ha
Running $2000-3000/10ha
Tools & materials $1000/10ha
(d)On-the-job training cost
Scientist & engineers $1000/ha
Extension officer $500/ha
Leading Farmer $250/ha

Sawah development: at least 10ha by one Power-tiller

Target cost: $1000-3000 /ha

Target speed of develop-ment: >3ha/year /powertiller

(3) Socio-Economic Skills for Rice farmers enpowerment

(a) Group organization & leading farmers training
(b)Training of powertillers assisted sawah development & sawah based rice farming
(c)Post harvest technology using small harvesters of $10,000 per set if sawah area >25ha & paddy production >100ton per year
(d)Loan system to buy agric. Machines and sawah lands
(e)Land tenure arrangement for secured rent >5-10 years

(4) Sawah based rice farming

(a)Management of water intake, storage, distribution, & drainage sytems
(b)Management of bunding & leveling
(c)Water Managt. of sawah depth of water irrigation timing
(d)Puddling skills
(e)Skills of Nursery & trans-planting
(f)Weed, pests, and birds Managt.
(g)Managnt. of Fertilizers, nutrient & organic matters
(h) Variety selection & Managnt
(i)Achievement of targeted yield

(1)Immediate target: Paddy yield >4t/ha, >20ton paddy /powertiller

(2)>50t paddy /year /power tiller will accelerate *sawah* Development

(3) Basic research on sustainable paddy yield >10t/ha is important

(1) To train qualified sawah farmers and or groups who could develop sawah >5ha and get annual paddy production >20ton using one powertiller within three years after the initiation of sawah development.
(2) To train the leading *Sawah* farmers is the key for sustainable and endogenous sawah development. The leading farmers can train farmers and farmers groups to achieve the target as qualified *Sawah farmers*.
(3) If site selection is suitable, sawah can be developed far easier in Africa than in Asia.

Sawah technology can reform traditional ODA & contractor based development : farmers to farmers technology transfer sites > > sites of extension officers > researchers' demonstration sites>> Traditional ODA

Skills on efficient and low cost sawah development using appropriate mechanization, such as walking power tiller, (III). Skills of sawah based rice farming using basic three GR technologies to sustain paddy yield >4t/ha, (IV).Socio-economic skills for rice farmers innovative empowerment for endogenous extension of Sawah ecotechnology through farmers' to farmers technology transfer (Wakatsuki 2013a and 2013b, Wakatsuki et al 2013a, 2013b, and 2013c).

Thus the capacity building of millions African farmers on integrated sawah ecotechnology will be major challenges. Thus Asian African collaboration will be really important and necessary.

Sawah Hypothesis 2 for Intensive long-term Sustainability and to combat global warming through African and Asian Adaptive SATOYAMA system, or Watershed Agroforestry systems.

The upper part of Figure 11 illustrates the concept of watershed eco-technology or "Watershed Agroforestry"(Wakatsuki and Masunaga 2005). The soils formed and the nutrients released during rock weathering and soil formation processes in upland areas arrive and accumulate in lowland areas through geological fertilization processes. These processes include soil erosion and sedimentation, surface and ground water movement, as well as formation of colluviums. Ideal land-use patterns and landscape management practices will optimize the geological fertilization processes by ensuring optimum hydrology in a given watershed. Irrigation, surface, and subsurface water also contribute to increase in the supply of such nutrients as Si, Ca, Mg, K and sulfate. This contribution provides an ecological engineering basis for sustainability of intensive lowland *sawah*-based rice farming.

The lower half of Figure 11 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). Science and technology on 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 to control of weeds without herbicides (Matsushita A 2013). This technology has to be research scientifically.

