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Sawah Technology「アフリカ水田農法」(2) Background on Co-Evolution of Genetic and Ecological Technology of Sawah Rice Farming on the Rice Green Revolution in Sub Saharan Africa

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Content

1. Relationship between grain productivity (yield) and population growth in the past 70, 800, and 1400 years of world history

Figure 1a shows the demographic dynamics of the major regions of the world from the 6th century to 2014, Asia, Europe, North and South Americas, Africa and Japan (UNDESA 2017, Roser 2017, Livi-Bacci 2012, Kito 2007). Figure 1b shows the historical change of paddy yield in Japan during 600-2014 (Takase and Kano 1969, Takase et al. 2003, Honma 1998, Wakatsuki 2013a and b) and the changes in wheat yields in Britain from 1250 to 2015, in France from 1820 to 2015, corn yields in the USA from 1860 to 2015 (Hopper 1976, Evans 1993, Overton 1996, Mitchell 1998, Apostolides et al. 2008, Fischer et al. 2014, Roser 2017, USDA 2017). The changes in paddy yield in China from 1950 to 2015 and the changes in paddy yields in major Asian and African countries from 1960 to 2018 are shown, too (FAOSTAT 2019).

It can be seen from Figure 1a and 1b that population growth around the world clearly correlates with agricultural development, i.e., an increase in the yield of staple food crops, such as rice, wheat and corn, at the national and regional level in a historical time frame. Even though it is not shown in the Fig. 1b and Fig. 2, the improvement in yield and expansion of cultivated land have progressed in a concerted manner. However, during these trends, short but severe food crises have occasionally occurred, caused by natural disasters, wars, and migration and such food crises will occur in future.
European population growth became evident after 1750, peaking at approximately 2000, but at a much slower rate than in other regions of the world. This is probably due to the massive immigration to the new worlds, especially to North and South America as well as Australia, New Zealand and some areas in highland Africa. The surge in population of the Americas is estimated to occur shortly after 2050, independent of Europe. The

peak population in Asia will be just prior to 2050, which coincides with the period of green revolution in the region. Africa is lagging Asia about 50 years, agronomically.

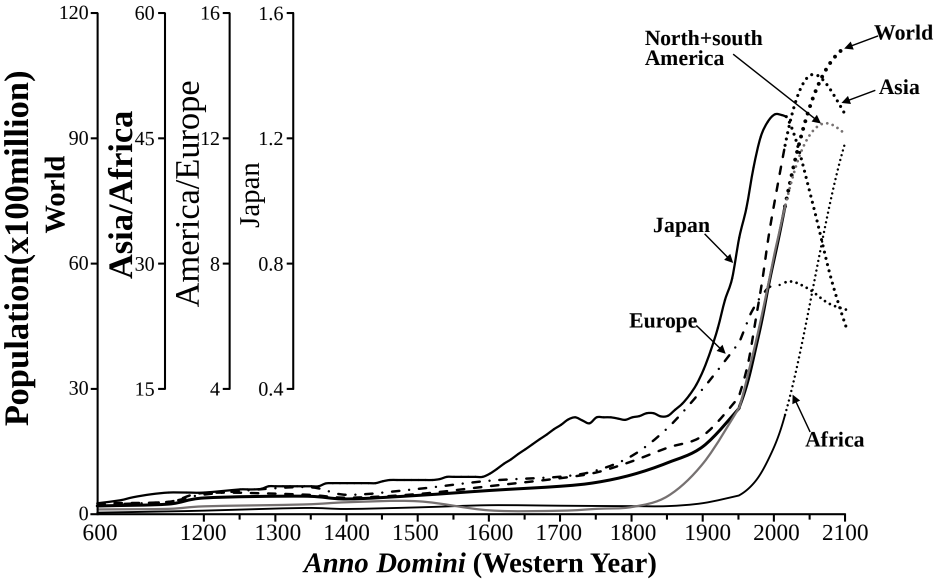

Fig 1a. Relationship between population and grain yield in terms of time span for 1400 years

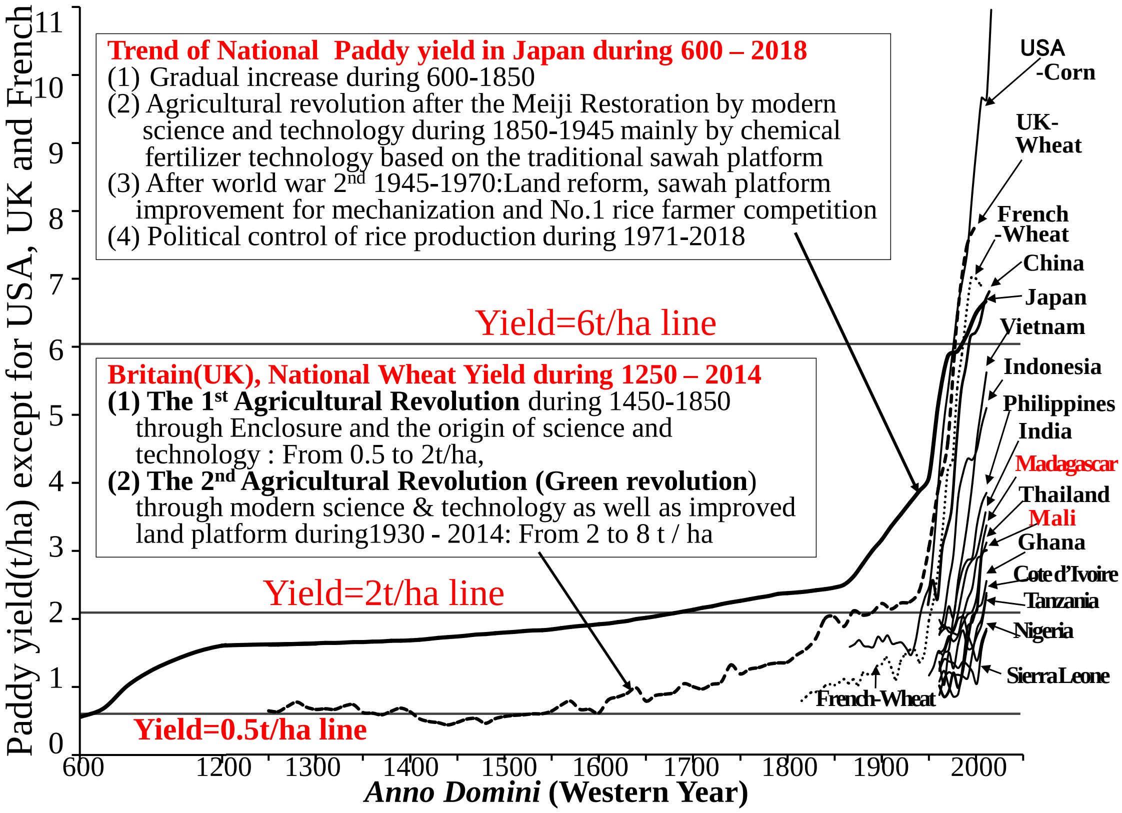

Figure 1b. Comparrative trends between the demographic increases and major grain yield's incresases from the 6th century to 2018. The grains shown include the changes in paddy yield in Japan since the 6th century, changes in wheat yields in the UK since 1250, changes in wheat yields in France since 1800, changes in maize yields in USA since 1860, and changes in paddy yield in major Asian and SSA countries since 1961. The population dynamics include the region of Asia, Europe, North and South America, and

Africa as well as that of Japan.
The population of Sub Saharan Africa (SSA) has increased rapidly since 2000, and this trend will continue until approximately 2100. In Africa, the progress of the dual agricultural revolution - led by rice revolution - is that increases in both paddy yield and cultivated land area are progressing at the same time. This is expected to support an expected population surge in Africa from 2000-2100. Africa has not experienced an equivalent to the Asian Green Revolution.

Historically, the Japanese paddy yield has been double that of the UK wheat yield, a trend since 600-1200 up to the 1950s. This is based on historical data that supports the Sawah Hypothesis (2), concerning the land platform for intensive sustainable productivity. This is described in Sawah Technology (4): Principles and the theory: Sawah Hypothesis (1) the platform for scientific technology evolution and sawah hypothesis (2) the platform for sustainable intensification in watershed agroforestry.

As shown in the Figure 1b below, the UK national wheat yield during the first agricultural revolution (1250-2014) increased from 0.5 to 2 t/ha during 1450–1850, was based on the enclosure. The sawah hypothesis (1) is comparable and similar to the agricultural development of this British enclosure. During UK's second agricultural revolution, yield increased from 2 to 8 t/ha, from 1930s to the present. This is based on modern science and technology, which is somewhat similar to the earlier green revolution technologies, although a bit advanced when compared to the Asian green revolution.

Japan has the longest historical data on national rice yield dating from 600 until present. Rice yield gradually increased from 0.5 t/ha to 2.5 t/ha between 600 and 1850, before Japan's agricultural revolution raised that figure to 6 t/ha from 1850 to 1970 based on improvements in science and technology. However, between 1971 and 2018, the Japanese government implemented a policy to reduce paddy rice production by reducing the area under cultivation (In Japanese *GEN-TAN*「減反」policy, Arahata 2014). Varieties with lower yield were preferred for cultivation, due to their higher quality and market price. Thus the growth rate of productivity decreased and was overtaken by the UK's wheat and China's grain yield as shown in Fig.1a and Fig. 2.

