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Sawah Technology (4Paper): Practices and Potential of Irrigated *Sawah* System Development and *Sawah* Based Rice Farming by Farmers' Self-help Efforts

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Contents

(Note on this paper)

Although major part of the *sawah* technology described in this manual paper had published for targeting "Inland valley ecology" in the following ①-③proceedings by 2013, **the *sawah* technology has evolved possible to cover "flood plain and inland basin/delta ecology" after the success of "Kebbi rice revolution" in Nigeria during 2011 to 2017 as well as "Chad basin, the biggest wetlands in Africa" for empowering returnees/refugees by *sawah* technology at Salamat state, Chad, during 2015-2017". Thus these recent ongoing activities were included in this revised paper.** ①The First International Workshop on "*Sawah* Eco-technology and Rice Farming in Sub-Saharan Africa", November 22–24, 2011, Kumasi-Ghana (2012). Some parts of this paper are published in ② the proceedings of the 1st, 2nd,and 3rd International Conference on Rice for Food, Market, and Development (rice-Africa), Abuja, Nigeria March 3–5, 2011, March 5-7, 2013 and May 6-8, 2014 as well as ③the 1st, 2nd and 3rd Africa Rice Congress, Dar es Salaam, Tanzania, 31 July-4 August, 2006, Bamako, Mali, March 22–26, 2010, and Yaounde, Cameroon, October 24-27, 2013.

1. Abstract

Among the 240 million hectares (ha) of vast wetlands in Sub-Saharan Africa (SSA), the estimated potential area is about 20%, 50 million ha (40 million ha for irrigated area and 56 million ha for annual rice harvested area respectively), because of hydrological limitations. This potential will be one of the biggest challenging frontiers for our global society by 2050. If the potential harvested area of 50 million ha of *sawah* with paddy yield 5 t/ha are realized, the annual paddy production will be 250 million tons for one billion people, which give us time before to stabilize population explosion. The *sawah* technology is effective in all types of lowlands in SSA, i.e., small inland valleys, flood plains, inland basins/deltas and coastal deltas.

The site-specific farmers' personal irrigated *sawah* system development and *sawah* based rice farming (*sawah* technology) offers efficient and endogenous development with low-cost rice intensification of sustainable paddy yield at least 4–6 t/ha. If sawah type infrastructure is available and if we apply improved agronomic practices such as System Rice Intensification (SRI) or any other advanced agronomic practices, the paddy yield can reach higher than 10t/ha. However, African wetlands are quite diverse and different from Asian wetlands in terms of hydrology, topography, soil, and socio-economic-historical settings. Therefore careful site-specific *sawah* development and management technologies must be researched, developed, and disseminated with continuous improvement and evolution (*Kaizen*) through trial and error processes. For the sustainable development and management of *sawah* systems by local farmers, self-propelled efforts and small-scale machineries such as power tillers are necessary. The *sawah* technology was successfully tested, demonstrated, and evolved during 1997 to 2017 in Nigeria and Ghana as well as Togo and Benin, especially in locations where appropriate sites were selected and trained lead farmers were backstopped by *Sawah* technology experts properly.

This manual paper described practices on four components of skills of *sawah* technology to achieve successful dissemination and evolution of sawah systems for rice green revolution: (1) site and appropriate time selection and site-specific *sawah* system design, (2) skills for efficient and cost-effective *sawah* system development using small machineries, such as power tiller, (3) rice farmers' socio-economic empowerment for sustainable and endogenous development and management of *sawah* systems, and (4) *sawah*-based rice farming to realize a sustainable paddy yield at least 4t/ha and 20-75 ton of annual paddy production per one set of power tiller within three years after the initiation of new *sawah* development. This will empower numerous 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. Since investment cost of 5ha of sawah will be $5000-$15000 and annual profit will be $2500-$15000, the investment can recover within 2-3 years. This can compare 10-30years of private business enterprises and ODA based development. 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 may be still necessary.

Since rice farmers have to master relatively wide range of skills, intensive on-the-job training is very important. Once mastered, however, the skills can be transferred from farmers to farmers. Thus it will be relatively easy to scale up the successes likes at Kebbi state and Bida of Niger state to nationwide of Nigeria and at Ashanti region and Volta region to full Ghana, Benin and Togo as well as West Africa and SSA to realize rice green revolution.

2. Potential of Irrigated sawah system development in Sub Saharan Africa (SSA)

As we described in a separate companion paper on "*Sawah* technology (3Paper & 3PPt) Principle: Sawah hypotheses (I) the platform for scientific technology evolution, Sawah hypothesis (II) the plat form for sustainable intensification through in watershed agroforestry systems (Africa Satoyama systems)" and others published in Sawah technology home page (http://www.kinki-ecotech.jp/, Wakatsuki et al. 1998, Hirose and Wakatsuki 2002, Wakatsuki and Masunaga 2005), *Sawah* system infrastructures and Sawah eco-technology (hereinafter *sawah* technology) have been lacked in majority of Sub-Saharan Africa (SSA). Among the 240 million hectares (ha) of wetlands in SSA (Van Dam and Van Diepen 1982, Andriesse 1986, Windmeijer and Andriesse 1993), about 20% 50 million ha (56 million ha for annual harvest and 40million ha equipped for irrigation) are estimated to be appropriate sites for sustainable irrigated *sawah* system development, of which 9–21 million ha are in small inland valleys, 8–23 million ha in floodplains, 4–9 million ha in coastal deltas, and 5–20 million ha in inland basins/deltas, as shown in Table 1 (Wakatsuki et al. 1998, Hirose and Wakatsuki 2002, Abe and Wakatsuki 2011).