Lowland *sawah* systems can sustainably produce paddy at approximately 2t/ha without any chemical fertilizer application (Hirose and Wakatsuki 2002, Wakatsuki et al. 2009). Furthermore, lowland *sawah* systems can support rice cultivation continuously for decades, centuries, or more without any fallow period. In contrast, upland slash and burn rice fields hardly ever sustains paddy yields in excess of 1 t/ha without fertilizer. In addition to this lower yields, upland paddy fields require a fallow period to restore soil fertility, typically 2 years of cultivation and 8 or sometimes more than 15 years of fallow. This means that 1 ha of sustainable upland rice cultivation requires at least additional 5 ha of land. Therefore, sustainable upland paddy yield is actually not 1t/ha but less than 0.2t/ha. In all, the sustainable productivity of *sawah*-based rice farming is more than 10 times higher than that of the upland slash and burn rice (*Sawah* Hypothesis II). We know this to be true based on a long history and experience (not,

Macro-scale watershed eco-technological mechanisms to support Sawah hypothesis 2: Geological Fertilization of eroded top-soils and accumulation of nutrient rich water in lowland Sawah.

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

Micro-scale eco-technological mechanisms to support Sawah hypothesis 2: Enhancement of the availability of N, P, K, Si, Ca, Mg, and micronutrients by puddling and water management. Quality organic carbon accumulation to sustain soil fertility.