The Green Revolution ostensibly accounts for the sharp increase in agricultural productivity in developing countries of Asia and Latin America after 1960; however, similar trends of global agricultural productivity were not limited to developing countries (Fig. 1b and Fig. 2). Crops yields have increased significantly since 1940 in all countries. Japan was overtaken in productivity in the 1970s by the United Kingdom, France and the United States of America. At present the highest grain yield is achieved by corn growers in the US.

Substantive historical data of grain yield, spanning at least 1000 years, appears to belong only to the two island nations of the UK and Japan. This is most likely due to such relatively smaller nations not experiencing the almost catastrophic social fluctuations experienced in continental countries. Data from the US can be ignored in this comparison due to that country's relatively short history; however, data from China and India from a time-frame comparable to the UK and Japan may be limited to areas similar in size to those two nations.
Some sporadic estimated yield data from China has been recorded: 2.0 t/ha in Jin dynasties (Eastern and Southern), from 317 to 589, 2.5 t/ha in Tang dynasty, (518 to 907), 2.9 t/ha in Song dynasty (960–12799, 2.8 t/ha in Ming dynasty (1368– 1644), and 2.2 to 2.8 t/ha in Qing dynasty (1636–1912) (Perkins 2017, Guo 2012, Wu 1985). However, no trends can be found in these data during China's history between 317 and 1912.

2. Recent improvement in grain yields in Sub-Saharan African (SSA) countries

Figure 2 shows the change in paddy yield since 1700 in order to more clearly show the impact of the green revolution accompanying the development of science and technology in recent years by country. Fig.2 also shows the yield data of wheat for UK and France. Fig. 2 shows the historical trend of paddy yields of Japan during 1700-2014. The figures also shows the trends of paddy yield in major countries of paddy production in Asia and SSA during 1961-2014 except for China (1949-2014). Numerical means of FAOSTAT 2017 and USDA PS&D Online 2017 were used to draw the trend curve. For comparison, wheat yields in UK during 1700-2014 and French during 1830-2014 and paddy yield of USA during 1880-2014 are also shown in the Figure 2. These data Sources are “Yields-Our World in Data” (Roser 2017), FAOSTAT and USDA PS&D Online (2017, 2018, 2019), Overton (1996), Hopper (1976), Takase and Kano (1969), Mitchell (1998), and Apostolides et al. (2008).

As shown in Figure 2 below (more details trends are shown in the Figures 5a and 5b as well as Figure 6 of Sawah Technology (1) Statistics), major sub Saharan African (SSA) countries have collectively been unable to improve grain yield during 1961–2000. Madagascar, with Asian-styled irrigation methods for rice production is the exception to this, which explains the relatively higher yield in Eastern/Middle/Southern Africa (1.7 t/ha). The independent yield of Eastern/Middle/Southern Africa, however, has been consistently low up until the 1990s. In contrast, Western Africa yield has grown from 1 t/ha in the early 1960s to meet the same level as Eastern/Middle/Southern Africa by the 1990s. For this reason, productivity improvement for SSA *in toto* has not been recognized.

However, the trend of yield increase between 2005 and 2010/2020 is now apparent (FAOSTAT 2022), and is similar to trends in Asia 50 years ago. Although majority of 48 SSA countries have various appropriate ecologies for rice cultivation, agricultural history, ecology, and the reliability of statistical data are extremely diverse. Due to the large diversity across the 48 SSA countries, paddy productivity is best assessed for individual countries. As shown in Figures 1 and 2, the trends of yield differentiates between countries after 2010. The national mean paddy yields of the SSA’s top 10 countries during (2001-05:mean) – (2016-20:mean) have been significantly improved as follows, Madagascar (2.4 to 3.1 t/ha), Senegal (2.5 to 3.5 t/ha), Mali (2.2 to 3.4 t/ha), Ghana (2.2 to 2.9 t/ha), UR Tanzania (1.8 to 2.8 t/ha), Corte d’Ivoire (1.9 to 2.7 t/ha), and Burkina Faso (1.8 to 2.2 t/ha). These values are comparable to Thailand (2.9 to 3.9 t/ha), India (3.0 to 3.9 t/ha) and Philippines (3.4 to 4.0 t/ha). Paddy productivity of some counties such as Sierra Leone (1.0 to 1.2 t/ha), Nigeria (1.4 to 1.5 t/ha) and Guinea (1.7 to 1.3 t/ha) has no clear improvement during 1961-2020. Some countries such as Madagascar, Nigeria, Guinea and DR Congo contained data showing anomalous fluctuations and incredibly fixed yield values (FAOSTAT2022).

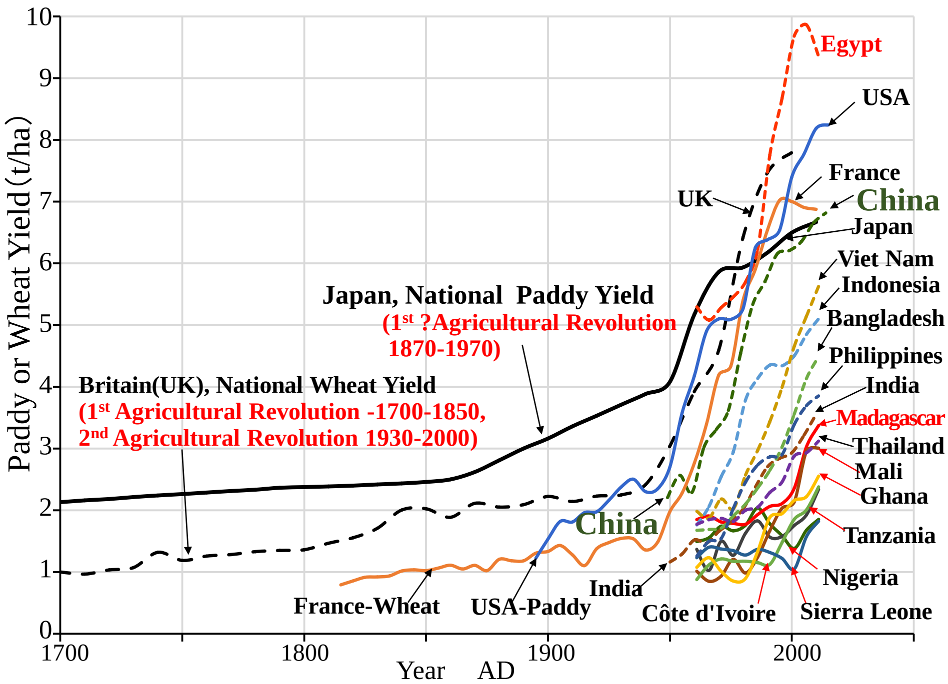

Figure 2. Historical Trend of paddy yields of Japan during 1700-2014. Paddy yields in major rice countries in Asia, Egypt and SSA during 1961-2014 except for China (1949-2014). The wheat yields in England during 1700-2014 and French in 1830-2014 and Paddy yield of USA in 1880-2014

3. Definition, genesis and evolution of sawah system platform and sawah technology

Historically, Madagascar and a Sukuma land of Tanzania have developed irrigated sawah platform and sawah technology before 1900 (Crowther et al. 2016, Thornton and Allnut 1949, Meertens et al 1999, Kanyeka et al. 1994). Majority of SSA countries have no such rice cultivation platform before independent in 1960s. Hence there is no sawah concept and word of sawah based rice farming. Never the less, international organizations such as IRRI, IITA, AfricaRice, and recently AGRA have emphasized for the past 50 years on breeding technology only. This is because of the “huge” success of the semi dwarf IR-8 variety, miracle rice, at IRRI and etc. to realize rice Green Revolution in Asia and successive recent genome revolution (Wang et al. 2018). In SSA, rice farmers have very little concept on the improved cultivation platform, with understandably no vernacular to accompany it. In SSA, the word ‘paddy’ merely means land cultivated for rice, and does not distinguish between irrigated paddy fields, rain-fed paddy fields, non-paddy wetland fields, and upland paddy fields. In addition, ‘paddy’ is the most common term used in FAO to describe rice grains with husk. This is one of the main reason why efforts of international organizations have not been successful over the past 50 years.

3-1.What is *sawah*, paddy and irrigation?

The English word ‘paddy’ field is often used to describe the system shown in Figure 3. As shown in Table 1, the word originated from ‘padi’, which means rice/grain in Malay-Indonesian. English term, "paddy," also means rice plant or rice grain with husk, such as paddy yield and paddy production. The term ‘padi’ has no original meaning to describe a rice growing environment nor the eco-technological definition of improved rice growing fields. As shown in the Table 1, the term ‘sawah’ is also of Malay-Indonesian origin, and refers to a bunded, puddled and leveled rice platform with water inlet and outlet to control water condition, especially control of water depth and flow in rice fields, and thus soil fertility (Wakatsuki et al. 1998). We propose to use the term of sawah due to the diversity of English word of ‘paddy’.

Table 1. Definition and genesis of technical terms of Paddy and Sawah System Platform

	English	Malay-Indonesian	Chinese（漢字, Japanese）
Grain and Plant	Rice	Nasi	米, 飯, 稲
Biotechnology	Paddy ←····	Padi	稲, 籾
Environment Ecotechnlogy	(Paddy)? ↙	Sawah	水田(Suiden)

Note: Asian countries like China, Japan, Malay-Indonesia and others have diverse own words to describe diverse rice culture. But there are no proper concept and technical term such as *Sawah* or *Suiden* (水田 in Japanese) in English/French and local languages in West Africa and SSA. The English term of paddy originate padi in Malay-Indonesian, which means just rice plant and or unhusked rice grain.