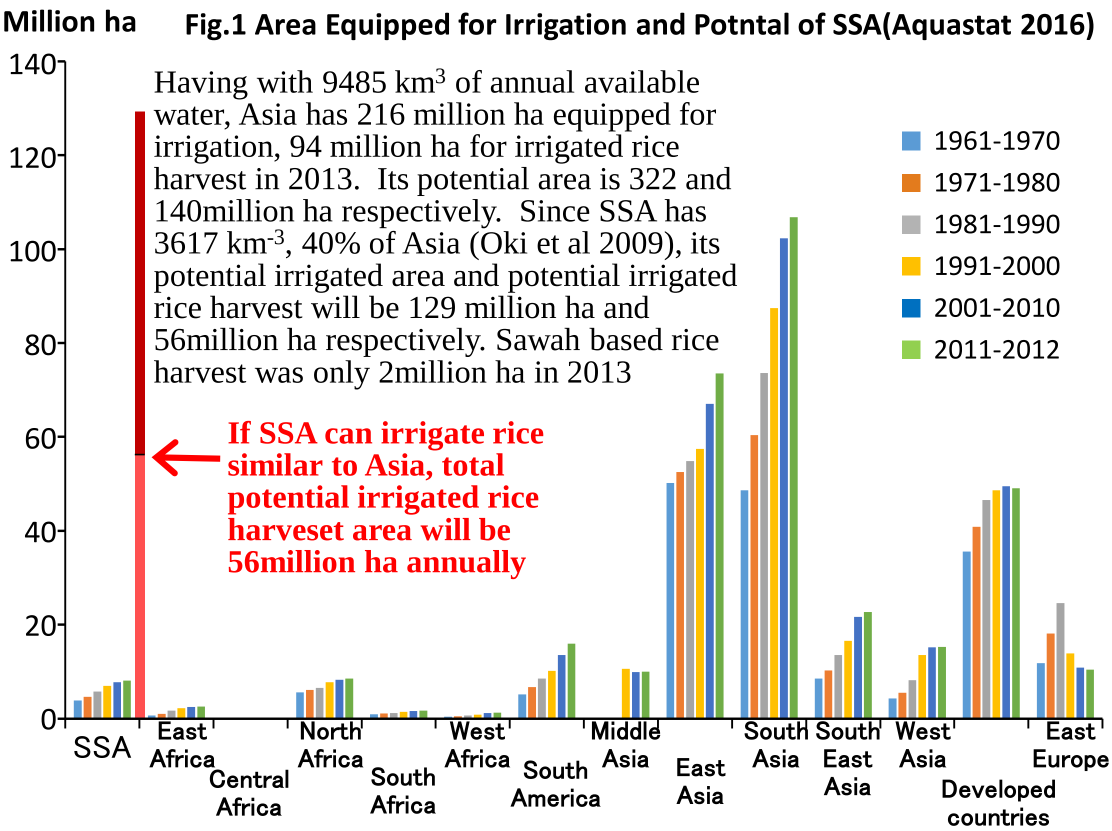
Table 1. Distribution of wetlands and potential irrigated sawah area in Sub Saharan Africa (SSA) (Andriesse 1985, Windmeijer & Andriesse 1993, Potential Sawah area estimate by Wakatsuki 2002 and 2015)

Classification	Area (million ha)	Area for potential irrigated sawah development
Coastal swamps	17	4-9 million ha (25-50%)
Inland basins(deltas)	108	5-20 million ha (5-20%)
Flood plains	30	8-23 million ha (25-75%)
Inland valleys	85	9-21 million ha (10-25%)

Note 1. Although initial priority was small inland valleys because of easier water control, flood plains and inland basins (delta) in Sudan and Guinea Savanna zones should be given priority, such as Kebbi, Jigawa, and Borno in Nigeria and Chad, where wide distribution of shallow ground water (Gleeson et al. 2012, Fan et al. 2013) makes small pump irrigated sawah efficient and soil fertility is high.

Note 2. Estimated potential sawah area and paddy production are 0.5-1 million ha and 2-4 million tons of paddy in Ghana, 3-5 million ha and 12-20 million tons in Nigeria, and 26-73 million ha and 104-292 million tons in SSA. Estimations in Table 1 can be supported by following data, i.e. Asia has 140million ha of potential (94 million ha of sawah rice harvest in 2013) with 9485 km^3 of available water, whereas SSA has 3617 km^3 of water availability (40% of Asia) gives 56 million ha potential harvest area (only 2 million ha sawah rice harvest in 2013) (Oki et al 2009, AQUASTAT 2016, FAOSTAT 2016)

Fig.1 Area Equipped for Irrigation and Potntal of SSA(Aquastat 2016)



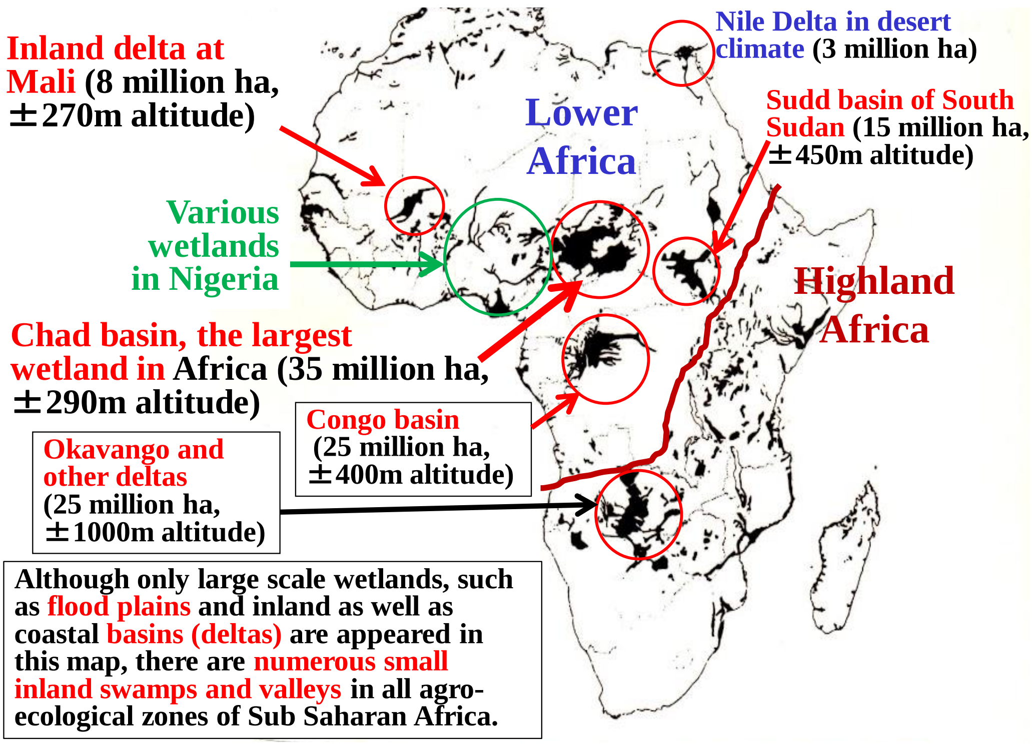


Fig. 2. Distribution of flat wetland soils in Africa (Van Dam and Van Diepen 1982)

