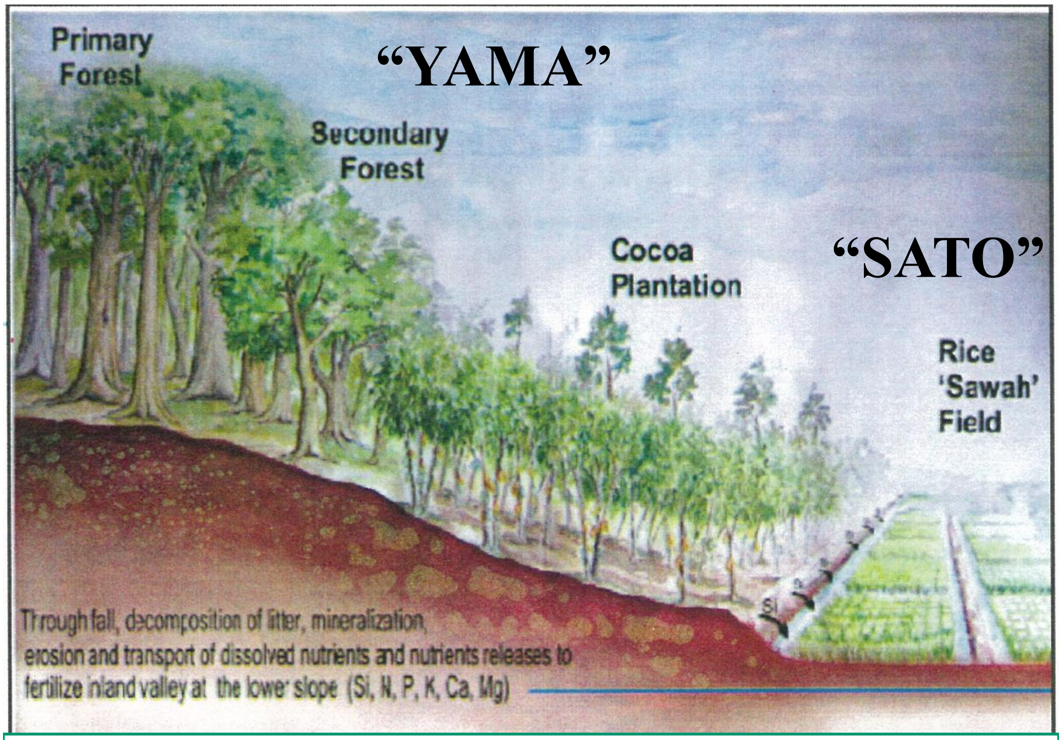


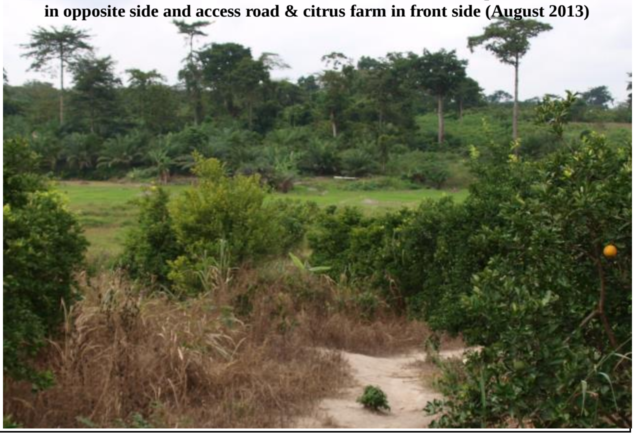
Figure 16. One Example of Africa SATO-YAMA Concept Map by Dr. Owusu, FoRIG, Ghana which is a watershed agro-forestry applicable to Cocoa belt region in West Africa.

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:

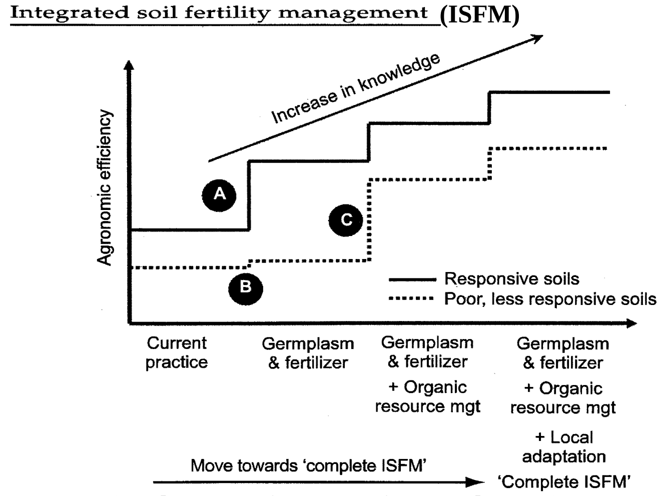
To improve varieties through breeding, i.e., Genetic improvement. Target is DNA improvement.