Figure 3. Various sawah system platform. ①West Sumatra, Indonesia (0.4646S 100.59E), ②Ashanti, Ghana(6.8882N 1.848W), ③Yunnan, China (by Otsuka 2004), ④Dainaka polder, Shiga Prefecture, Japan (35.181N 136.131E), ⑤ Google earth image taken near the ①location, ⑥perfectly levelled sawah platform ready for transplanting at Bali, Indonesia(8.473S 115.13E), ⑦ is 1 ha demonstration irrigated sawah platform developed in Jega flood plain, Kebbi State, Nigeria(12.199N 4.373e), ⑧ shows portable pump irrigated sawah plot of the ⑦ site.

Most of the *paddy* fields in Asian countries correspond to the definition of the term of *sawah* fields as shown in ①-⑧ photos in the Figure 3. Therefore, the paddy fields are equivalent to *sawah* for Asian scientists. However, in West Africa and SSA, the term paddy (field) refers to a rice growing field in general, including upland, rainfed lowland, and various irrigated rice growing fields, such as no bunding, bunded but not leveling and bunded with leveled rice fields and so on. In order to avoid confusion and to stress the focal point for realizing the long-awaited rice green revolution through improved water control by irrigated sawah platform, the term *sawah* is proposed (Wakatsuki et al. 1988 and 1998).

All of the eight photos shown in Fig. 3 are irrigated rice cultivation platform described (defined) as *Sawah* in Malay-Indonesian, *SUIDEN*「水田」, in Japanese, and *Paddy field* in English (Table 1). The Malay-Indonesian term Sawah means man-made improved rice growing environment, or a growing 'platform' for good agronomical practices. The essential target of the platform is to easy water control.
The photo ① was taken in August 2010 near Batu Sangkar, in West Sumatra, Indonesia. The Google Earth image of ⑤ was taken around the area of ①. Photo ⑥ shows the sinuous contours of perfectly levelled and terraced sawah system platform, north of the West coast town of Tabana along the lower slopes of Mt. Batukau, Bali, Indonesia (Helmi and Lueras 1990). The two small red circles indicate farmers and the three green circles indicate rice nurseries for transplanting. Photo ② was taken in September 2001 at Adugyama village near Kumasi city in Ashanti province, Ghana. This sawah platform was developed by farmers by their own effort through on-the-job training under JICA (Japan International Cooperation Agency)/CRI (Crops Research Institute, Ghana) joint study program for sawah technology development (Wakatsuki et al. 2001a and 2001b). Photo ③ shows numerous rice terraces in Yunnan, China (Otsuka 2004). Photo ④ is a large *SUIDEN* plot with a size of approximately 1 ha and was taken on May 2012 at Lake Biwa alluvial plain, Shiga Prefecture, Japan. Since the height difference in the plot is leveled to within ± 5 cm (within ± 2.5 cm in ultra-high quality sawah), small rice seedlings with a plant height of 15 cm or less can be transplanted with a mechanized rice trans-planter. The irrigation canal is visible in the foreground. Photo ⑦ shows for a 1 ha demonstration site of NCAM (National Center for Agricultural Mechanization, Nigeria) sawah team developed by farmers for on-the-job training on the Zamfara River flood plain, south of Jega, Kebbi, Nigeria. The photos was taken when the transplanting was just completed. Photo ⑧ is a small pump for irrigation where the groundwater level is shallower than 5 m. Both photos were taken in May 2011. The dry season in this area is from November to June.

3-2. Sawah and sawah system (platform) definition

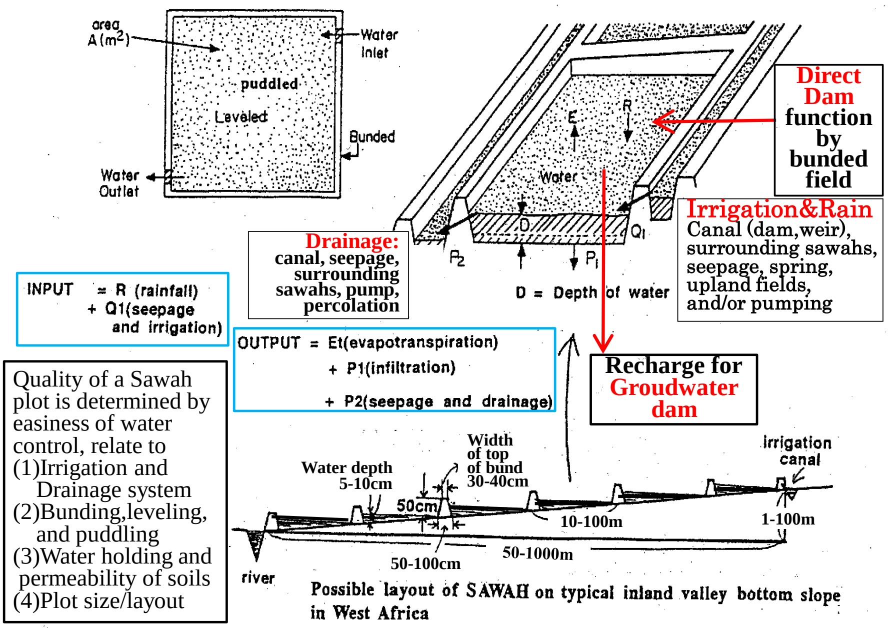

Figure 4. Sawah plot: A bunded, leveled, and puddled rice field with inlet of irrigation and outlet to drainage, thus control water and weeds as well as manage nutrients

Figure 4 shows the basic structure and properties of a sawah plot. One sawah plot is partitioned or demarcated by appropriate bunds (ridges or levees) based on topography, hydrology and soil type.

The basic characteristics and structure of all sawah plots are as follows:
(1) Bunding using soil materials with appropriate height, width with appropriate compaction and or surface sealing to control water leakage. There is a cost, but a concrete can replace the soil materials,
(2) Levelling surface soil within 10 cm height difference, i.e., ± 5 cm, within one *sawah* plot bunded,
(3) Water inlet connecting irrigation canal/pumping hose and water outlet to drainage canal/ direct drainage to the subsoil,

(4) The surface of sawah plots are puddled to facilitate levelling for good water control and reducing weed as well as sustainable soil managements.

In a standard *sawah* plot, the water inlets and outlets should be installed within the bunds with gates that connect with the irrigation and drainage (Figure 4, upper part). Proper knowledge and practical skills (especially of sloping pattern and hydrology in a watershed) of the field are needed to do this. In an extensive watershed, the slope (lower part of Figure 4 and Figure 5) guides the interval of bunding. The aim should be to maintain an interval that will permit standard leveling (within 10 cm height difference in a sawah plot) of the puddled soil for optimum water control.

Rain-fed sawahs have no man-made irrigation and drainage facilities except for direct rainfall and natural water harvesting and drainage using topography. Sometime outlet(s) of upper sawah(s) plots are the inlet(s) of lower sawah(s) plots. The layout of bunding normally follows topographic contour lines to minimize the need for leveling construction work. As for the shape of each sawah plot, rectangles are suitable for streamlining the work of rice agronomy.

The quality of a sawah plot is determined mainly by the quality of leveling. If the height difference in a plot of sawah is within 5cm (± 2.5 cm) it is high quality (Matsushita 2013), within 10 cm (± 5 cm) it is considered standard quality, and if within 20 cm it is considered marginal to get the targeted yield of 4 t/ha. If more than 30 cm, the yield will be less than 3 t/ha because of poor water control, poor weed control, and poor nutrient management. Puddling, irrigation, drainage, and ground water recharge practices can improve water cycling as shown in Figure 4 and 5. Despite the universal characteristics of the basic sawah plot design, there is diversity across rice growing regions based on local hydrology, soil, terrain, rainfall, temperature, and vegetation. In addition, the historical, societal and economic culture of the local community will affect diversity of sawah design and management. The result is an extremely diverse sawah system platform.

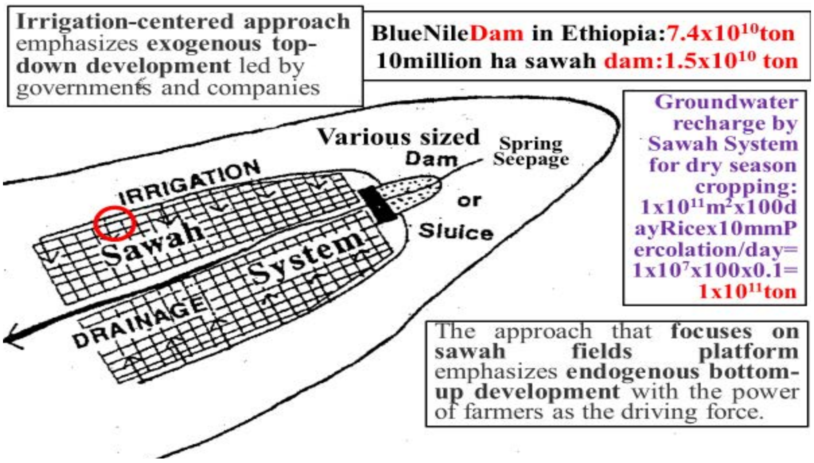

Fig. 5. Irrigated sawah system platform for sustainable rice cultivation by control water in watersheds of Inland valleys, Flood plains and Deltas. As shown in Figs. 6 and 7, which are the expansion of the red circled area as a model of Fig.5, apart from core dam/weir/sluice and irrigation and drainage canal system, numerous sawah plots have dam and ground water recharge functions

