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 Ecotechnology 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 ④simultaneous progress of sawah development, capacity building and technology transfer from farmers to farmers.
Why variety, fertilizer and irrigation technologies can not work in farmers' rice field in Africa?

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

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 Sokwae, Kumasi, Ghana Three Green Revolution technologies can’t apply

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

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

**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)**

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

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)

<table>
<thead>
<tr>
<th>Entry No.</th>
<th>Cultivar</th>
<th>Irrigated Sawah</th>
<th>Rainfed sawah</th>
<th>Upland like fields</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HIL</td>
<td>LIL</td>
<td>HIL</td>
<td>LIL</td>
</tr>
<tr>
<td>1</td>
<td>WAB</td>
<td>4.6</td>
<td>2.9</td>
<td>2.8</td>
</tr>
<tr>
<td>2</td>
<td>EMOK</td>
<td>4.0</td>
<td>3.8</td>
<td>3.9</td>
</tr>
<tr>
<td>3</td>
<td>PSBRC34</td>
<td>7.7</td>
<td>3.5</td>
<td>7.6</td>
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<tr>
<td>4</td>
<td>PSBRC54</td>
<td>8.0</td>
<td>3.7</td>
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<td>5</td>
<td>PSBRC66</td>
<td>5.7</td>
<td>3.3</td>
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<tr>
<td>6</td>
<td>BOAK189</td>
<td>7.2</td>
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</tr>
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<td>7</td>
<td>CT9737</td>
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<td>4.0</td>
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<td>4.0</td>
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<td>11</td>
<td>WITA34</td>
<td>7.7</td>
<td>4.1</td>
<td>7.7</td>
</tr>
<tr>
<td>12</td>
<td>C123CU</td>
<td>6.9</td>
<td>4.0</td>
<td>6.9</td>
</tr>
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<td>6.5</td>
<td>4.0</td>
<td>6.5</td>
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<td>7.3</td>
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<td>7.6</td>
<td>4.0</td>
<td>7.6</td>
</tr>
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<td>7.5</td>
</tr>
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</tr>
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<td>23</td>
<td>WITA06</td>
<td>7.5</td>
<td>3.8</td>
<td>7.5</td>
</tr>
<tr>
<td>Mean (n=23)</td>
<td></td>
<td>7.2</td>
<td>3.8</td>
<td>7.1</td>
</tr>
</tbody>
</table>

Because of cost of green revolution technology, yield must be higher than 4t/ha
Sawah is a man-made, improved rice-growing environment with demarcated, bunded, leveled, puddled fields and smoothed surface. Both Bio- & Eco-technologies must be developed in appropriate balance. Varieties could solve the main problems in Asia. Is this also true in SSA? No! last 40 years experiences. Water in (irrigation) Water out (drainage) Sawah is a man-made, improved rice-growing environment with demarcated, bunded, leveled, puddled fields and smoothed surface.

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

Bio-technology and Eco-technology
Breeding to improve Variety Sawah to improve Ecology & Environment

Good Variety Good Sawah
Good Yield Good Tilling & Grain
Good Puddling Soft&low Bulk density topsoil
Good Sawah

Good weed competition
Good rooting, nutrient supply & Water saving
Good Water control

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

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)

<table>
<thead>
<tr>
<th>Classification</th>
<th>Area (million ha)</th>
<th>Area for potential irrigated sawah development</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coastal swamps</td>
<td>17</td>
<td>4-9 million ha (25-50%)</td>
</tr>
<tr>
<td>Inland basins</td>
<td>108</td>
<td>1-5 million ha (1-5%)</td>
</tr>
<tr>
<td>Flood plains</td>
<td>30</td>
<td>8-15 million ha (25-50%)</td>
</tr>
<tr>
<td>Inland valleys</td>
<td>85</td>
<td>9-20 million ha (10-25%)</td>
</tr>
</tbody>
</table>

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 3 million 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.
Large scale irrigated sawah system at Mwea, Kenya, 5860ha (potential 8000ha). Both sites have been received continuous huge ODA support since 1960. Both have problems in terms of cost-effectiveness, sustainable management, and endogeneous development, Google earth, 2009 and 2010.

Small scale irrigated sawah at Tema, Accra, Ghana, 50ha (potential 100ha). Both sites have been received continuous 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 systems in inland valleys of Ghana and Nigeria.