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

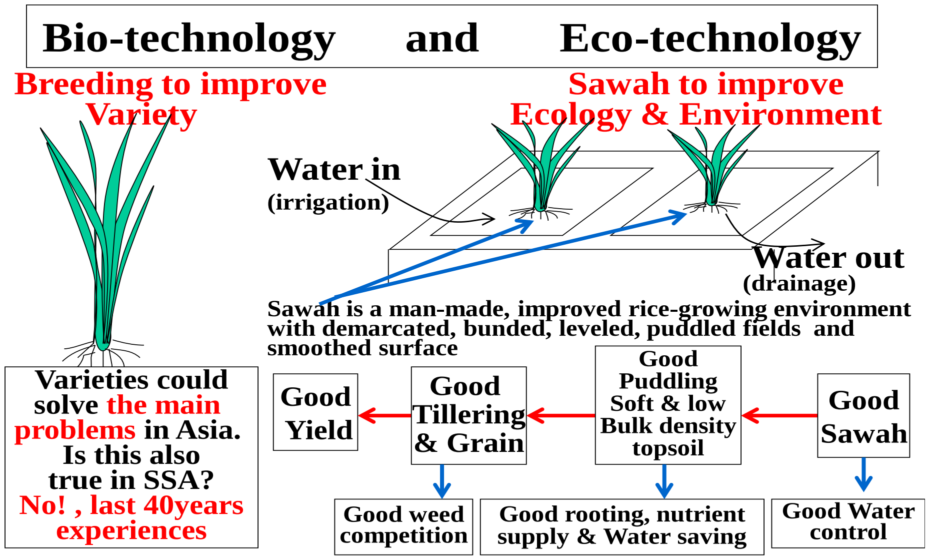


Fig 18. Rice (variety) and environment (Sawah) improvement. Both Bio & Eco-technologies must be developed in appropriate balance

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.