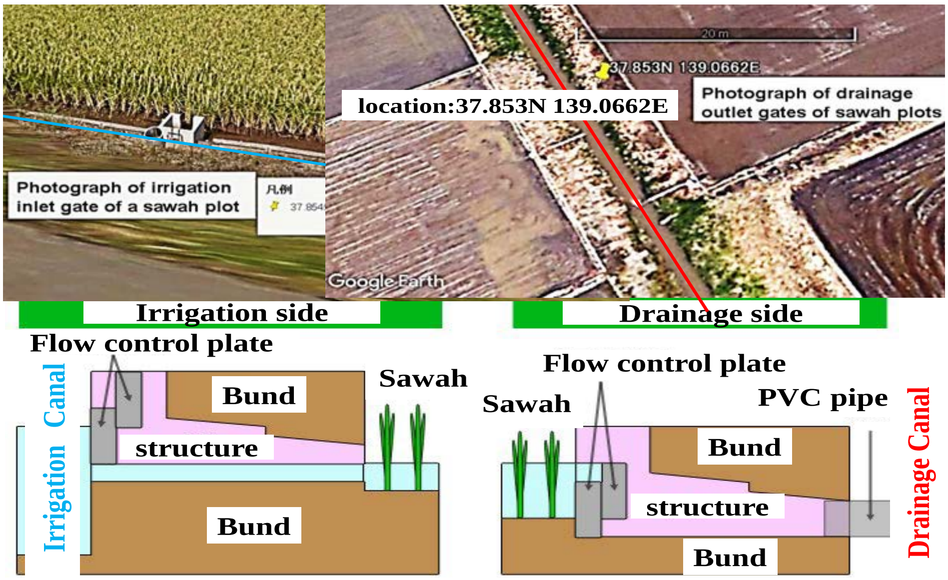

Fig.6. Example of Japan's most advanced evolutionary stage 6 Sawah platform in Niigata prefectures.

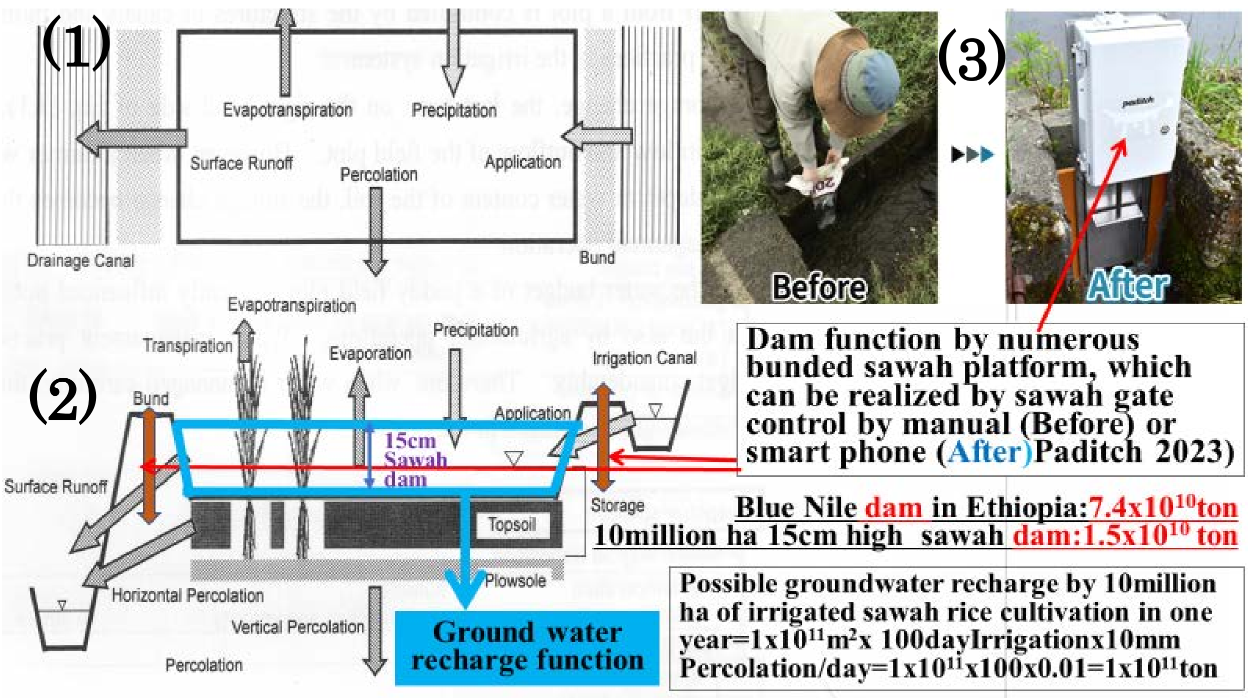

Fig.7. Future possible lowland strategy and technological measures by irrigated sawah platform to solve water balance in Sub-Saharan African agriculture (Drawing was cited by Watanabe 1999, Paditch photos were cited https://paditch.com)

Figure 5 shows a sawah system with irrigation and drainage facilities including dam and spring in a small inland valley watershed. This is a typical sawah model that can be found in all areas. This figure is a very simple diagram, taking as an example a small inland valley watershed area in the upper reaches of a river, but even as a watershed area including a floodplain of a larger river in the middle reaches, and a watershed area including the huge delta of alluvial plain in the most downstream part, it is basically the same as a watershed.

Figure 6 (upper) shows an enlarged view of typical structure of sawah plot platform in the rice center of the Niigata Plain (location 37.853N 139.0662E), which is a rice center in Japan. The blue lines indicate the irrigation canals (often pipelines), and the red lines indicate drainage canals. Figure 6 (lower) shows the structure of the gates of both the inlet and outlet, which are installed to prevent the destruction of the bunds of the Sawah plots during water intake and drainage.

Figure 7 shows that although each one is small, if the intakes and drains of the numerous gates of sawah plots are properly managed in an integrated manner either manual management by individual farmers or a digital technology-based management of a large number of automated gates (Padich) using smartphones as shown in (3), they can achieve a water storage capacity comparable to that of a large dammed lake. It also shows that the soil layer of a Sawah plot can act as a platform for recharging groundwater if it has adequate permeability and water storage. (1) shows the vertical and horizontal movement of water in a sawah plot. (2) shows that each sawah plot can be a mini dam with a maximum depth of about 15 cm and a platform for groundwater recharge. This sums up the dam and groundwater recharge functions of the sawah platform for the entire White Nile and Blue Nile catchments with a potential of 10million ha (Figure 35 in Sawah technology (4) as a future vision for water balance and sustainable agriculture in the Nile river system. (shown as Figure 35 in Sawah technology (4)). In Figure 7, hydrological function of sawah system platform is compared to the Grand Ethiopean Renaissance Dam, of which water storage capacity of $7.4\text{x}10^{10}$ton (Wikipedia A 2022). If we assume the total sawah development potential is about 10Mha in the downstream countries of Sudan, South Sudan, and Egypt, the groundwater recharge function is about 10^{11}ton per year and the the dam effect is about $1.5\text{x}10^{10}$ton / year. Total hydrologican function is larger than the Etiopian dam. It is not inferior the Etiopian dam even incudle the power generation, maximum of 16,153 GWh. Because of dangers of a serious water crisis between Egypt and Sudan in the lower reaches and Ethiopia. Thus the future value of the sawah platform at SSA must be emphasized

Figure 8 below shows a demonstration model as an example of Sawah Technology in the inland valley of the Biem river that is flowing near the village of Biemso No. 1 in Ashanti region, Ghana (GPS location is 6.882N 1.848W). The Google Earth image was taken in January 2008, which data was at the eighth years after the end of the action research operation to develop the sawah platform by farmers' self-help efforts (Wakatsuki et al. 2001a and 2001b, Buri et al. 2012). Photograph ② of Figure 4 shows the sawah system which was taken from the north west direction as shown by the arrow in Figure 3. Total area of the two sawah system platform models was approximately 7 ha at 2008. It was 1.8ha at the time of the action research project ended on 2000 (Wakatsuki et al 2001a). The scale is shown by a 300 m marker in the center of the image.

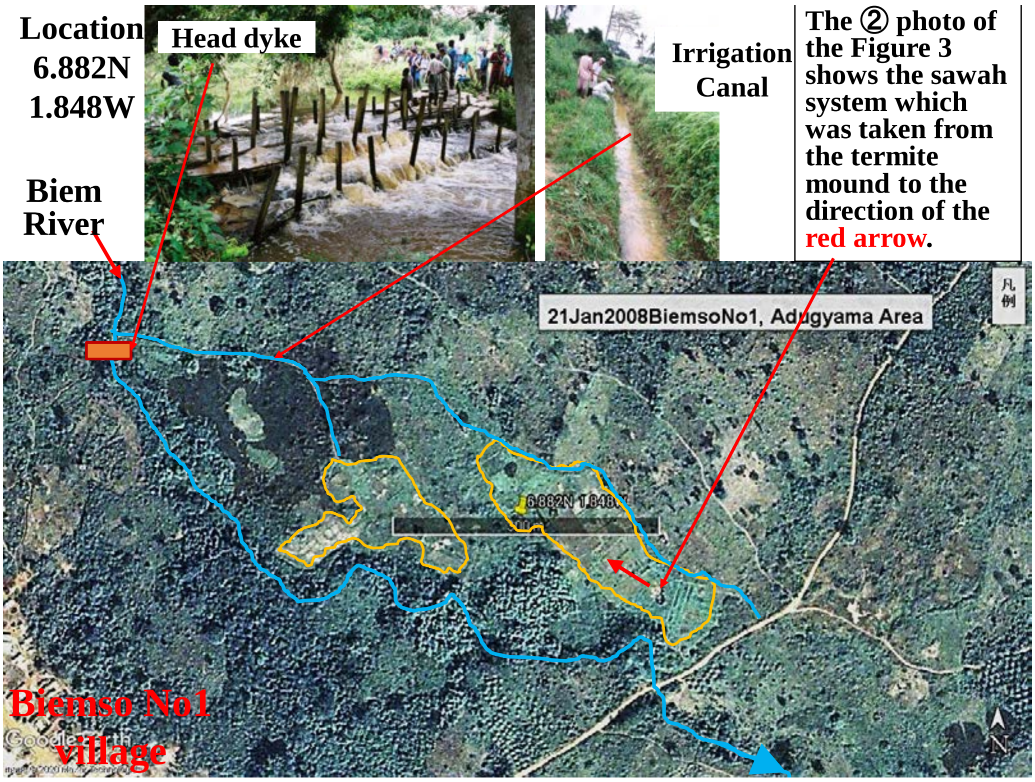

Figure 8. shows a demonstration model of Sawah Technology in the inland valley downstream of the Biem river flowing near the village of Biemso No. 1 in Ashanti Province, Ghana (GPS location is 6.882N 1.848W). The Google earth image was taken in January 2008 while the field demonstrations were conducted from 1999 to 2008 (Wakatsuki et al. 2001a and 2001b, Buri et al. 2012)