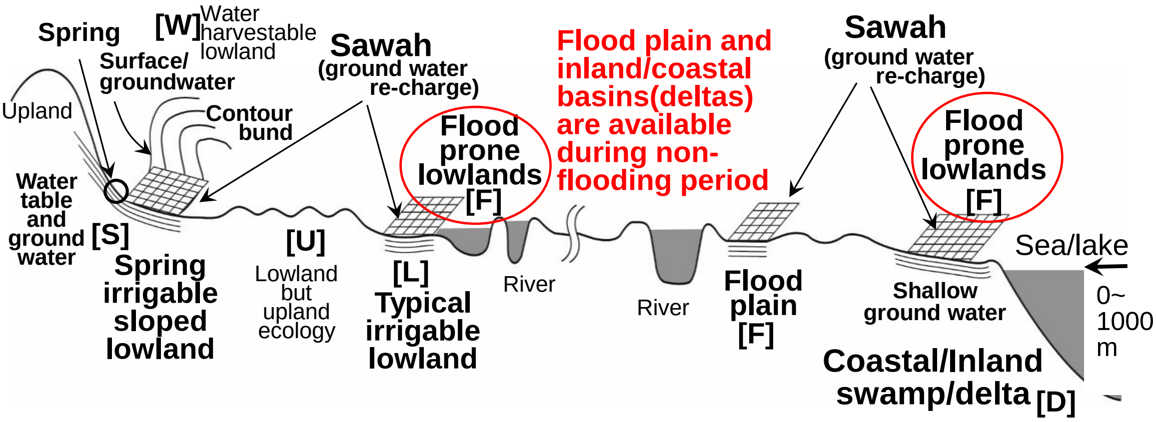
The potential area on inland basins (deltas) is revised considerably in the Table 1, because of recent findings of huge areas with shallow and moderate depth (< 10-20m) of groundwater in savannah zones, stretching from Sudan and Chad basins to Senegal and Mauritania on various altitudes as shown in Fig 1, 2 and 14 (Gleeson et all 2012, MacDonald et al 2012, Fan et al 2013, and Xie et al 2014). Total area range of sawah system development is 26-73 (mean 50) million ha. This estimation of 50 million ha is also supported by the comparison of annual water availability between Asia and Africa, i.e., 9485 km^{-3} water is supporting 137 million ha of sawah based annual rice cultivation area in Asia (mean paddy yield 4.6 t/ha in 2011), thus 3617 km^{-3} of water may support about 50 million ha of both irrigated and rain-fed sawah area in Africa (Oki et al 2009, FAOSTAT 2015). If paddy yield 5t/ha of sawah/crop and this area potential is realized, more than 250 million tons of annual paddy production will be possible in near future by 2050 for one billion people, which give us time before to stabilize population explosion.

3. Characteristics of various wetlands of SSA compared to Asia in relation to irrigated sawah system development

3-1. Characteristics of African wetlands

As shown in Figure 3, appropriateness for *sawah* system development is affected mainly by hydrological and topographical conditions (Hirose and Wakatsuki 2002). Extreme sandy soils (>95% of sand and <3% of clay) are not appropriate because of too rapid water permeability to control water in *sawah* plots. Initially small inland valleys in Guinea savannah zone and rainfall rich tropical forest zones, such as Ashanti in Ghana and Niger state as well as BRACED (Bayelsa, Rivers, Akwa Ibom, Cross river, Edo and Delta) states in case of Nigeria, were given the highest priority for development to apply the *sawah* technology, because controlling small gravitational water is easily done by farmers' own efforts. One of the reasons why the ecology of lowlands in West Africa is so diverse (Jamin and Windmeijer 1995) can be explained partly from Fig. 3-5. Inland valleys and flood plains as well as deltas have various micro-topographies as shown in Fig. 3, of which spring irrigable sloped land and typical irrigable lowland can be developed easily to irrigated *sawah* systems using simple weir and dyke. Many areas of inland valleys that have upland ecology have the lowest priority for sawah development. Water harvestable lowland along the foot slopes (Fig. 3) can be developed as contour bunded sawah systems.

Because of diversity in hydrology, topography, soils, climate, vegetation, and geology as well as socio-economic, cultural and historical conditions, the *sawah* technology must fit into such diverse conditions. As shown in Table 1, the lowland area of SSA is enormous, 240 million ha (Andiresse 1985), because of characteristics of natural environment, particularly scarce water resources (Fig.4), the potential area for sustainable *sawah* development cannot cover all the lowlands of SSA (Table 1). Lowland soil formation by sedimentation of eroded topsoils in SSA is much smaller than in tropical Asia (Fig. 5). This will be a basic ecological limiting factor to develop *sawah* systems in SSA (Table 1).



Diverse irrigation options: Rainfed sawah, sawah to sawah/contour bund water harvesting, spring, dyke, river, pump and shallow tube well, peripheral canal, interceptor canal, tank

Wetland sawah development priority: [S] [L] [F]* [D]* > [W] > [U]
*Even large flood plain and deltas, farmers can practice sawah based rice farming using small water pump and shallow tube wells, except for 2-3 months flood period. Since flood water power of majority of African big rivers are not so destructive, sawah systems developed by farmers can survive under flooded water. Bunded sawah systems can not only recharge ground water, but also contribute to trap eroded fertile topsoil particles in flood water to sustain fertility.

Fig.3. Diverse wetlands/lowlands and targeted sites of sawah technology along topsequence of inland valley, flood plain, and costal/inland delta in SSA.