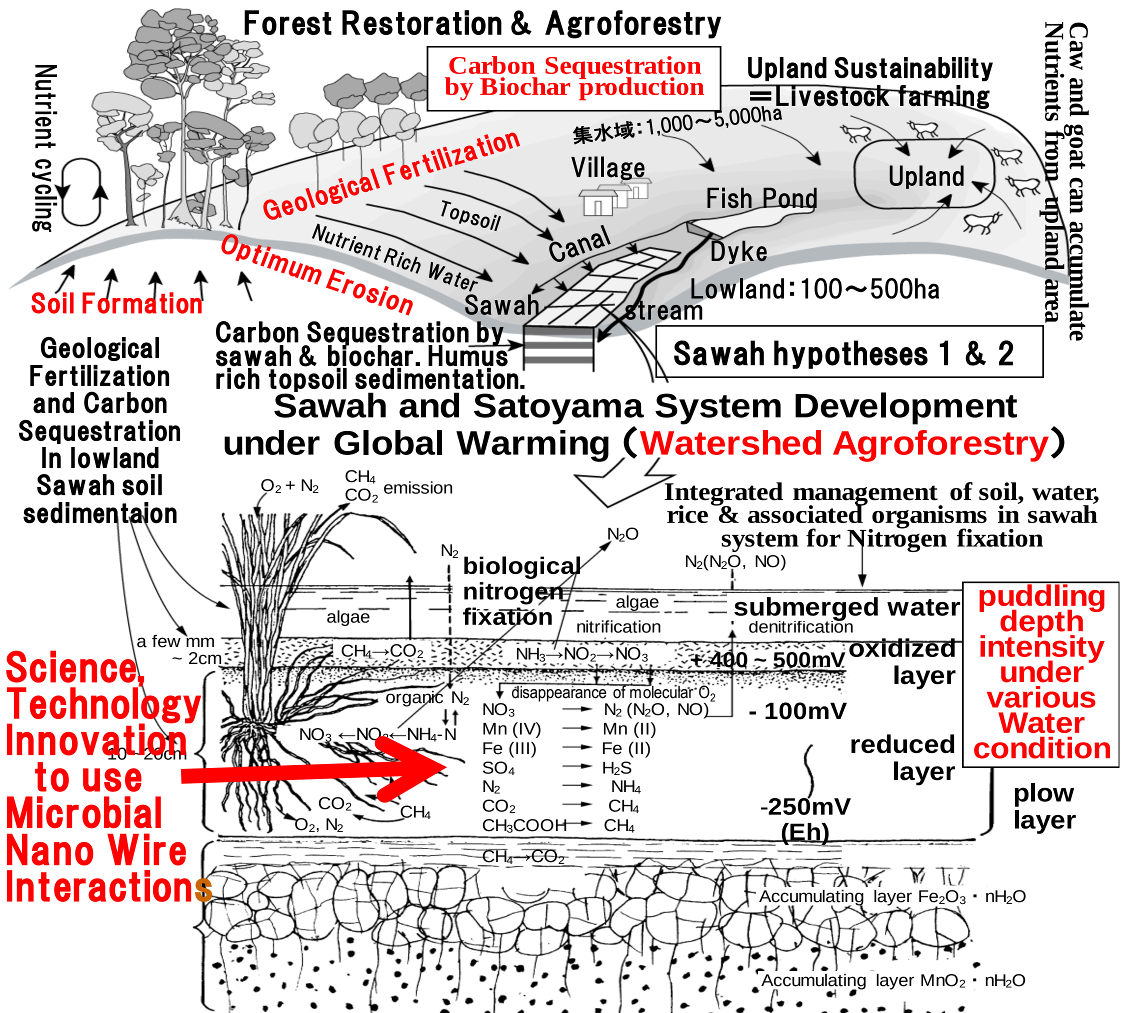


Fig 12. Sawah hypothesis 2 of multi-functionality & creation of African SATOYAMA (or Watershed Agroforestry) systems to combat food crisis and global warming.

experiments) of *sawah*-based rice farming in Asia, although no scientific or quantitative confirmation exists yet. We therefore must determine the sustainable yields quantitatively under SSA conditions. It is known that the development of 1 ha of lowland *sawah* field enables the conservation or regeneration of more than 10 ha of forest area. *Sawah* fields can, thereforecontribute to not only increased food production but also to forest conservation, which in turn enhances the sustainability of intensive lowland *sawah* systems through nutrient cycling and geological fertilization processes (watershed agroforestry or African SATO-YAMA system). SATO means villagers' habitat and YAMA means multipurpose forests managed by villagers. Because of sustainability of intensive lowland *sawah* systems, degraded upland fields can be converted to multipurpose forests. Thus as shown in Figure 11, *sawah* fields can contribute to the alleviation of global warming problems through the fixation of carbon in forest and *sawah* soils in ecologically sustainable ways (Hirose and Wakatsuki 2002, Wakatsuki et al. 2009).

Road map to solve possible global food and environmental Crises by African Adaptive Sawah Development through the Asian and African collaboration

Table 7. Road Map to realize Rice Green Revolution by *Sawah Ecotechnology* (Site Specific Farmers' Personal Irrigated *Sawah* Development by Million Farmers' Self-Support Efforts) in SSA: Importance of Asian African Collaboration.

(1) **1994-2002 : (10 sites, 6ha of sawah) :JICA/CRI & MEXT, Japan assisted Sawah project:** West African wide survey on traditional rice farming and basic research on Site Specific Sawah development by farmers' self support efforts at Bida, Nigeria and Kumasi, Ghana

(2) **2003-2007: (20 sites, 30ha, benchmark waterhshed): MEXT assisted basic research S:** Basic Action research to develope Site Specific Personal Irrigated Sawah development by farmers at Bida, Nigeria and Kumasi area, Ghana

(3) **2007-2012:(>100 sites, >200ha, Sawah Ecotechnology): MEXT assisted specially promoted research: Kinki & Shimane Univ/NCAM/FadamaIII /SRI/CRI, JIRCAS, and SMART-IV:** Sawah ecotechnology establishment and to prepare large scale action research on *Sawah* ecotechnology dissemination at Nigeria, Ghana, Togo and Benin

(4) **2013-2017: (>1,000 sites, >10,000ha of sawah in Nigeria and Ghana: Sawah ecotechnology dissemination and Marketable Rice Farming project proposals to both Nigeria and Ghana government as well as World Bank/JICA : Possible** collaboration with ESAFS scientist and Africa rice/IRRI: To start nation-, West Africa- and SSA-wide innovative dissemination on Sawah ecotechnology

(5)**2018-2025: (> Million ha of Sawah): Establishment Institutional organization for Africa wide dissemination through full Asia/African collaboration and endogenous *Sawah* Ecotechnology development**

(6)**2026-2050: (> 10 Million ha of Sawah): African wide spontaneous *and rapid sawah* expansion and the Realization of African Rice Green Revolution: Africa will be global food basket**

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