3-3. Sawah, *Paddy*, and Irrigation

Another frequent source of misunderstanding in SSA is the term "irrigated rice." In Asia, the meaning of this term is clear, as the *sawah* was developed by local farmers over the past hundreds or thousands of years as described later before the recent advent of irrigation projects (after the 1970s) by Asian governments. However, in West Africa and SSA, both irrigation and *sawah* are new and the concept of *sawah* has been lacking. Improvement of sawah quality and management can result in more efficient irrigation and fertilizer use, and when combined with improved varieties of rice can raise crop yield in SSA. Lowland sawahs can sustain rice yields higher than 4 t/ha through macro-scale natural geological fertilization from upland, and micro-scale mechanisms to enhance various nutrients' supplies as described later in Sawah Technology 4 (Principles and Theory). This requires appropriate selection of lowland areas.

There have been many irrigation systems in SSA which are not standard sawah systems as shown in Figure 9, Figure9A, and Figure 9B. These photos were taken in the biggest official rice irrigation project of northern Nigeria. The poor performance of past irrigation projects in SSA can be explained by the lack of proper sawah platform development (Fujiie et al. 2011) and no appropriate management skills of rice scientists, engineers, extension officers and farmers in majority of SSA countries.

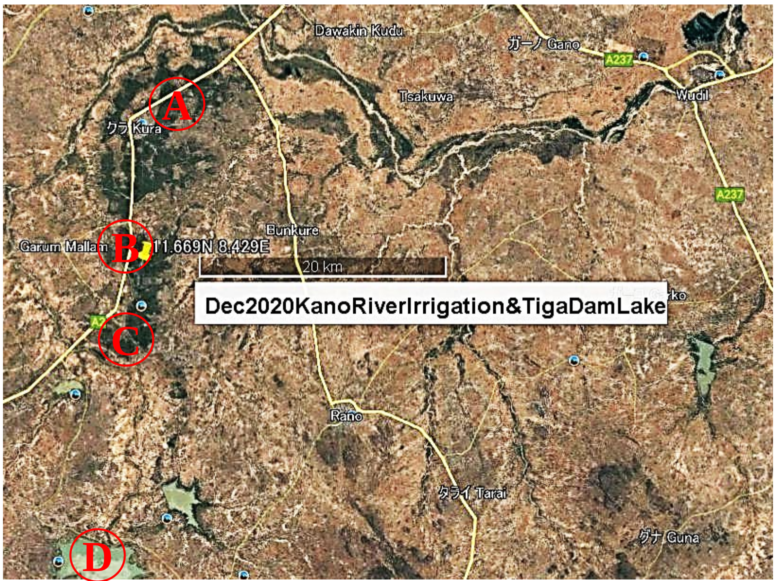

Figure 9. The whole picture of an irrigation project site of Kadawa (B and C area), Kura (A area) and Tiga Dam lake, which were developed in the Kano River basin of Nigeria. The total irrigated area reaches 15,000ha. Majority of sawah plots are rudimentary micro-sawah systems. The Tiga dam lake is approximately 13,000ha.

Figure 9A and 9C. Expansion of the areas of A and C in the Figure 7. It can be seen that there are more than 400 sawah plots in 1ha. The scal marker is 100 m long. The area of one sawah plot is approximately 5mx5m=25 m ^{2}, which is the evolutionary stage 3 of micro rudimentary sawah. The lines at approximately 100 m intervals are irrigation drainage lines and working roads. GPS of A site is 11.777N 8.45^{E} and C site is 11.619N 8.43E.

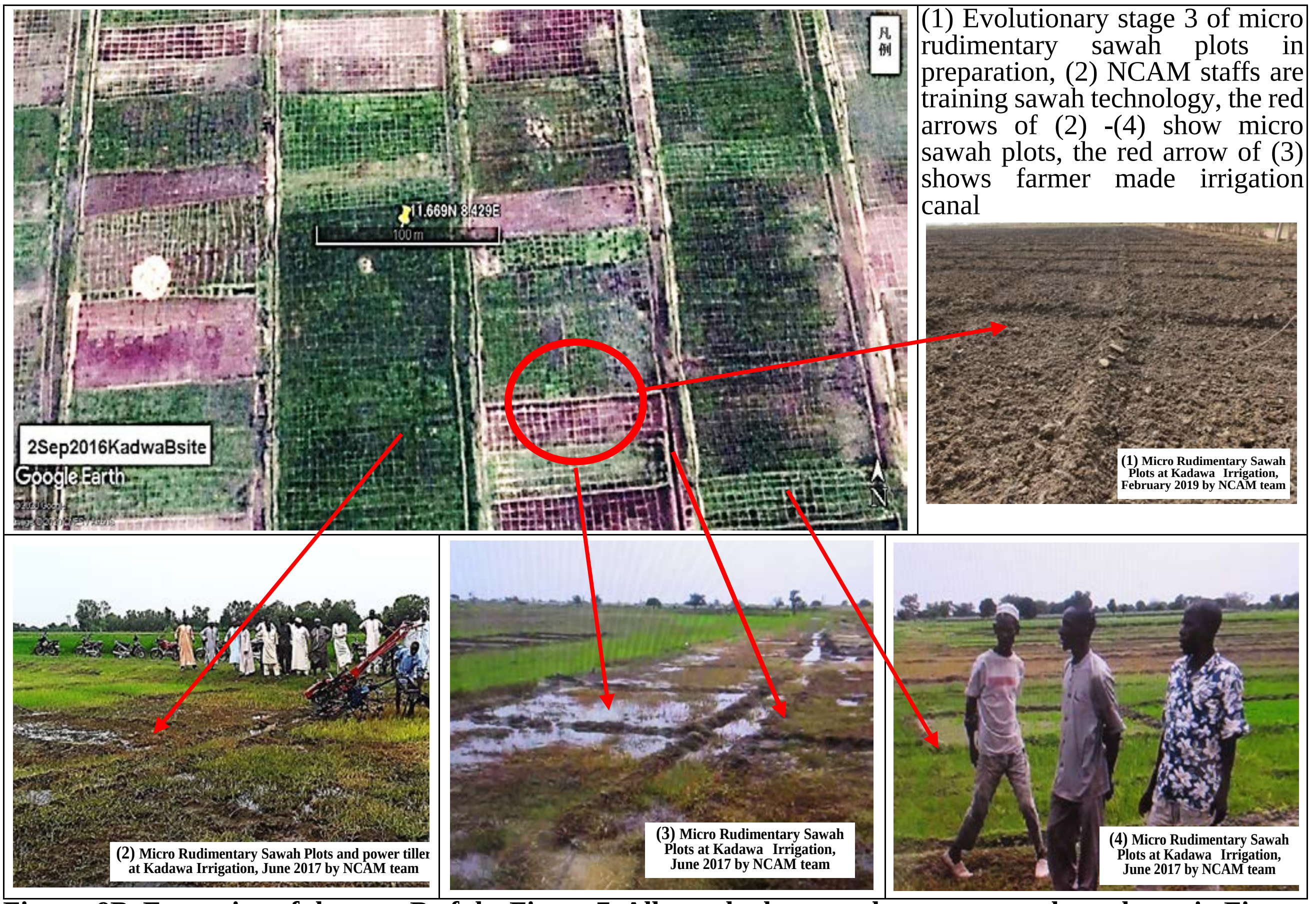

Figure. 9B. Expansion of the area B of the Figure 7. All sawah plots are almost same to those shown in Figure 9A and 9C. Photos (1)-(4) were all taken at the Kadawa irrigation site near the (B) area of Figure 9 showing micro rudimentary sawah. GPS position is 11.669N 8.429E.

As seen in the (2) photo in the Figure 9B, the size of one section of the traditional micro rudimentary sawah system (evolutionary stage 3) was the same size of power tiller, 3-5m length. Bunds are small, easy to break, and leaks water easily. This system has been continued since 1986 (observed by Wakatsuki). Thus irrigation water, fertilizer and high yielding varieties cannot work effectivly. As shown in Figure 10, the sawah technology using power tiller was demonstrated in 2017 by NCAM team under the program of Sasakawa Global 2000.

Figure 10. Sawah technology training and demonstration by NCAM sawah team using a powered tiller at the location shown in the Figure 9B (2). Photo taken on July 2017.