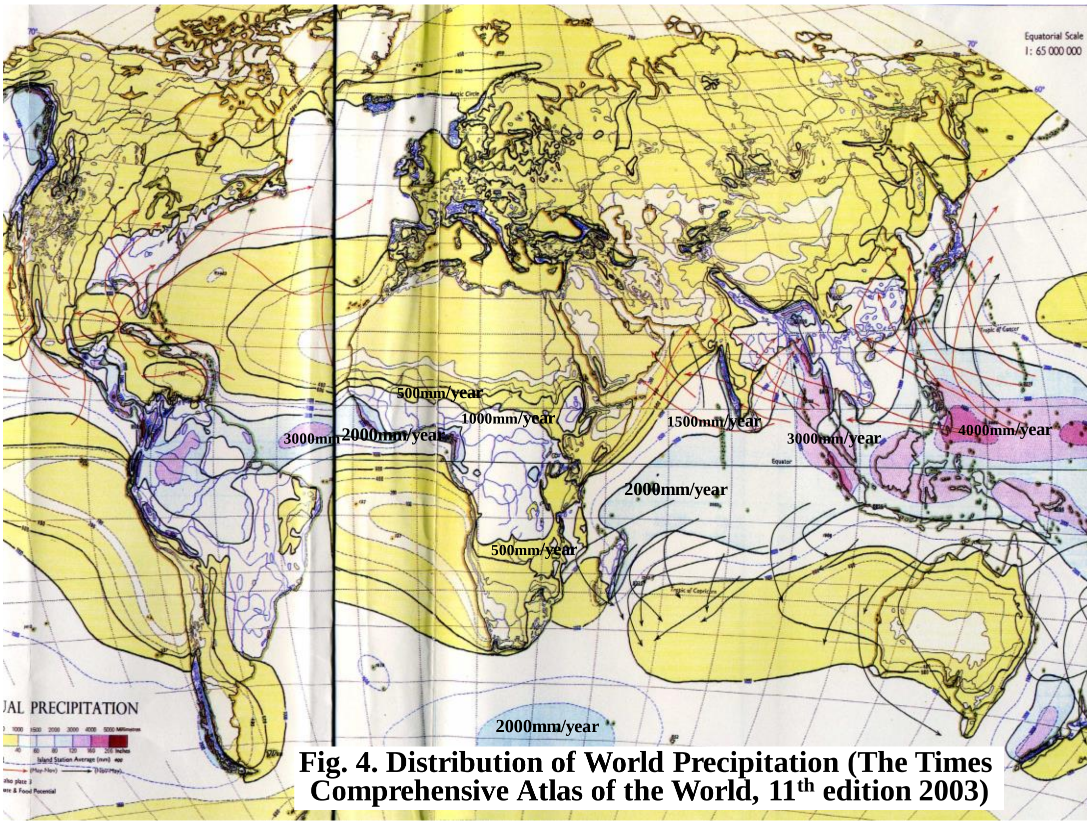


Fig. 4. Distribution of World Precipitation (The Times Comprehensive Atlas of the World, 11th edition 2003)

Can watersheds of SSA sustain sawah system? High rate of soil erosion and lowland soil formation can be compensated by high rate of soil formation in Asia. However soil formation, soil erosion and hence lowland soil formation are appeared to low in comparison with Asian watersheds. This is because of many huge inland basins/deltas are trapping sediments, such as Mali, Chad, Sudd, Congo and Okavango (see Fig. 2)

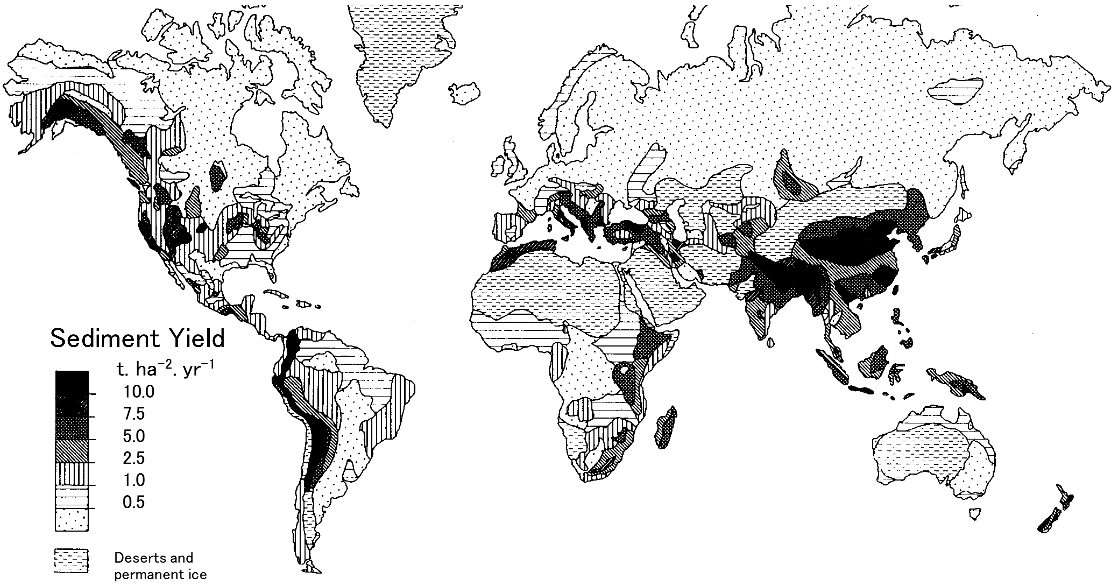


Fig.5. Rate of soil erosion in the world (Walling1983)

3-2.Kebbi Rice Revolution by Promotion of Sawah Based Farming on the Flood plains

However, since both wet and dry season trials during 2011-2014 on flood plains and inland basin (delta) of Sokoto and Niger river at Kebbi state of Sudan savanna zone at northern Nigeria, it became clear that some large flood plains as well as inland basins (deltas) in the Sudan savanna zone, such as Kebbi, Sokoto, Jigawa, Yobe and Borno states in Nigeria, can also be given higher priority if an appropriate cropping season can be selected to avoid flooding season during August to October and using shallow groundwater by tube wells, less than 10-20m depth.

During 2011-12, two power tillers supplied by Sawah team of Kinki University/NCAM for demonstration resulted in 18 ha of *sawah* development by farmers' self-support efforts who were trained by *Sawah* experts of Nigeria and Japan. Kebbi farmers bought additional 22 sets of power tillers to develop more than 200 ha of *sawah* by the end of 2013. As shown in Fig. 6 and Table 4, during dry season of October 2013- May 2014, half year, the cultivated sawah area reached to 199 ha and produced 12596.5 tons of paddy(mean yield 6.3 t/ha) (Yeldu HH 2014). Then 1000 sets of power tillers were bought by Kebbi state government, which distribution to farmers had started in April 2015 to boost *sawah* technology dissemination. This will increase the total area covered by sawah technology in the state more 10,000 ha within a few years. It seems Kebbi state could produce annual paddy production 1 million tons in 2014 -15.

3-3.Kebbi Rice Revolution through Sawah System Development and Evolution

Fig.7 shows soil and landuse survey route and soil sampling points of AR1-AR4 in 14th -16th of December, 1987 (Oyediran 1990). The trip was supervised by Wakatsuki who took photographs in Fig. 7 and 8. The two photographs in Fig. 7 show rice fields at almost same location but in 1987 and 2015. Fig.8. shows farming systems in 1987 at Sokoto river flood plain at Arugung and Birinin Kebbi area. Non sawah rice cultivations were common practice at that time. National Cereals Research Institutes had stations deep water rice research at that time. But nowadays deep water rice has no more importance. Onion cultivations using shallow borehole by both hand and pump irrigation were observed at that time, although minor portion. However as seen in Fig. 9, by 2011, all over the flood plains have shallow tube well and small pump irrigated micro sawah plots for onion and rice cultivation. These irrigation systems were evaluated as successful results under Fadama 1- III project assisted by World bank (2002) and Nigerian and Kebbi state Government (Dakingari 2013). This program constructed and trained 50,000 tubewell and small pump irrigation for about 30,000ha micro sawah plots for both onion and rice cultivation by 2011. Rice yield, however remain 2-3t/ha before introducing sawah technology.

