Implementation of Innovative Sawah Eco-technology to Realize Endogenous Rice Green Revolution in Nigeria and Sub Saharan Africa*

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Abstract

Almost all agricultural research results could not scale up to farmers' fields during last 50 years in Africa. Thus, the Green Revolution (GR) is yet to be realized. To increase rice production, both "varietal improvement" and "improvement of ecological environments" are equally important. However, "sawah" research and development to improve farmers' ecological environments have been largely neglected in Africa. We, sawah team, could innovate sawah ecotechnology package based on the long term action research in Nigeria and Ghana during 1986-2011. 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 ($4000) within three years. The technology was successfully tested at 50 sites and 100 ha in Ghana and 100 sites and 200 ha in Nigeria. Through the on-farm demonstration, the technology was positively evaluated by participating farmers under Fadama III project, Nigeria and Council for Scientific and Industrial Research, CSIR, Ghana. In November 2011, the first international workshop on Sawah Ecotehnology was organized at Kumasi, Ghana. The sawah technology has four components, i.e., **(I). Skills for site selection and site specific sawah system design**. **(II). 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.** Immediate our target is to scale up the sawah ecotechnology from the testing & demonstration stage to the point of total dissemination and rapid expansion, i.e. 500 sites and 5000ha at inland valley and flood plains in all 10 states in Ghana and 26 major states in Nigeria, respectively. Traditional ODA-based development of such scale claims more than $100million only for development. This sawah ecotechnology, however, makes realize the same scale of development using less than $10million with the on-the-job training of scientists/engineers, extension officers and leading farmers. Thus this 5000ha of sawah development can train stake holders for next 50,000ha of sawah development and capacity building, and so on. The sawah ecotechnology will be core arms to realize GR in Africa, because of its role ①platform for three GR technologies, ②low cost, and ③accelerated site specific endogenous expansion by ④ simultaneous progress of sawah development, capacity building and technology transfer from farmers to farmers.

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Non-Sawah upland paddy field Guinea, Aug.03

Degraded non-Sawah lowland Paddy field, Sierra Leone, Jan. 1989

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

Sawah developed by China farmers using hundreds - thousands years(Otsuka 2004)

Small pump based Oasis type sawah development at savanna floodplain performed paddy yield 7t/ha at Jega, Kebbi state, Nigeria (May 2011)

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

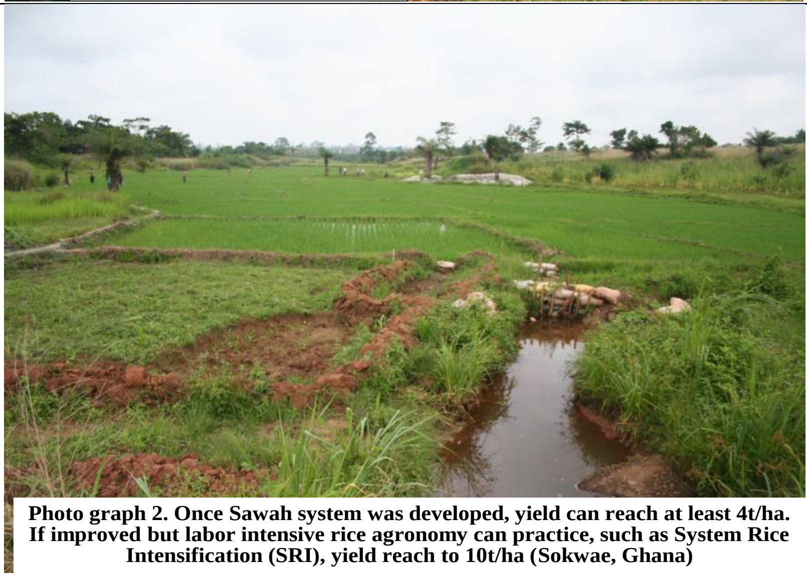


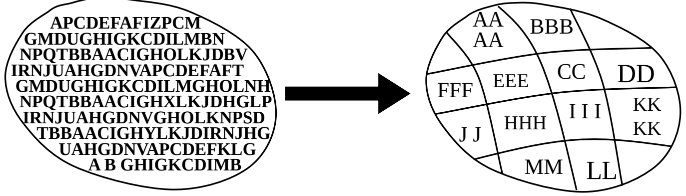
Photo graph 2. Once Sawah system was developed, yield can reach at least 4t/ha. If improved but labor intensive rice agronomy can practice, such as System Rice Intensification (SRI), yield reach to 10t/ha (Sokwae, Ghana)

<u>Farmers' Paddy Fields</u>: 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.