<table>
<thead>
<tr>
<th>Development cost ($/ha)</th>
<th>Large-scale development</th>
<th>Small-scale development</th>
<th>Sawah technology</th>
<th>Traditional system</th>
</tr>
</thead>
<tbody>
<tr>
<td>10000–30000</td>
<td>10000–30000</td>
<td>1000–3000</td>
<td>30–60</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield (t/ha)</td>
<td>4–6</td>
<td>4–6</td>
<td>4–6</td>
<td>1–2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Running cost, including machinery ($/ha)</th>
<th>600–800</th>
<th>600–800</th>
<th>400–600</th>
<th>200–300</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farmer participation</td>
<td>Low</td>
<td>Medium–High</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Project ownership</td>
<td>Government</td>
<td>Government</td>
<td>Farmer</td>
<td>Farmer</td>
</tr>
<tr>
<td>Adaptation of technology</td>
<td>Long to medium</td>
<td>Medium to short</td>
<td>Medium to short</td>
<td>Easy</td>
</tr>
<tr>
<td>Technology transfer</td>
<td>difficult</td>
<td>difficult</td>
<td>Medium to short</td>
<td>Few technology transfer</td>
</tr>
<tr>
<td>Sustainable development</td>
<td>Low (heavy machinery used by contractors in development)</td>
<td>Low to medium</td>
<td>High (farmer-based and small power-tiller used in development and management)</td>
<td>Medium</td>
</tr>
<tr>
<td>Management</td>
<td>Difficult</td>
<td>Easy</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td>Adverse environmental effect</td>
<td>High</td>
<td>Medium</td>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

† 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 1999–20, 2 ha sawah development claimed 2seasons in 2 years.
The irrigated sawah area expanded 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 Institute, Ghana. Total sawah became 6 ha by November 2011.

Facing page: 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.
Rice transplanting at sawah plots, which water conditions can be controlled by farmers using bunding, leveling, puddling, water inlet & outlet.

Powertiller assisted leveling

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 savannau floodplain performed paddy yield 70ha at Jega, Kebbi state, Nigeria May 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).

Upper Makuridi, Benue Lower, Asaba, Delta

ADEMILUYI, YINKA SEGUN
Upper Makuridi, Benue
Lower, Asaba, Delta

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

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Lower, Asaba, Delta

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

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)
Ejiti of a leading farmer of Yakub was the first Sawah village by 2005. (QuickBirds Jan 08)

Irrigation canals made by farmers. Water sources are permanent springs.

Traditional Oasis type. Irrigated rice fields by Nago People, which are similar to Rudimentary Sawahs at Jomon and Yayoi in Japan.

10 ha of irrigated Sawah by farmers. Ecotechnology.

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

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

“YAMA”

“SATO”

Left: nitrogen fixing Azola

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.
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
Bunding quality & Mgt.
Drought and Flooding measures
(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

(2) Efficient & Low cost Sawah Development: Skill & Technology
(a) Skills for bush clearing & de-stumping
(b) Skills for bunding, canal construction and treatment
(c) Cost for hired labors, tools, power tiller purchasing and management
>10ha of development/3-5 years using one power tiller
Purchasing $3000-5000/10ha
Running $2000-3000/10ha
Tools & materials $1000/10ha
(d) 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

(3) Socio-Economic Skills for Rice farmers empowerment
(a) Group organization & leading farmers training
(b) Training of powertillers
attested sawah development & sawah based rice farming
(c) Post harvest technology
using small harvesters of $10,000 per set if sawah area
>25ha & paddy production >20ton 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 systems
(b) Management of bunding & leveling
(c) Water Management of sawah
depth of water irrigation timing
(d) Puddling skills
(e) Skills of Nursery & trans-planting
(f) Weed, pests, and birds Management.
(g) Management of Fertilizers, nutrient & organic matters
(h) Variety selection & Management
(i) Achievement of targeted yield

(1) Immediate target: Paddy yield >4t/ha,
>20ton paddy Powertiller
(2) >50t paddy/year
/powertiller will accelerate sawah Development
(3) Basic research on sustainable
paddy yield >10t/ha
is important

Sawah technology can reform traditional ODA based
development: Farmers to farmers technology transfer sites >> sites of extension officers >> researchers’ demonstration sites >> Traditional ODA.
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 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 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
(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

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


3. Ashaiman & Okyereko, Ghana: Small scale irrigation project. Rehabilitation of 137ha and technical cooperation using 2 billion yen grant during 1997-2000. Malfunction in 2011. The site was originally developed by Taiwan team in 1960s. High development cost $50,000/ha and difficult endogenous development.

4. Investment of Private Company: Government of Nigeria, or Proposal JICA (4 billion yen loan) for 5000 ha of irrigated sawah development within 5 years by Sawah Ecotechnology: 100-500 core sites, each 50-100ha 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 $25000/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.

6. 5-10 Million ha of Sawah development during 2029-2050: African wide rapid expansion and Realization of African Rice Green Revolution

Thanks
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.
Suitable Sawah site
Drought prone upland like site
Nation wide dissemination & adaptive evolution of sawah ecotechnology to >500 sites & >5,000 ha of irrigated sawah and >20,000 ton of annual paddy production within 5 years

Innovation of sawah ecotechnology

① site selection & system design,
② speedy & cost effective development,
③ farmers empowerment,
④ advanced rice agronomy

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