Table 4. Extension of Sawah Rice Production Technology in Kebbi State during March 2011 to April 2014

1. Kinki University/NCAM Demonstration and Training, March 2011–April 2012

Local Government	Farmers	No.of powertiller supplied/ bought	Total sawah developed(ha)	Total No. of 100kg bag	Paddy yield in ton/ha
Arugungu*	shared	2 shared	6.5	487.5	7.5
Birinin Kebbi*	shared	2 shared	3.5	227.5	6.5
Jega*	shared	2 shared	8	560	7
	Total	shared	18	1275	7.1(mean)

* Demonstration and dissemination sites sites are shownin Google erath maps of Fig. 6

2. Sawah Technology extension, April 2012-October 2013

Local Government	Farmers	No.of powertiller supplied/ bought	Total sawah developed (ha)	Total No. of 100kg bag	Paddy yield in ton/ha
Arugungu*	MGD farm*	2	15	975	6.5
	JUM farm	1	10	650	6.5
	ABK farm	1	4	260	6.5
	AK farm	1	3	180	6
	AMB farm	1	4	240	6
	Dr YA farm	1	4	240	6
	ANL farm	1	3	180	6
	AMI farm	1	6	390	6
	ASD farm	1	5	300	6
Birnin Kebbi	ABA farm	1	4	260	6.5
	BB farm	1	3	180	6
	AS farm	1	3	180	6
Bagudo	ABB farm	5	35	2450	7
Jega	HHJ farm	1	7	455	6.5
	AUA farm	1	20	1200	6
Suru	Dr.UD farm	1	5	300	6
	Total	22	131	8440	6.4(mean)

3. 2014 Dry season rice in November 2013 to May 2014

Local Government	Farmers	No.of powertiller supplied/ bought	Total sawah developed (ha)	Total No. of 100kg bag	Paddy yield in ton/ha
Arugungu*	MGD farm*	2	20	1400	7
	JUM farm	1	10	650	6.5
	ABK farm	1	8	480	6
	AK farm	1	6	360	6
	AMB farm	1	5	300	6
	Dr YA farm	1	5	300	6
	ANL farm	1	5	325	6.5
	AMI farm	1	10	650	6.5
	ASD farm	1	5	300	6
Birnin Kebbi	AAA farm	1	4	no data	no data
	BB farm	1	6	360	6
	AS farm	1	6	360	6
Bagudo	ABB farm	5	50	3500	7
Jega	HHJ farm	1	14	910	6.5
	AUA farm	1	40	2400	6
Suru	Dr.UD farm	1	5	300	6
	Total	22	199	12595	6.3(mean)

The sawah technology demonstration and training were operated by Nigerian sawah team during 2010-2012 at 6 states, i.e., Kebbi, FCT, Benue, Ebony, Delta, and Lagos, under the agreement between NCAM/Kinki University and Fadama III/World bank in 2010. Although majority of demonstration and training were successful, endogenous sawah technology development is still not so clearly visible at the moment except for Kebbi state. As shown in Table 4 and Fig. 10-13, Kebbi rice revolution has started (Dakingari 2013). Major reasons of success are good rice ecology, success prehistory of Fadama projects, excellent collaboration and field oriented working style in all stake holders from governor to farmers in Kebbi state. Thanks to the Kebbi rice revolution, Nigerian sawah teams could evolved their sawah technology for not only inland valleys but also flood plains and inland basin/delta areas.

3-4. Potential of Flood plains and Inland Basins (Inland Deltas) as new target of Sawah Technology

Fig. 14 shows characteristics of topography (left by Araki 2008) and groundwater of Africa (Fan et al 2013). Africa is stable continent, which has about 10 steps of flat peneplains of various altitudes, which are shown as C, D, E, F, and G in Fig. 15-17. The D flat land has 300m altitude. This wetlands correspond to Chad and Mali basins. The E has 400 m altitude. These wetlands correspond to Sudd and Congo basins. The flat land of F has about 600m altitude. This is tableland/plateau surrounding wetlands of Chad, Congo and Sudd basins. The G basin has about 1000m altitude. This is highland basin in East and South Africa, typically Okavango basin/deltas and surrounding areas. These basins are not good sites for rice cultivation, because of cold climate and game reserves for ecological importance. The percentage of area between 200-500 m altitude is 38.9% (1.2 billion ha) and 28.2% (0.86 billion ha) between 500-1000m in Africa, both of which contains vast inland wetlands, such as flood plains and inland basins. But in Africa, the percentage of area less than 200m (A < 50m, and B about 80m altitude in Fig. 17, mainly coastal plains and inland valleys) is only 9.7% (0.3 billion ha) including coastal lowland/wetlands. Whereas Asia has vast lowlands less than 200m, which is shown as in Fig. 17, 24.6% (1.1 billion ha), which become major wetlands for rice in Asia.

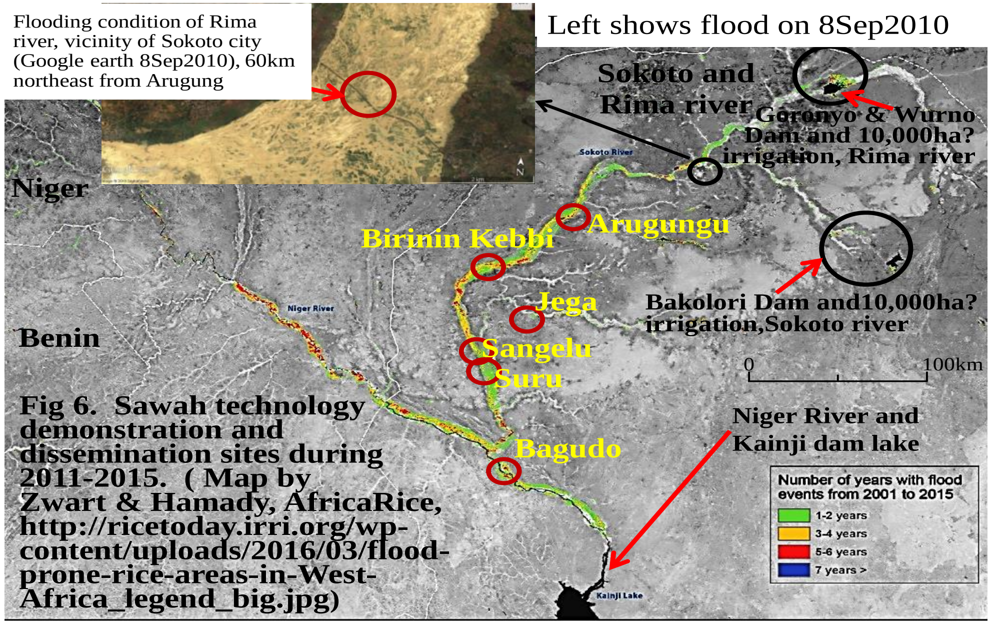


Fig 6. Sawah technology demonstration and dissemination sites during 2011-2015. (Map by Zwart & Hamady, AfricaRice, http://ricetoday.irri.org/wp-content/uploads/2016/03/flood-prone-rice-areas-in-West-Africa_legend_big.jpg)