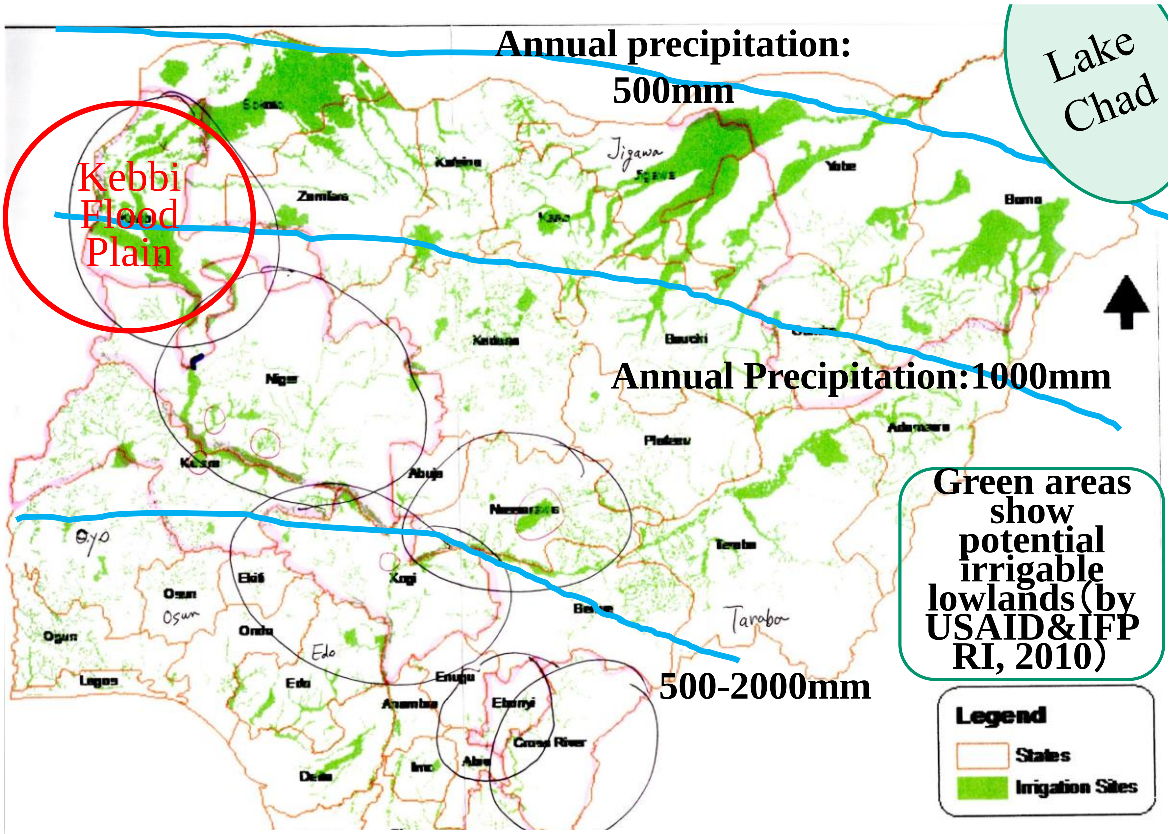


Fig.19. Major lowlands distribution in Nigeria (USAID and IFPRI, 2010)

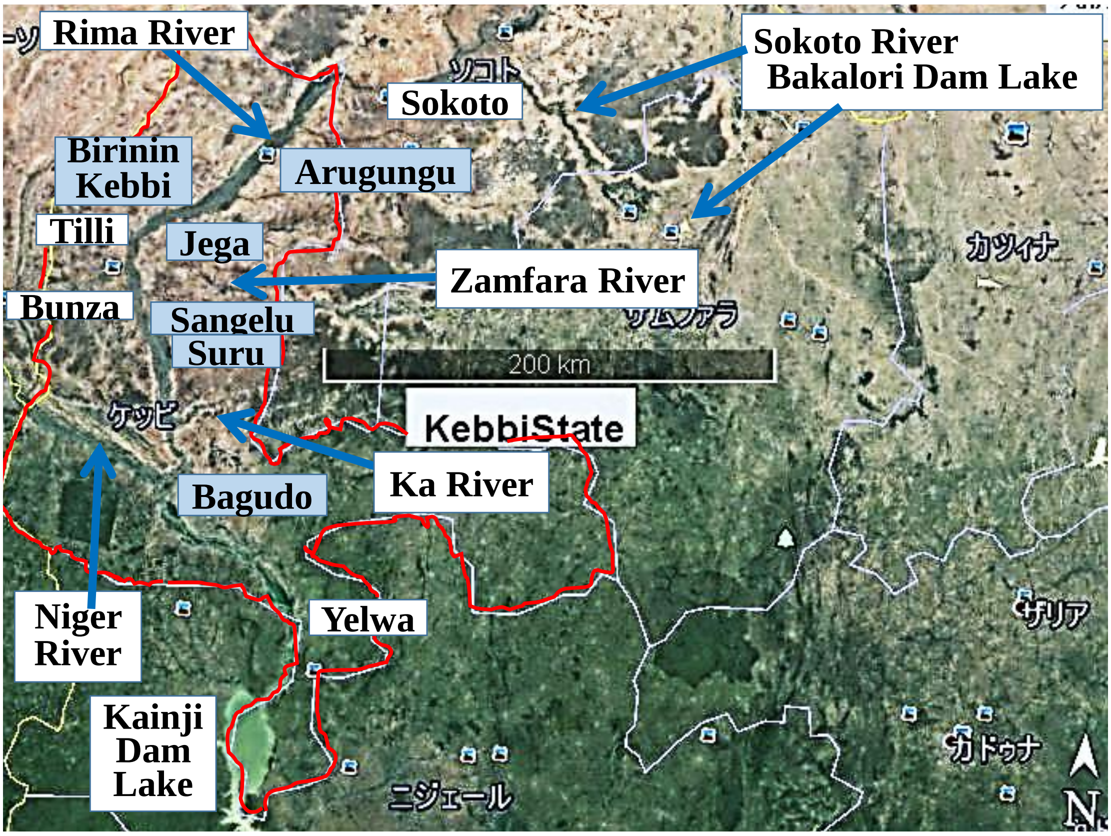


Figure 20. Google Earth of Major Flood plains of Kebbi State, Nigeria. Total Area is estimated 0.4-0.5 million ha. Sawah Technology training and demonstration in collaboration with Fadama III under the World Bank project had done at 6 regions of Argungu, Birinin Kebbi, Jega, Sangelu and Bagudo during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