<u>Sawah Fields</u>: 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.

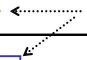
Fig 6. <u>Sawah hypothesis (1):</u> Farmers' Sawah should come first to realize Green Revolution. Farmers fields have to be classified and demarcated ecotechnologically. Then scientific technologies can be applied effectively.

Without sawah, System Rice Intensification (SRI) farming and any other advanced agronomic methods can not be practiced.
SRI needs good leveling and water controllable rice fields, i.e., Sawah fields, Sumatra, Indonesia, Aug,10

No proper English/French &local language in West Africa 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



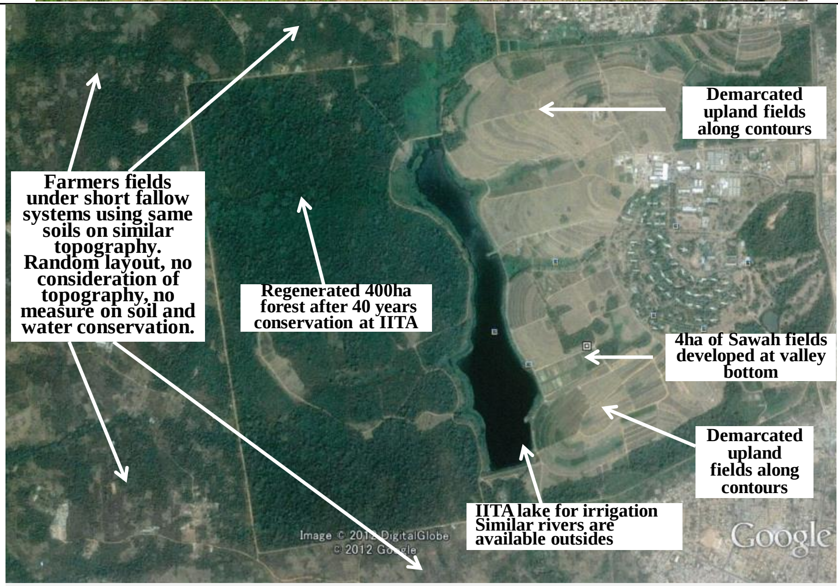
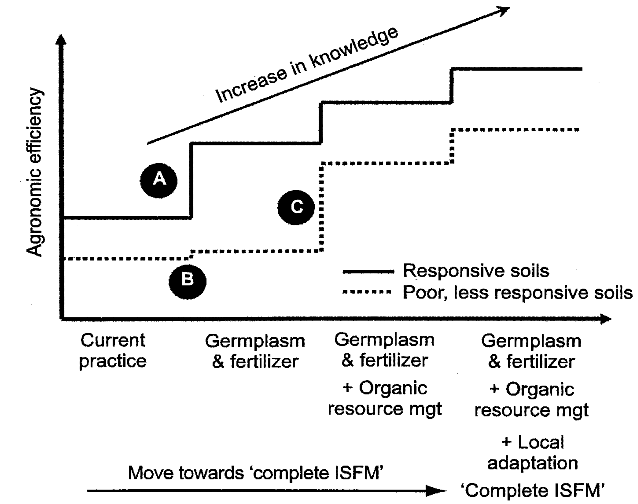


Fig.1: Sawah Hypothesis 1 : Prerequisite Platform condition to apply scientific technology is existing in 1000ha of IITA's research fields", but not in surrounding farmers fields

Integrated soil fertility management (ISFM)



(Vanlguwe,Bationo, Sanginga et al, 2010)

Figure 8. Concept of Integrated Soil Fertility Management can not work without proper platform like sawah

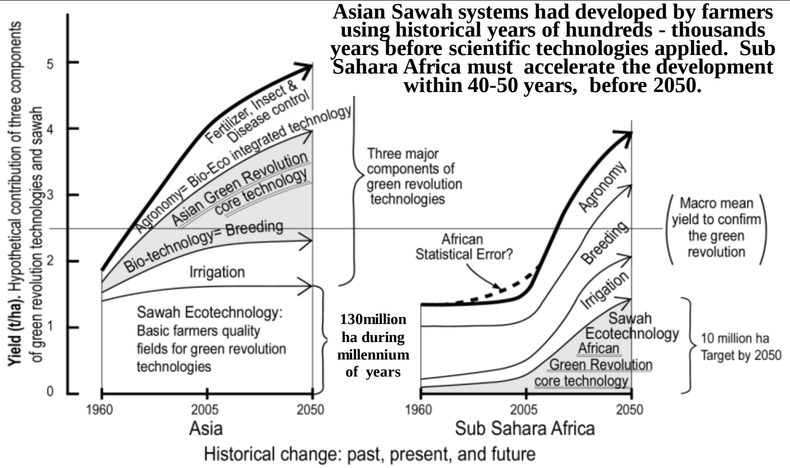


Fig. 2: Sawah hypothesis (1) for Africa Green Revolution:

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.