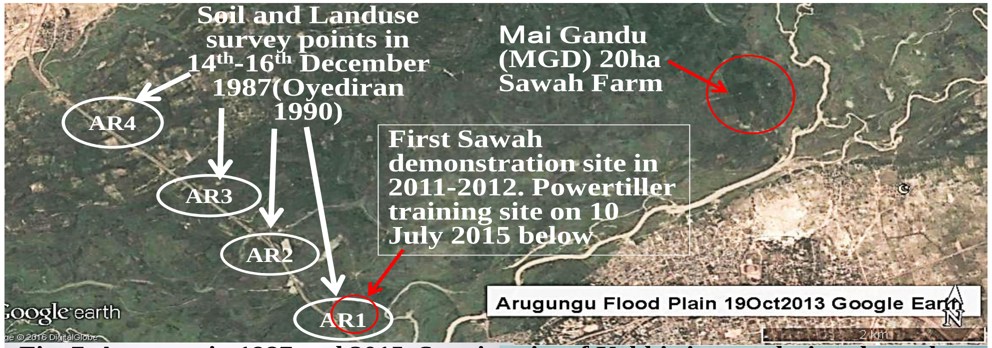
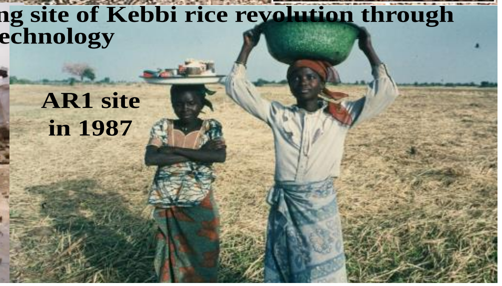


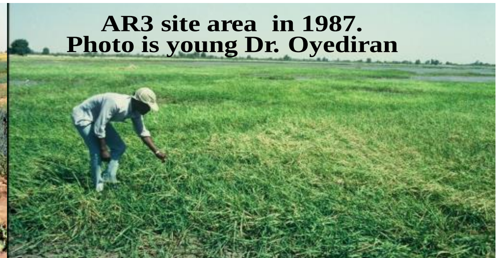
Fig. 7. Arugung in 1987 and 2015. Starting site of Kebbi rice revolution through sawah system evolution through sawah technology

Kebbi Powertiller and sawah technology training on 10th of July 2015 at AR1 site



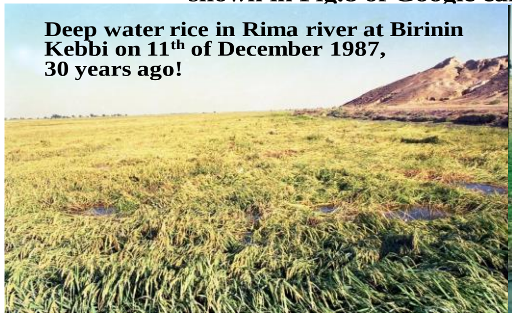
AR1 site in 1987

AR1 site area in 1987

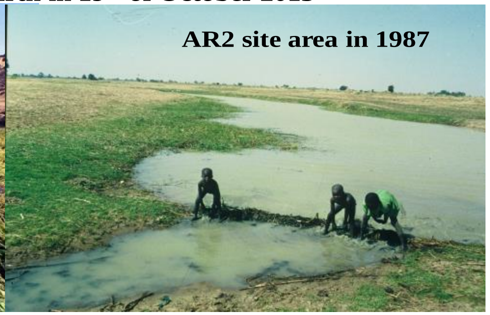


AR3 site area in 1987. Photo is young Dr. Oyediran

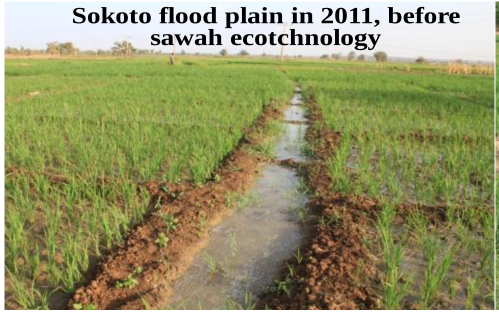
Fig. 8. Arugung in 1987. Starting site of Kebbi rice revolution through sawah system evolution through sawah etchnology. Position of AR1, AR2, and AR3 are shown in Fig.8 of Google earth in 19th of October 2013



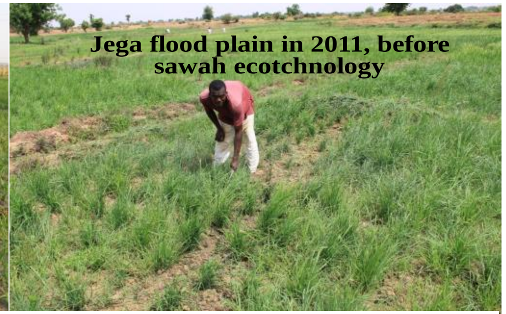
Deep water rice in Rima river at Birinin Kebbi on 11th of December 1987, 30 years ago!