Within the red parallelogram, which is drawing on the background of the Figure 10, poor bunds of the micro sawah plots can be seen. The irrigated micro rudimentary sawah fields have been cultivating both for rice and vegetable for more than 30 years. Through sawah technology, poor bunds were strengthened and levelled. Each sawah plot was expanded to more than 100-200m^2, and was developed as a standard sawah plot using the paddler and the leveler attached to the power tiller. Transplanting of young healthy seedlings mage double the paddy yield from 2-3t/ha on the micro rudimentary sawah plots to 5-6t/ha on standard sawah plots.

Kano river Irrigated sites of micro sawah plots and onion/wheat (Feb 2019)

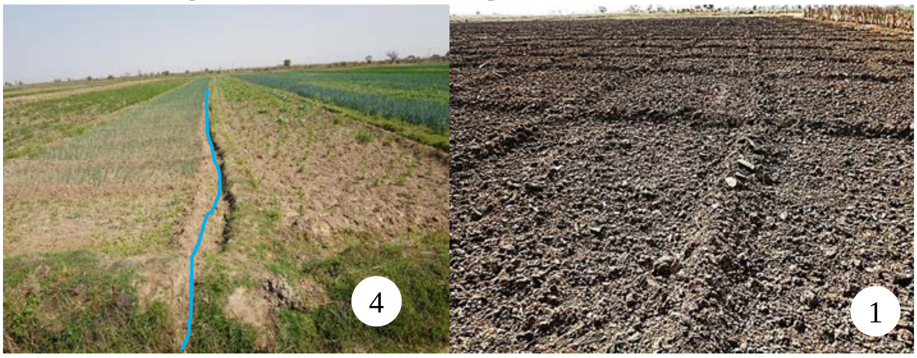

Figure 11. Irrigation systems of Kano river site. ① shows rudimentary micro sawah system platform for rice cultivation of 20-50m^2 size with no leveling and poor bunding, ②Major irriagtion canal and diversion dyke, ③ The Tiga Dam lake for irrigation, which loacation is shown at (D) site of the Figure 9, ④Irrigated wheat, onion and or other vegetables cultivation platform with tertiary irrigation canal, which is shown in blue line.

Micro sawah plots (Evolutionary Stage 3) at Archaeological site of early period of Yayoi era, about 2400-2500 years ago, Nakanishi, Nara, Japan, One plot size is 10-25m^2. (Photo by T. Komori, 2011, http://tsu-com515.my.coocan.jp/H23.11.12.Naka nishiIseki.html).

wooden weir to intake river water for irrigation

Figure 12. Irrigated micro rudimentary sawah system platform used for rice cultivation about 2400-2500 years ago at Nakanishi Archaeological site, Nara, Japan.

Figure 12 shows the archaeologically excavated irrigation micro-rudimentary sawah platform. This is similar to the majority of the farmers on the irrigated sites in Kano today, as shown in Figures 9A, 9B and 9C. At that time in Japan, 2500 years ago, the only tool used by farmers was the hand hoes. Currently African hoes are similarly major tools of the rice farmers at the Kano site. Since agricultural tools and agricultural land platform are co-evolutionary relationship, this is the only possible platform which hoe based farmers can develop and cultivate.

3-4. The synergy of eco-technology and biotechnology for improved rice cultivation

As shown in Figure 13, eco-technology, such as sawah technology, can improve the water control of growing environment, and bio-technology, which improves the variety, are two wheels of a car for improving rice cultivation. Historically, the contributions of high-yielding rice varieties to the green revolution in Asia have been overestimated, and has had the effect that rice research in SSA largely favored breeding during the past 50 years. Sawah technology research within the last 35 years has attempted to complement this research.

We use the terms Sawah Eco-technology and Sawah technology, both of which have the same content. However, when we want to clarify the comparison and contrast with Biotechnology, which is a technology that focuses on breeding as a rice cultivation improvement technology, we use the term Eco-technology, which focuses on improving the growing environment. Otherwise, omit the Eco prefix and use the word sawah technology.
Initially the target was to develop eco-technology in comparison with biotechnology to improve rice growing ecology and environment (i.e., to improve soil condition through good water control). However, since the term sawah simply describes rice growing ecology and environment, sawah technology and sawah eco-technology can be used interchangeably.

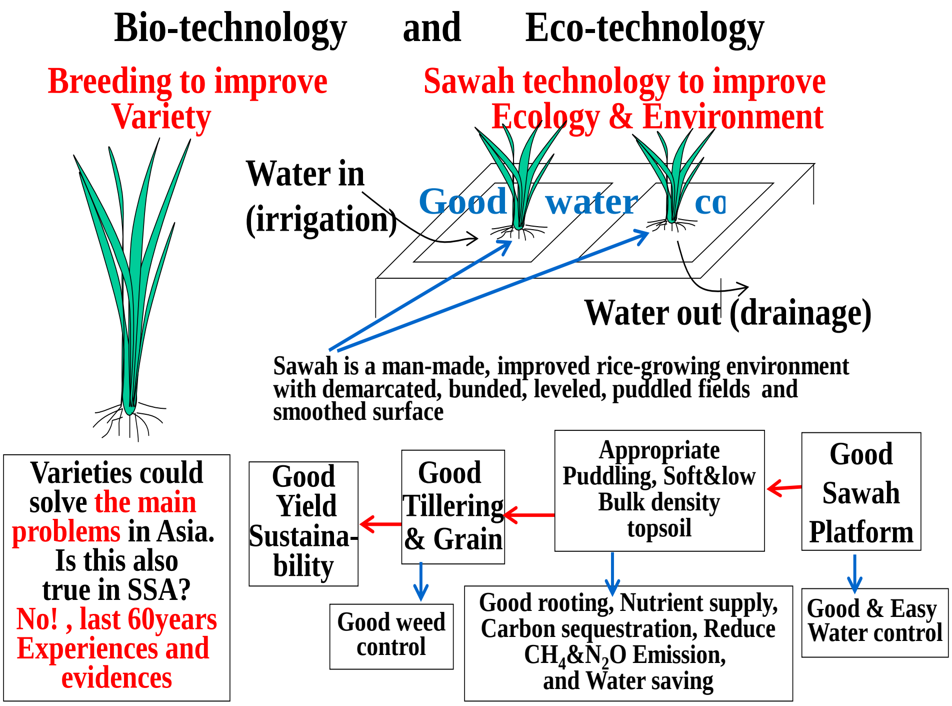

Figure 13. Both Bio- and Eco-technologies have to be developed in appropriate balance

Multi-disciplinary targets of Sawah technology and Sawah Eco-Technology are as follows:
(1) to increase productivity and sustainability of whole watersheds and/or landscapes,
(2) to be viable to local socio-economic and socio-cultural settings,
(3) to integrate agronomy, agricultural engineering and ecological sciences, and
(4) to develop interdisciplinary connections between all agricultural sciences.

4. Impact of co-evolution of improved genetic and ecological technologies on rice farming

As shown in Table 2, rice farming can be improved by two aspects of technology. Improvements in both the breeding technologies of rice, and irrigation regimes of sawah platforms have seen improvement in rice yields. Both sciences have a synergistic effect when combined, as is common with integrated management in agriculture.

Table 2. Two Aspects of technology evolution in rice farming

Evolution (improvement) of rice "variety" by breeding	**Evolution (improvement) of rice field of "sawah platform" by sawah technolgy**
(1) Domestication of Asian rice, *Oryza sativa* (Japonica, Indica, Aus / Boro), in the vicinity of China, India, Myanmar border >10,000 years ago was confirmed by Genetic studies. **(2) After that, the distribution Asian rice spread all over the world, co-evolving with sawah system platform** **(3) African rice, *Oryza Glaberrima* was domesticated in the Niger basin thousands of years ago. But Sawah platform was not not invented.** **(4) An interspecific hybrid variety (NERICA) was invented, but co-evolution with the growing environment (Sawah platform) has not been promoted.**	**(1) Archaeological studies have shown that Sawah platform was invented about 5000-7000 years ago in the middle reaches of the Yangtze River, China and has evolved. This technology was transferred to Japan 3000 years ago, and has evolved. It was similarly transferred to Asian countries and then to the world.** **(2) In SSA, Sawah technology was transferred to Madagascar about 1000 years ago and to the Sukuma land of Tanzania at least 100 years ago. In West Africa, the French government promoted the irrigation without sawah platform through the Office du Niger since 1932. During 1960s-70s Taiwan team introduced the sawah platform in Cote d'Ivoire, Senegal, Burkina Faso, Rwanda, and other SSA countries.** **(3) Since 2010, especially since 2017, Google Earth images, which are captured in chronological order, are able to depict the accelerated evolution of the sawah platform in SSA.**

The Asian Green Revolution may have overestimated the impact of high yielding crop varieties (HYV) on yield improvement. However, in Sub-Saharan Africa, research strategies have been more focused on very high expectations from varietal improvement through bio-technology such as NERICA Rice, not only by SSA countries but also by international organizations such as Africa Rice Center (AfricaRice), International Institute of Tropical Agriculture (IITA) and International Rice Research Institute (IRRI) and the Consultative Group for International Agricultural Research (CGIAR). The "*paddy*" *system* of growing rice has been improved in recent years, and is known locally in Japan as a *Suiden Platform, i.e., Sawah Platform* in Malay-Indonesian.