Agriculture needs
Good Environments and Good Varieties :

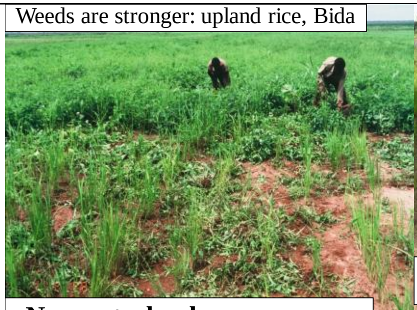
Both Biotechnology and Ecotechnology have to be researched, developed and innovated in good balance

Bio-technology :

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

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 watersheds.


Weeds are stronger: upland rice, Bida


Nupe's indigenous partial water control system

No ec-otechnology measures


Inland Valley, Sierra Leone


Once Sawah systems are developed by farmers' self-support efforts and water is controlled, majority of HYV can produce higher than 5 t/ha

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

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

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

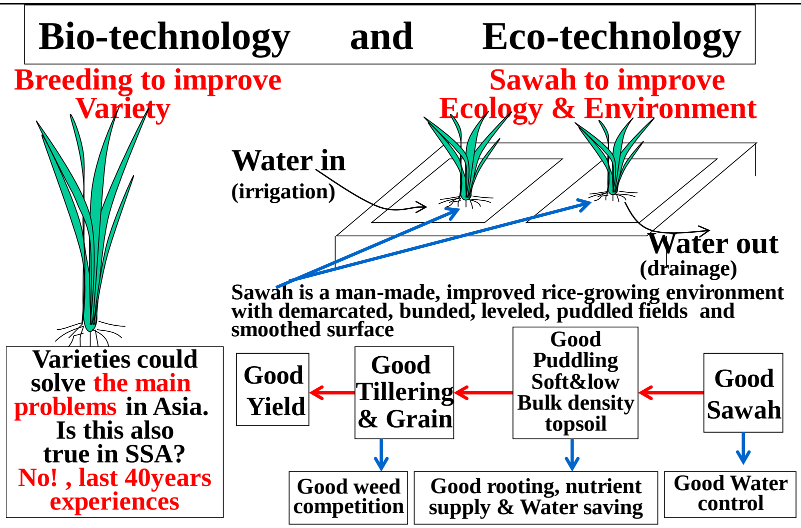


Fig. Rice (variety) and environment (Sawah) improvement. Both Bio & Eco-technologies must be developed in appropriate balance

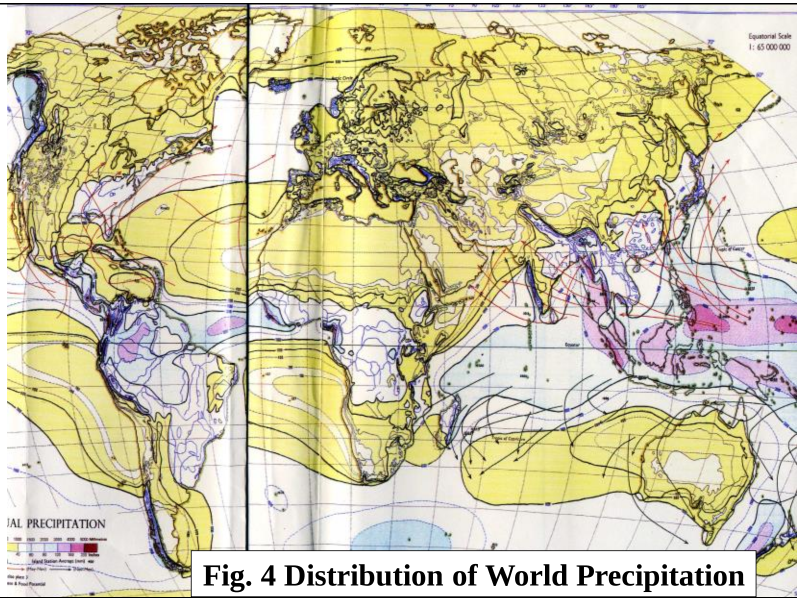
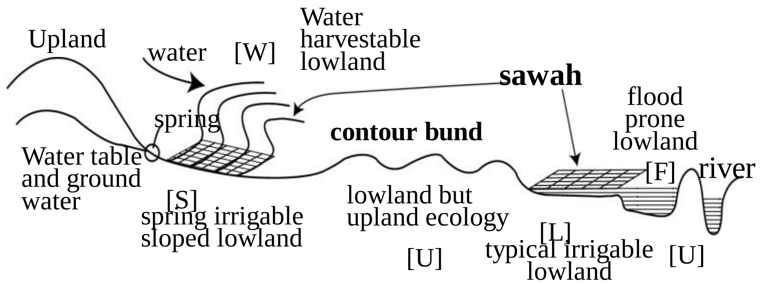