AR2 site area in 1987



Sokoto flood plain in 2011, before sawah ecotchnology



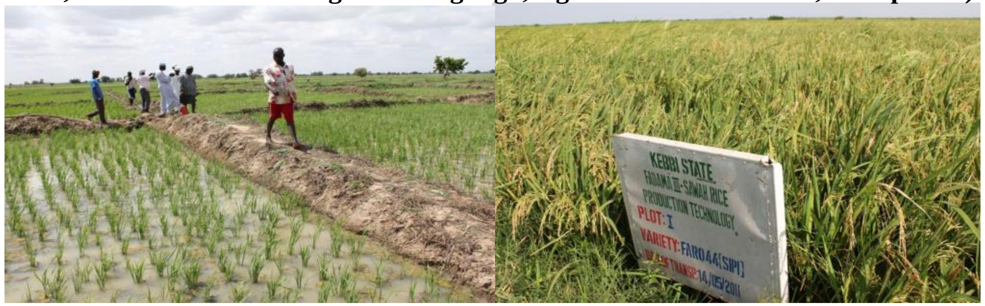
Jega flood plain in 2011, before sawah ecotchnology

Fig. 9. Micro Irrigated micro sawah rice and vegetable fields. Poor water use efficiency and weedy rice field before Sawah technology applied at Kebbi, Nigeria

AR3 site area in 2011

AR3 site area in 2011

Fig. 10. Demonstration & training of sawah technology(upper two are Jega on April, 2011, lower left is AR1 in Fig. 7 at Arugungu, right is at Birinin Kebbi, on Sep 2011)



20 ha of sawah developed by Mr. Abdullahi Maigandu Arugungu

June 2014

35 ha of sawah developed by Alh. Bello Baidu at Bagudo, Niger river floodplain

Fig. 11. Sawah development and evolution at Arugungu and Bagudo in Kebbi rice revolution sites (Photographed locations are shown Fig. 6,7, 12b and 13)

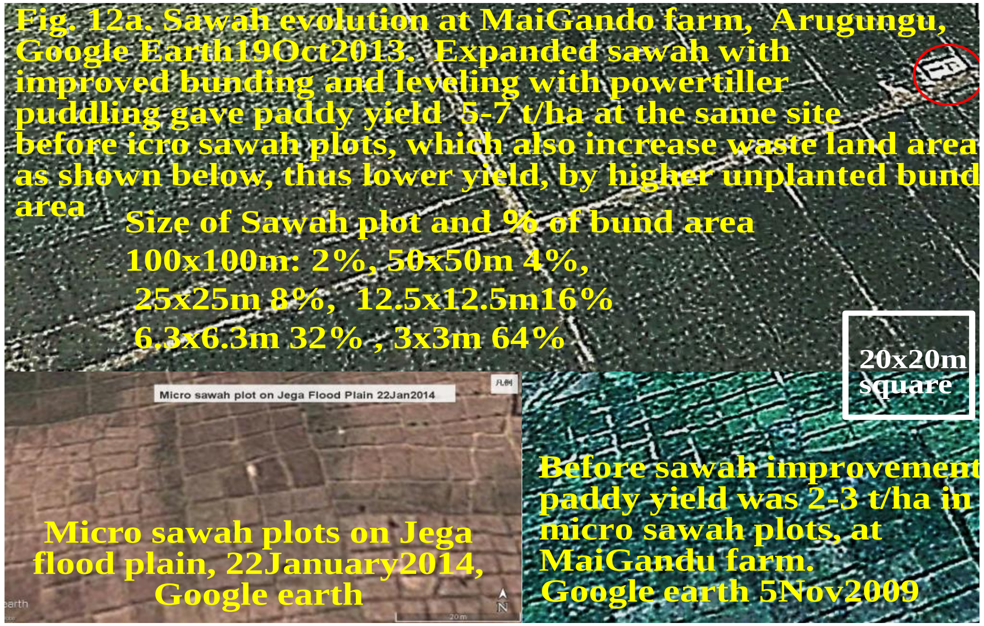


Fig. 12a. Sawah evolution at MaiGando farm, Arugungu, Google Earth19Oct2013. Expanded sawah with improved bunding and leveling with powertiller puddling gave paddy yield 5-7 t/ha at the same site before icro sawah plots, which also increase waste land area as shown below, thus lower yield, by higher unplanted bund area

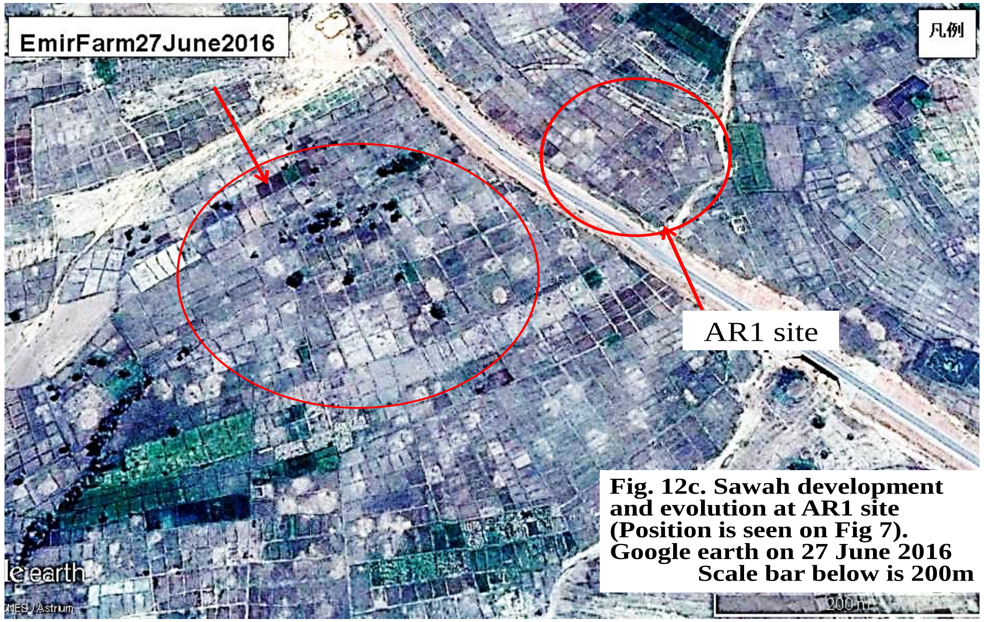
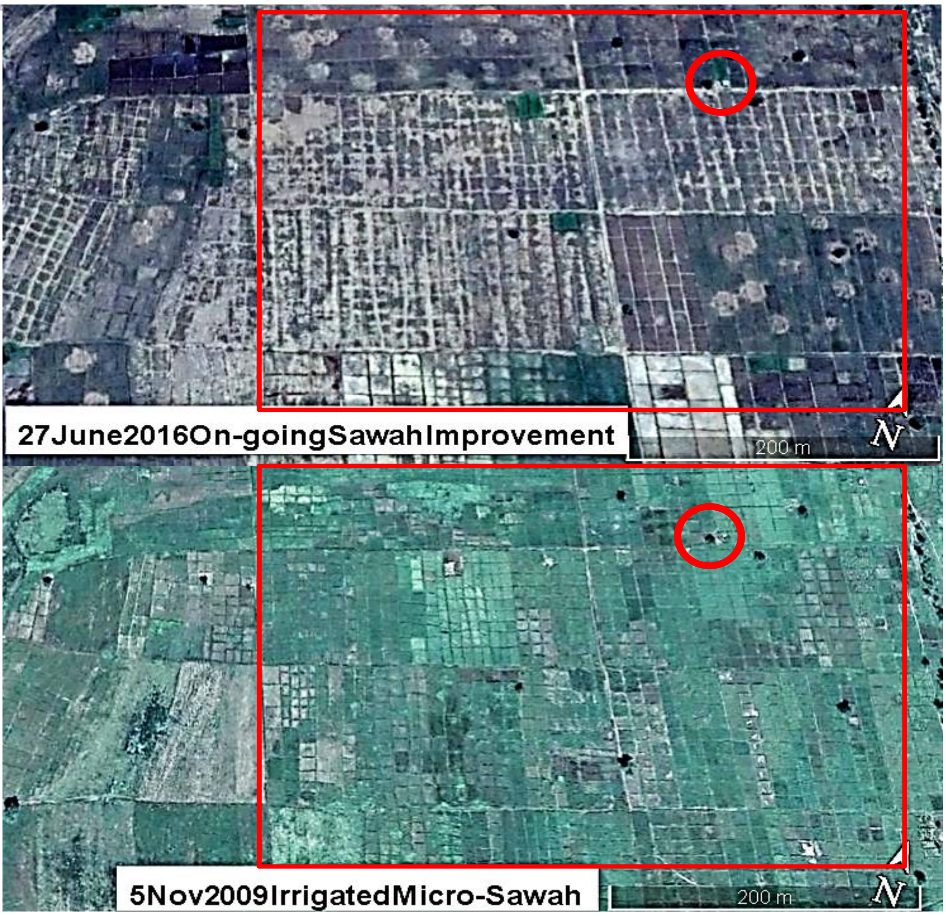