Recent genetic studies estimate that Asian rice, *Oryza sativa* was first domesticated 10,000 years ago and was most likely the Japonica type. This was followed by *O. indica* and *O. australiensis*. This domestication and evolution of *Oryza sativa* was considered to occur near the border areas of middle to southern China, Northeastern India and Myanmar (Huang et al. 2012, Choi et al. 2017, Mizuno et al. 2020, Zheng et al. 2016). Some reports show that *Oryza sativa* subsp. *japonica* and *Oryza sativa indica* have been domesticated independently (Cheng 2019). Asian rice has since been cultivated world-wide and has evolved further (Meyer and Purugganan 2013). The varietal evolution of Asian rice has co-evolved with developments of the sawah system.

According to Khush (1997), *Oryza* originated approximately 130 million years ago in Gondwana, with different species spreading into different continents, with the cultivated species originating from a common ancestor. African rice, *Oryza glaberrima*, was domesticated in the Niger basin, Guinean Highlands and the Inland delta of Mali approximately 3000 years ago, six to seven thousand years after the domestication of Asian rice (Buddenhagen and Persley 1978, Wang et al. 2014, Veltman et al. 2019). Various archaeological and genetic studies have also revealed that the origin of sawah-based rice farming systems used to control both water and weeds started around 5000-6000 years ago along the Yangtze river basin (Zong et al. 2007, Gross and Zhao 2014, Liu et al. 2017, Deng et al. 2015) and dispersed throughout Asia. This dual development of genetic improvement and sawah use then dispersed outside of Asia.

Sawahs were not developed in Africa possibly due to the relatively recent domestication of rice there and other unknown sociohistorical and agroecological reasons. Farming technology reached Madagascar 1200-1300 years ago through the migration of Austronesian language-speaking people from what is now the Malay-Indonesian area (Crowther et al. 2016). According to Carpenter (1978), the first appearance of *Oryza sativa* on the East African coast rice may have occurred 2000 years ago. In the 1930s, the British colonial officer noted that farmers constructed small bunds around rice fields to control water in Sukuma land, Tanzania, south of lake Victoria (Thornton and Allnut 1949, Meertens et al. 1999, Kato 2019). In West Africa, the French government established the Office du Niger in 1932 to develop one million hectares of land within 50 years to produce cotton initially and then rice (Ertsen 2006). Currently, the government of Mali (Wikipedia on Office du Niger 2020) manages approximately 100,000 ha of irrigated land mainly for rice (90%) and sugar cane (10%). Since 1960, the Office du Niger has been under the control of the Government of Mali, but with no sawah system, the average yield had been at a relatively low level of 2 t/ha up to the 1990s (Table 2). During 1960s–70s a Taiwan team transferred the Asian style sawah technology to Cote d'Ivoire, Senegal, Burkina Faso, and other SSA countries (Hsieh 2001, 2003).

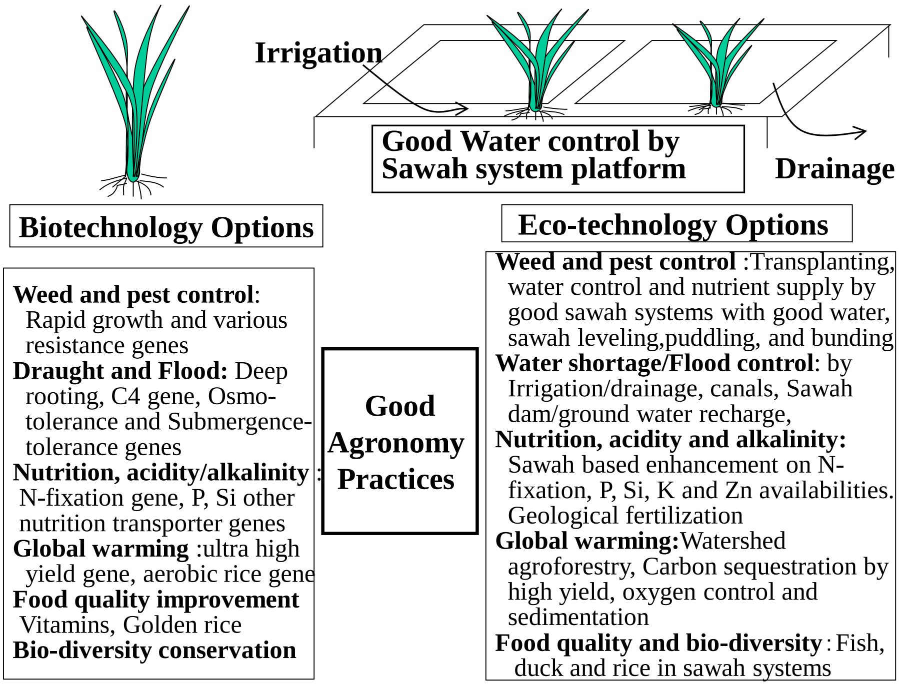

Figure 14. Good agronomy practices can be achieved through optimal balance of biotechnology and ecotechnology options in rice production.

Figure 14 shows the improvement and evolution of Good agronomic practices (GAP) in rice cultivation through research and development and trial-and-error practices of a combination of biotechnology and Sawah ecotechnology options that are most suitable for the characteristics of each local area. As shown in the figure, there are the following six items as specific goals for technological improvement of rice farming. That is, (1) weed and pest control, (2) drought and flood control, (3) nutrient management, (4) global warming control, (5) food quality improvement, and (6) biodiversity conservation. Details of each item will be explained in Sawah Technology (4): Principles and Theory, in the section of the Sawah hypothesis 2: The platform for sustainable intensification as watershed agroforestry (Africa Satoyama system) to combat global warming and the Multi functionality of sawah platform system.

5. Science, technology and innovation (STI) of the green revolution (GR)

5-1. The Asian and Latin American green revolution

The green revolution of rice and wheat in Asia is an interesting example of the synergy of science, technology and innovation in agriculture. The development, in 1935, of wheat variety NORIN-10 by Dr. Inazuka Gonjirou, breeder at Iwate Prefectural Experimental Station, Japan, was the technological innovation which made possible the green revolution (Figures 15 and 16). Through numerous trials of cross-breeding, the NORIN-10, a semi-dwarf variety, was bred from Turkey Red, a tall variety, and Fruit Daruma, a dwarf variety. This same strategy was applied to the development of IR 8 (Miracle Rice) by IRRI (International Rice Research Institute) in the 1960s (Figure 16).

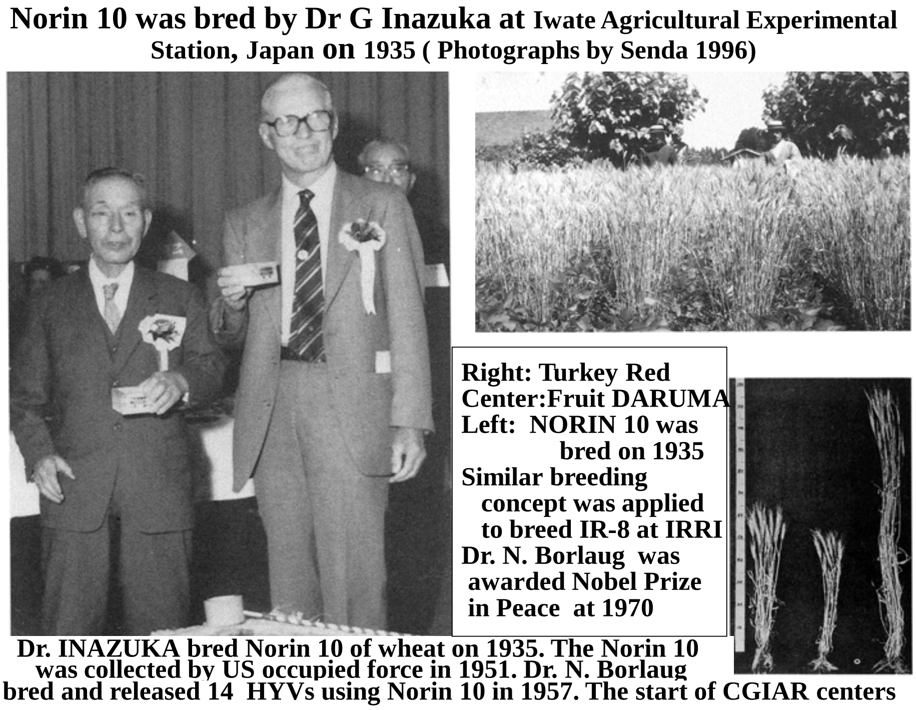

Figure 15. Dr. Inazuka and Dr. Borlaug, fathers of Green Revolution technology and innovation, respectively

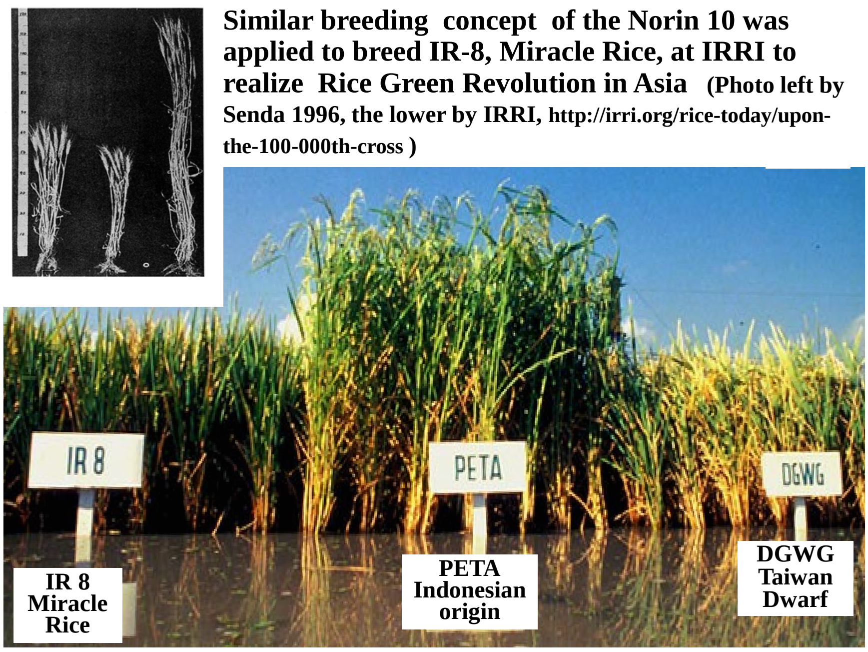

Figure 16. The Miracle Rice of IR-8 bred based on the breeding concept of Norin-10

It was after 1945 that the NORIN-10 technology became an innovation to stop the world's impending food crisis. By 1957, Borlaug developed 14 high yielding varieties (HYV) based on the NORIN-10 which was obtained from scientists in 1951 during the United States' occupation of Japan (Senda 1996, Hesser 2005). At the same time, international organizations such as CIMMYT (International Maize and Wheat Improvement Center) and IRRI were formed under Consultative Group for International Agricultural Research (CGIAR). These organization have contributed the spread of HYV (Hardin 2008).