Fig. 4 Distribution of World Precipitation



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]

Fig.5 : 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

Table 2 Distribution of lowlands and potential irrigated sawah in SSA (Hekstra, Andriesse, Windmeijer 1983 & 1993, Potential Sawah area estimate by Wakatsuki 2002,2012)

Classification	Area (million ha)	Area for potential irrigated 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 can be high priority,such as Sokoto, Kebbi, Yobe and Borno where personal pump irrigated sawah is efficient

Note 2. Estimated potential sawah area is 3million ha (annual paddy production 12 million ton) in Nigeria and 20 million ha in Sub Saharan Africa (SSA). Estimated area came from the relative amount of water cycle in monsoon Asia, which has 130 million ha sawah. However, if innovative technology will be developed, 5 and 50 million ha of sawah can be developed in Nigerian and SSA, respectively in future.

Left: Large scale irrigated sawah system at Mwea, Kenya, 5860ha (potential 8000ha). **Right:** Small scale irrigated sawah at Tema, Accra, Ghana, 50ha (potential 100ha). Both sites have been received continious huge ODA support since 1960. Both have problems in terms of cost-effectiveness, sustainable management, and endogeneous development, Google earth, 2009 and 2010

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

	Large-scale development	Small-scale development	Sawah 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)	600–800	600–800	400–600	200–300
Farmer participation	Low	Medium–High	High	High
Project ownership	Government	Government	Farmer	Farmer
Adaptation of technology / **Technology transfer**	Long, difficult	Medium to short difficult	Medium to short, needs intensive demonstration and on-the-job training (OJT) program Easy	Few technology transfer
Sustainable development / **Managment**	Low(heavy machinery used by contractors in development) Difficult	Low to medium Difficult	High (farmer-based and small power-tiller used in development and management) Easy	Medium
Adverse environmental effect	High	Medium	Low	Medium

† **Assuming 1 ton paddy is worth US$ 500; one power-tiller costs $3000-9000 in West Africa depending on the brand quality and accessories (2009 values). Selling prices, however, are $1500-$3500 for farmers in Asian countries.**

Site Specific and farmers' personal irrigated Sawah systems to realize green revolution in Africa

(Farmers self-support efforts is the Key)

Upper: May 1999, Biemso No1, Ghana, Lower: August 2000, the same site above. During the year in 1999-20, 2 ha sawah development claimed 2seasons in 2 years. The irrigated sawah area expaned to 10 ha by 2009

Upper: August 2009, Sokwae, Ghana. The center is a leading farmer and his both sides are Sawah staffs at Crops research Insititute, Ghana. Lower: January 2010. 3ha of irrigated sawah was developed within 3 months. Total sawah became 6ha by November 2011

Farmers sawah technology will prepare the platform for the green revolution technologies