Fig. 12c. Sawah development and evolution at AR1 site (Position is seen on Fig 7). Google earth on 27 June 2016 Scale bar below is 200m

Fig 12b. Evolution of Maigandu Sawah system (Fig 6&7 shows the position)is on-going after Sawah technology training in 2011-2015 using power tiller by NCAM sawah team (both are Google earth). Each Two red tetragram area has 12ha, in which about 2200 micro sawah plots exist, mean area is 55m^2 in 2009, while total sawah plots reduced to about 450, mean area expand to 270m^2 in 2016. Red circles show the position of photograps in Fig 11. Expansion of sawah plots resulted through improvement of bunds' quality for both water control and operations. Leveling quality of sawah soil surface was improved. These sawah evolutions improved intermittent irrigation efficiency and gave paddy yield, double 2-3 to 5-7t/ha.



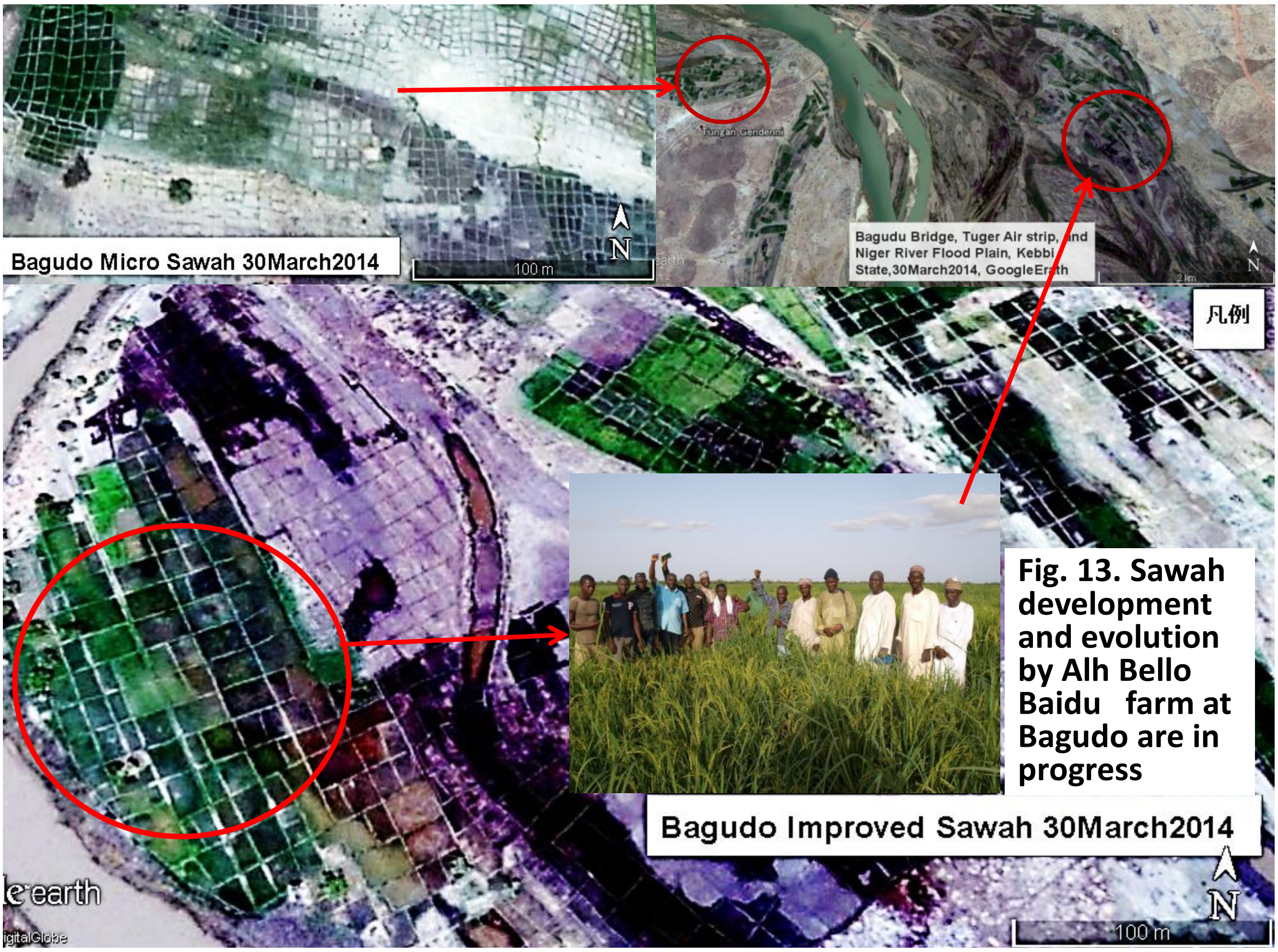


Fig. 13. Sawah development and evolution by Alh Bello Baidu farm at Bagudo are in progress