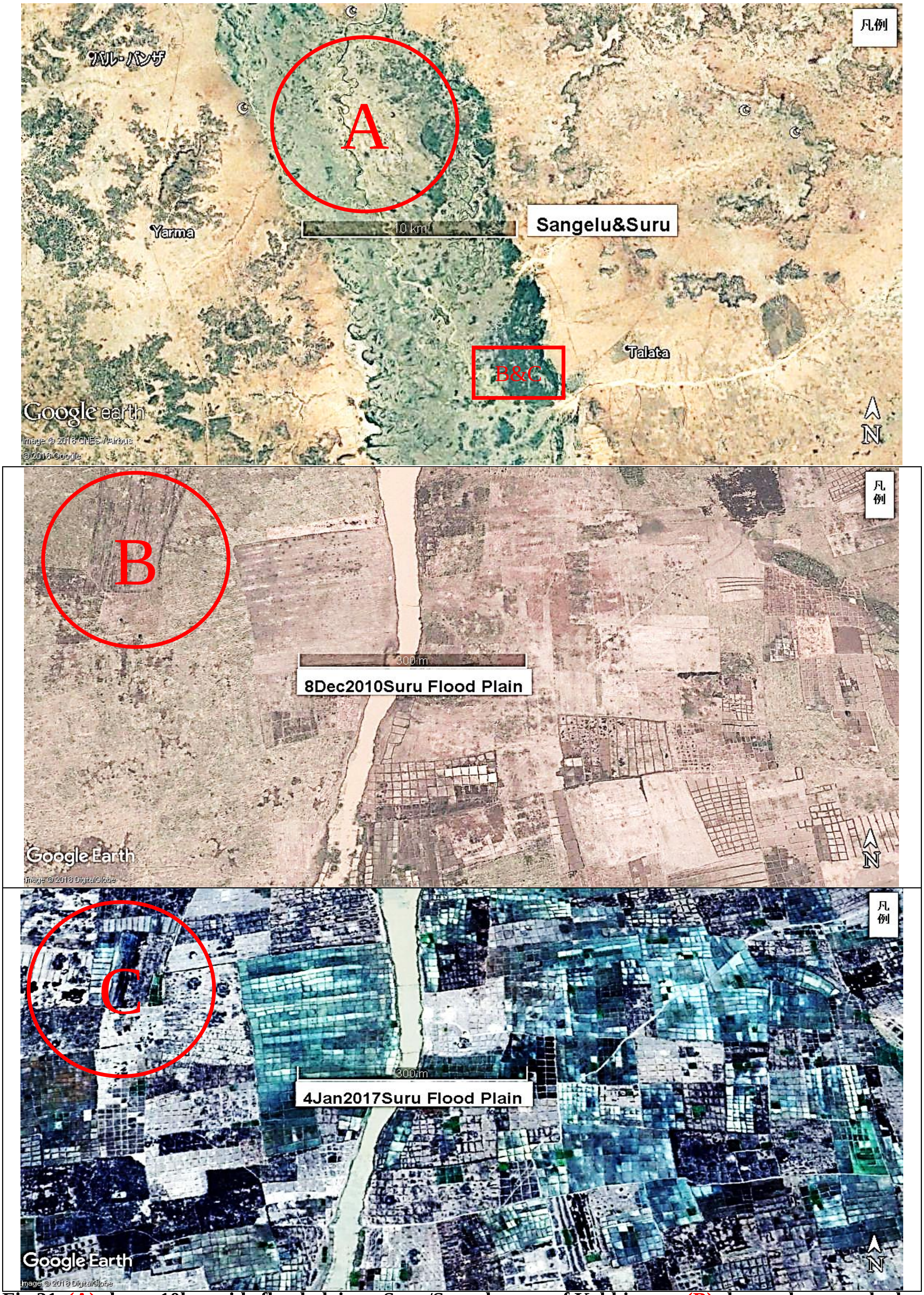


Fig.21. (A) shows 10km wide flood plain at Suru/Sangelu area of Kebbi state. (B) shows photographed in December 2010, before training and (C) shows in January 2017, after sawah technology training. Location of (B) and (C) are the same. Numerous sawah plots were developed by farmers during 2011-2017.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