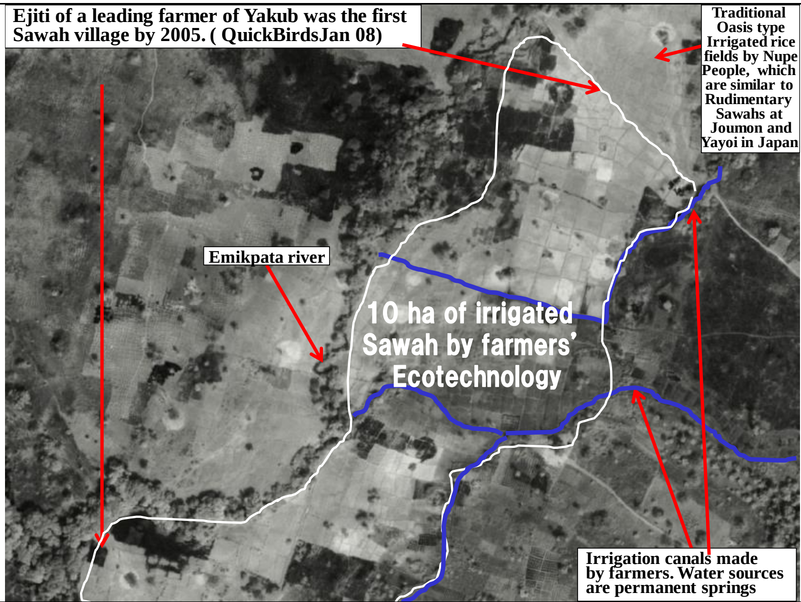
Restoration measure to connect spring water and sawah by irrigation canal and syphon pipes at Adugyama, Mr. Tawiah's site, August 2011


Training on topo-survey NCAM
Power tiller plowing and sawah system bunding based on topography
On the job training
Rice transplanting at sawah plots, which water conditions can be controlled by farmers using bunding, leveling, puddling, water inlet & outlet
Powertiller assisted leveling


Upper Makuridi, Benue
Lower, Asaba, Delta


Kebbi, Arugung demonstration site, Sawah fields: 3 September 2011


International workshop on sustainable sawah development by farmers' self-support efforts was organized at Kumasi, Ghana in collaboration with Agric. ministries of Ghana & Nigeria, JIRCAS-Japan, AfricaRice and our Sawah project. Now leading farmers can develop 5-10ha of new sawah fields within 1-2 years and produce 20-50 ton of paddy per year (Nov. 2011)
Bush lowland changed to 10 ha of irrigated Sawah by farmers' Ecotechnology
On the job training has expanded to the staffs of AfricaRice, Togo and Benin on various skills of sawah eco-technology (Afari, Ghana, Nov.2011)
Small pump based Oasis type sawah development at savanna floodplain performed paddy yield 7t/ha at Jega, Kebbi state, Nigeria(May 2011)



Japanese Inland Valley Watersheds (SATO-YAMA) : Integration of Forest, Pond and lowland Sawah in watershed, Boso Penisula

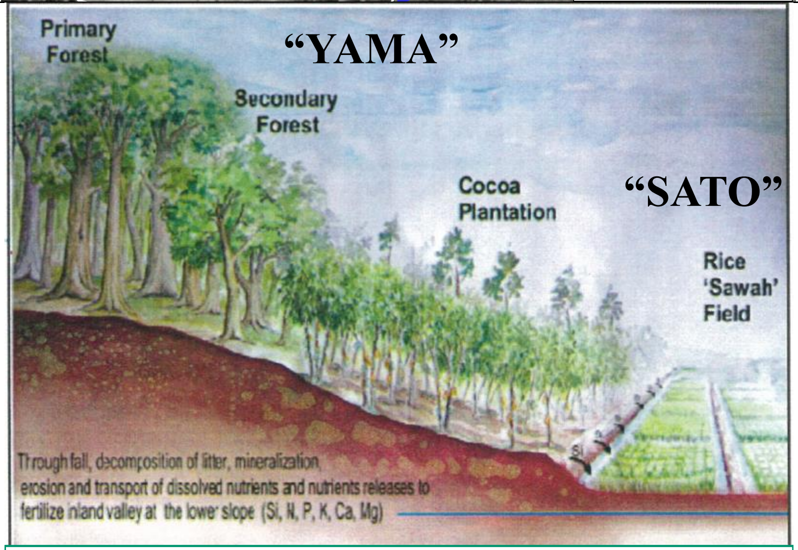


Figure 6. One Example of Africa SATO-YAMA Concept Map by Dr. Owusu, FoRIG, Ghana which is a watershed agro-forestry applicable to Cocoa belt region in West Africa.

Submerged sawah: Multi functional ecosystems of various interaction between Rice, Algae, Fish, Goose, microbes, and others

Left :nitrogen fixing Azola

Four Skills of Sawah Ecotechnology Innovation to Develop Farmers Personnel Irrigated Sawah Systems to Realize Green Revolution

(1) Site Selection Points & *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 Flooging measueres
(f) 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 selection

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 per 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.

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

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

<u>Sustainable green revolution by sawah and SATOYAMA systems for combating Global warming</u>: (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.

<u>Micro-scale eco-technological mechanisms to support Sawah hypothesis 2:</u> 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.

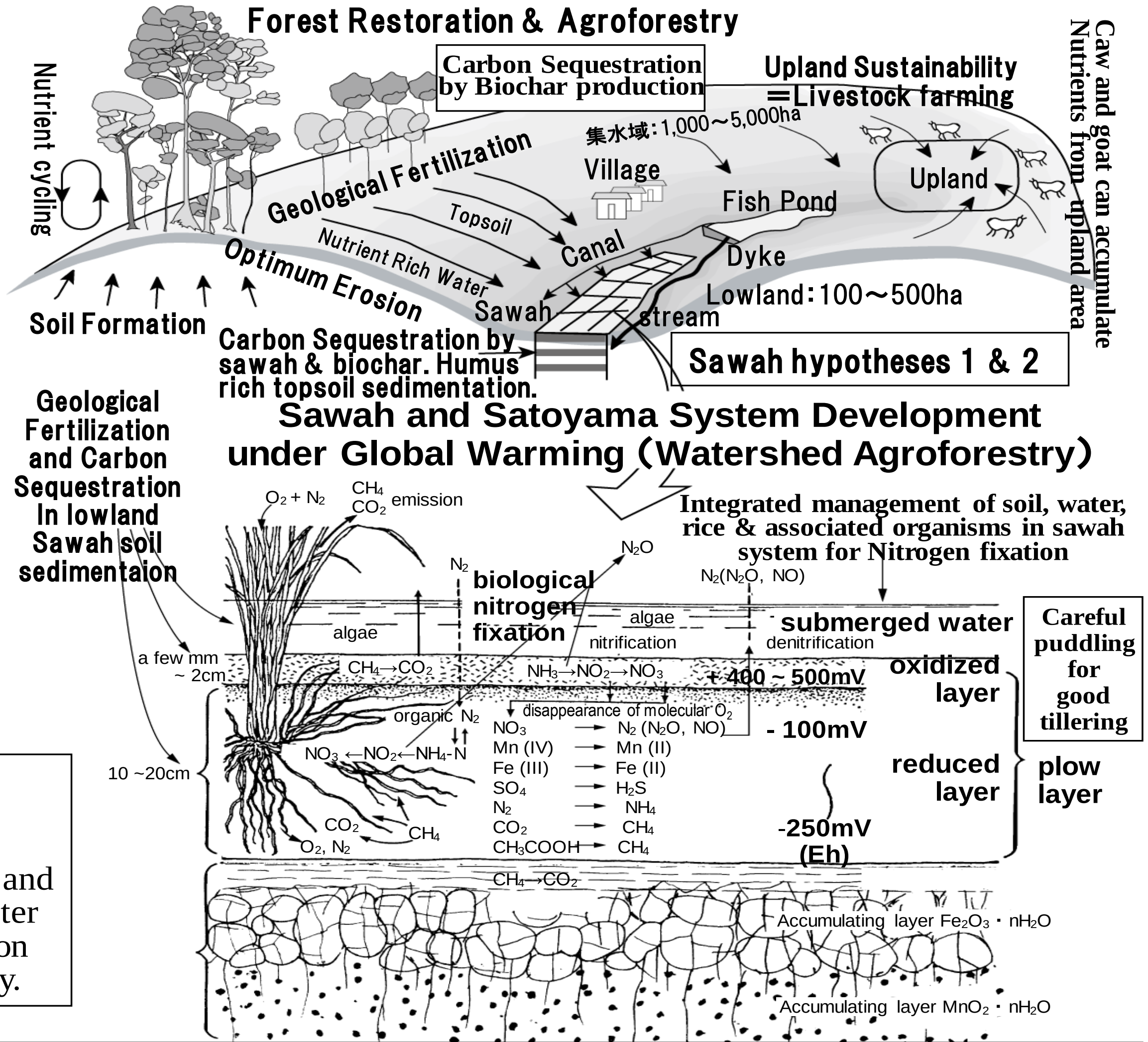


Fig 3. Sawah hypothesis 2 of multifunctionality & creation of African SATOYAMA (or Watershed Agroforestry) systems to combat food crisis and global warming.