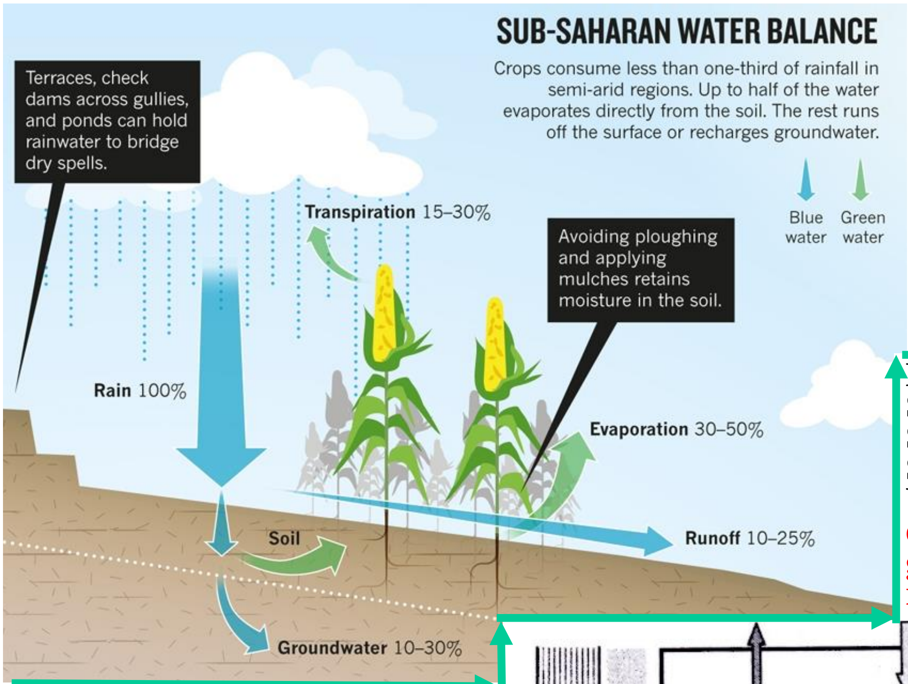
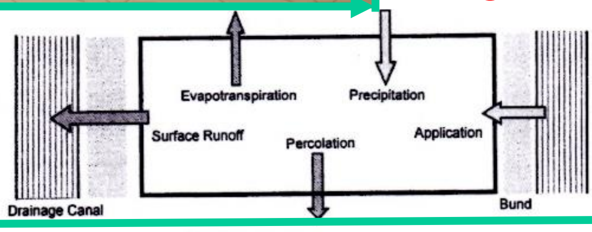


Fig. 22 Upland Strategy for Improve water Cycling by

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.

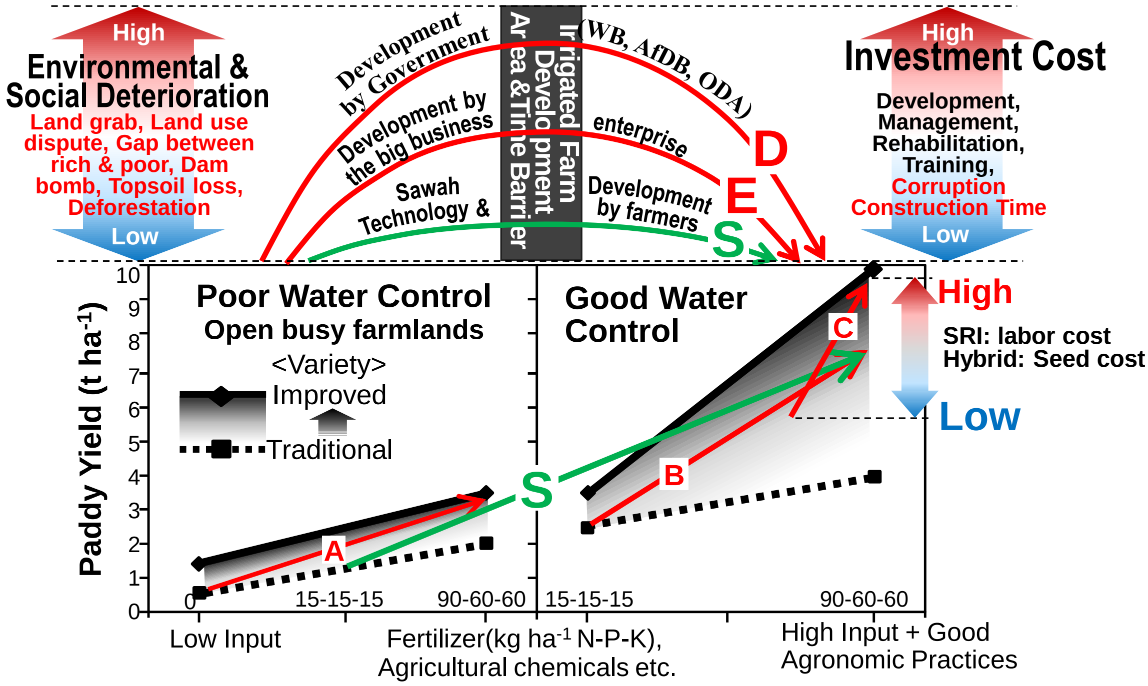


Figure 23. Six Strategies to Increase Paddy Yield and Production in SSA

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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