Multi Functionality of Sawah Systems

I. Intensive, diverse and sustainable nature of productivity

(1) Weed control is the most important function of Sawah system

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

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

(4) pH neutralizng 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

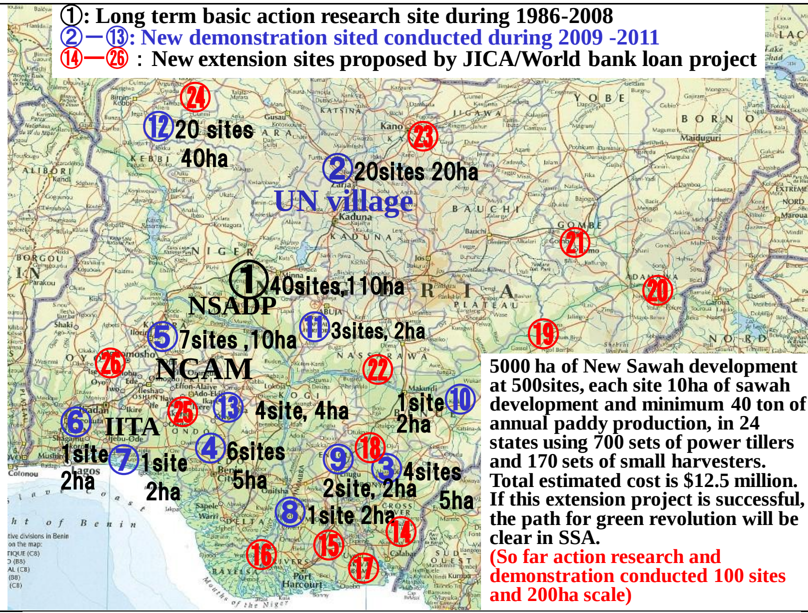
(3) Sawah systems as to control flooding & soil erosion and to generate electricity

(4) Denitrification of nitrate polluted water

III. To create cultural landscape and social collaboration

(1) Terraced sawah as beautiful cultural landscape

(2) Fare water distribution systems result in collaboration and fare society



5000 ha of New Sawah development at 500sites, each site 10ha of sawah development and minimum 40 ton of annual paddy production, in 24 states using 700 sets of power tillers and 170 sets of small harvesters. Total estimated cost is $12.5 million. If this extension project is successful, the path for green revolution will be clear in SSA.
(So far action research and demonstration conducted 100 sites and 200ha scale)

Sawah Ecotechnology: ODA Disruptive Innovation to Realize Endogenous Green Revolution in African

1. Lower Anambra, Nigeria : Total 22 billion Yen, ≒$100million, 17 billion was Yen loan. Huge pump irrigation of 3850ha developed by Japanese companies, full mechanization during 1981-1989. JICA grant for technical cooperation,1989-1993. High development cost $30,000/ha, Malfunction of both irrigation & mechanization since 1993. Both management and endogenous development are difficult.

2. Mwea, Kenya: 3000ha of new irrigation and 5860ha of rehabilitation during 2011-2016, 14 billion Yen loan, including planning consultant cost 0.7billion Yen in 1993-1996. Technical cooperation in 1989-1998 with 4billion Yen grant for rehabilitation of 5860ha. High development cost >$20,000/ha and management. Difficult endogenous development.

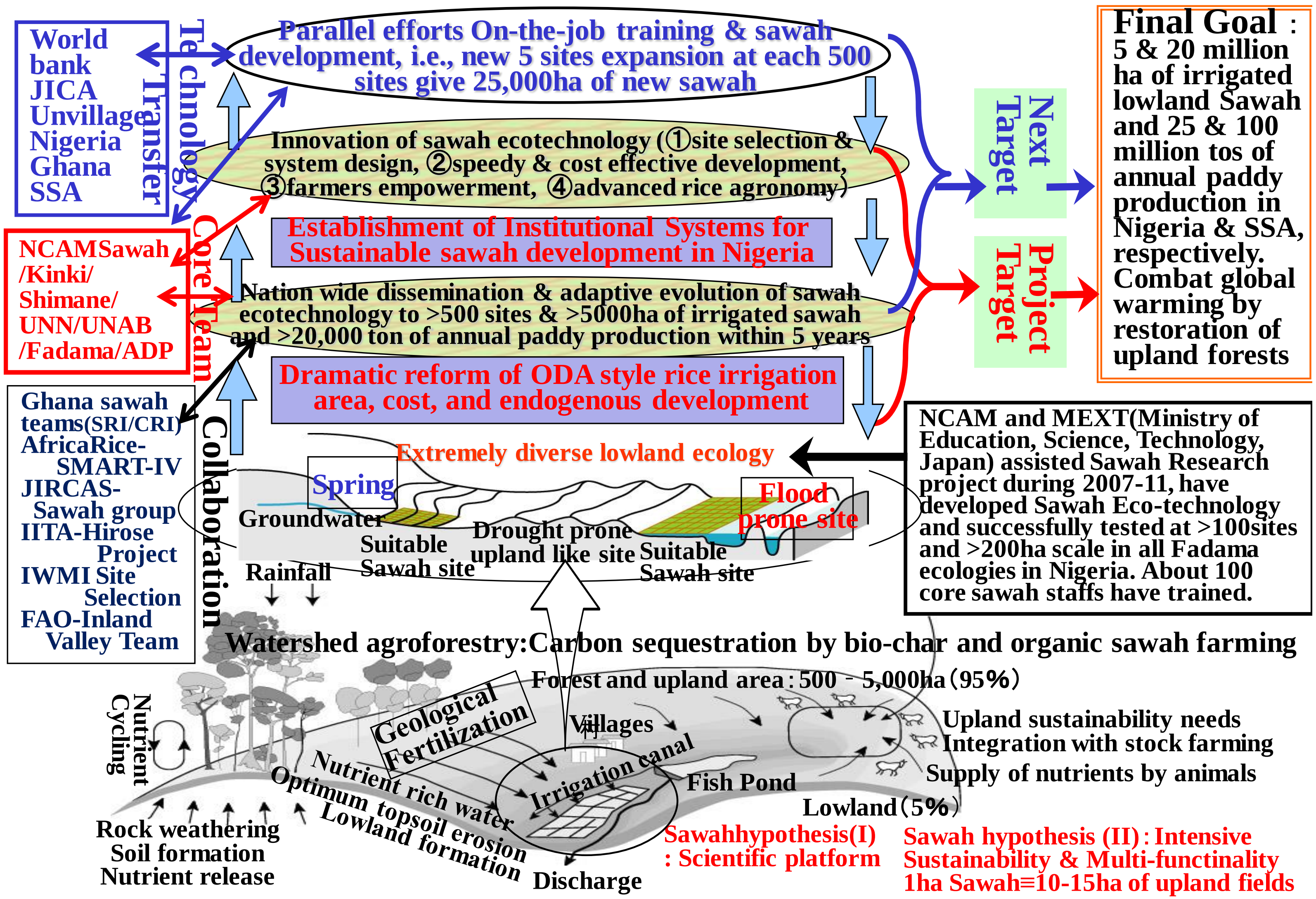
3. Ashaiman & Okyereko, Ghana : Small scale irrigation project. Rehabilitation of 137ha and technical cooperation using 2 billion yen grant during 1997-2006. Malfunction in 2011. The site was originally developed by Taiwan team in 1960s. High development cost $50,000/ha and difficult endogenous development.

The target of improvement of ODA projects by the application of Sawah Technology

4. Investment of Private Company, Government of Nigeria, or Proposal JICA 1billion Yen loan (≒$12.5million) for 5000 ha of irrigated sawah development within 5 years by Sawah Ecotechnology : 100-500 core sites, each 50-10ha sawah development. Total 5,000ha, >20,000 ton of annual paddy production, which is equivalent to $10million/year within 5 years. 700 sets of powertillers and 170 sets of small harvesters, $3 and $ 2 million (soft loan to farmers) respectively, Development logistics $ 2.5 million, Vehicle $ 1.5 million, training $ 2.5 million, Project management & consultancy $ 1 million, Development cost $2500/ha. Since core sites attract >3-5 new sites, thus total 1500-2500 new sites of >15000-25000ha of sawah by 2018. Thus sawah will expand with acceleration.

5. Half million ha of Sawah development during 2019-2028: Africa wide dissemination.
6. 5-10 Millions ha of Sawah development during 2029-2050: African wide rapid expansion and Realization of African Rice Green Revolution

Nupe village of Sheshi Bikum: 3 ha of sawah was developed in three months in 2010 using one powertiller of sawah project. Paddy production was about 13 ton, which is equivalent to $5000. Sawah farmers group bought additional powertiller of $3000. Sawah area expanded to 40ha by January 2012.



Overall Project Concept: Rice Green Revolution by Endogenous Sawah Eco-technology Dissemination and Nigeria Sawah Development Centre (NiSADEC)