5-2. The green revolution gene around the world

NORIN-10 was named for increased food production in developing countries in Asia and Latin America. The similar Japanese originated semi-dwarf wheat variety, "Akakomugi", also contributed to the dramatic increase in wheat production in developed countries in Europe and the United States of America after 1940 as shown in Figures 1b and 2 (Nishio 1998, Borojevic and Borojevic 2005, Daba et al. 2020).

5-3. Science of the green revolution gene

Scientific mechanisms of the semi-dwarf plant type such as NORIN-10 was elucidated by Professors Matsuoka and Ashikari at Nagoya University (Ashikari et al. 2002, Sasaki et al. 2002). They identified the semi-dwarf gene, sd1, 67 years after the development of NORIN-10 and its role in regulating gibberellin biosynthesis. Thus the scientific basis common to *Gramineae* crops, such as rice, wheat and corn, was elucidated (Tollenaar and Wu 1999, Tollenaar and Lee 2002, Zhan et al. 2020 and Matsuoka 2004) (Figures 15, 16 and 17).

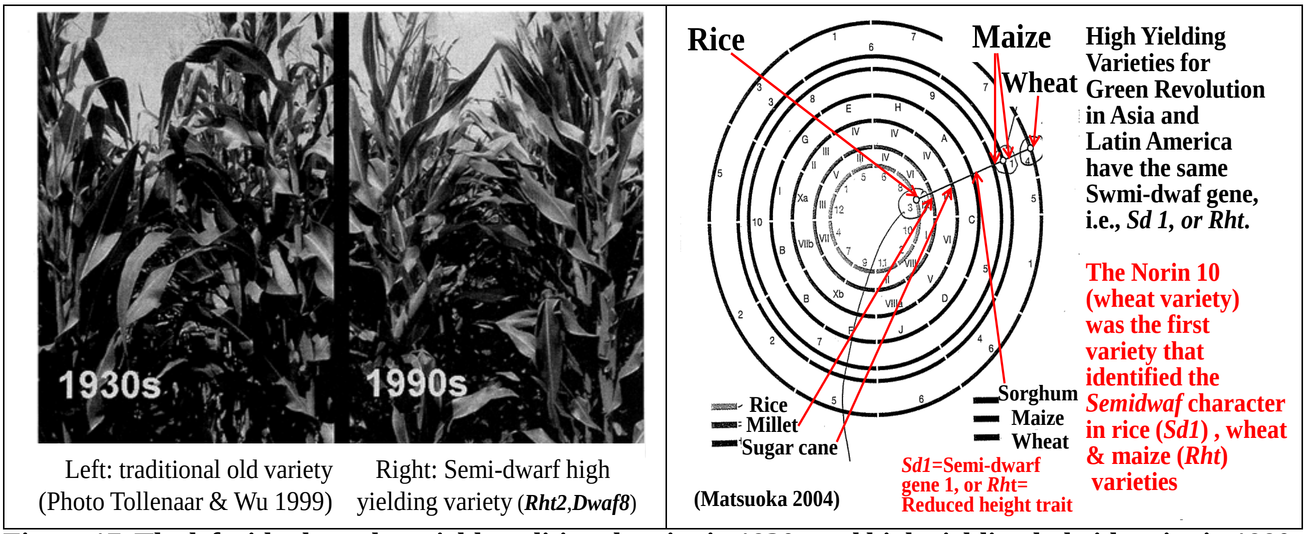

Figure 17. The left side shows low yield traditional maize in 1930s and high yielding hybrid maize in 1990s of the semi-dwarf gene *sRht2 orDwaf8*. The right side shows the major cereals of rice, millet, sugar cane, sorghum, maize, and wheat, all of which are belong to *Poaceae* or *Gramineae* family, all of which are thought to have a common semi-dwarf gene (*sd1 or Rht 1 or 2*).

6. The core technologies to realize the green revolution in SSA

6-1. Modern variety in Asian green revolution

Figure 18 and Table 3 show the estimation of the relative contributions of the three major rice cultivation techniques that fueled the green revolution of rice cultivation in Burma (Myanmar), Bangladesh, China, India, Indonesia, Philippines, Sri Lanka and Thailand (Herdt and Capule 1983). As shown in Table 3, the total paddy production increase in eight Asian countries during the 15 years period from 1965 to1980 was 117,379,000 tons. The biggest factor was irrigation, which contributed an increase of 28.8% (33,839,000 tons), the fertilizer contribution was 24.4% (28,597,000 tons), and the MV (Modern Variety or High Yielding Variety) was 23.3%

(27,370,000 tons). The effect of other factors, such as increase in the use of rain-fed and upland areas was 23.5% (27,573,000 tons).

Since these modern varieties have the semi dwarf gene sd1, the plant type is short, upright and the yield is high because it does not lodge under excess fertilization. However, the small grass type requires irrigation facilities to make transplanting possible, and good water management in order to compete with weeds. Therefore, these three factors are interrelated, and it is difficult to separate and evaluate them individually.

Table 3. ContributionContribution of Specified Factor to Rice Production Increases Achieved from 1965-1980

Year	Contribution of factors				
	MV effect	Fertilizer effect	Irrigation effect	Other factors (residual)	Total observed growth in output[a]
	Output increases (thousand t paddy)				
Burma	647	353	685	167	1,852
Bangladesh	420	1,284	1,091	2,759	5,554
China	13,231	11,507	16,153	9,609	50,500
India	7,998	10,867	11,209	5,078	35,152
Indonesia	3,162	2,680	2,773	4,998	13,613
Philippines	849	1,009	801	615	3,274
Sri Lanka	241	215	262	316	1,034[b]
Thailand	822	682	865	4,031	6,400
Total of above	27,370	28,597	33,839	27,573	117,379
	Value (US$ million)[c]				
	4,516	4,718	5,583	4,549	19,367

[a]Difference between 1980 and 1965 production (USDA FG38-80). [b]A 3-year average was used for 1965 because 1965 yields were unusually low. [c]Paddy was valued at $165/t.

Herdt RW and Capule C. 1983. Adoption, spread, and production impact of modern rice varieties, pp61, http://books.irri.org/9711040832_content.pdf

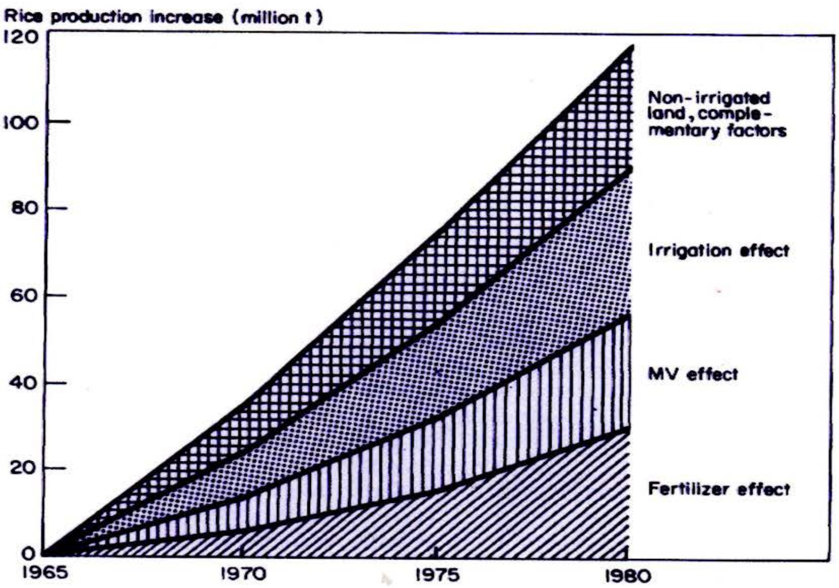

Figure 18. Estimated Contribution of 4 Separate Factors To Rice Production in 8 Asian countries, 1965-80.

Herdt RW and Capule C. 1983. Adoption, spread, and production impact of modern rice varieties, pp61, http://books.irri.org/9711040832_content.pdf

In Asia, both traditional irrigation and organic fertilizer technologies have existed for more than 1000 years, and modern chemical fertilizer technology was established during the period 1840–1920. The only new addition among three green revolution technologies was MV (modern variety). As stated by Khush (1997), the future development of bio-technology opens up a wide range of possibilities as follows: (1) high yield potential, (2) short growth duration, (3) multiple disease and insect resistance, (4) superior grain quality, and (5) tolerance for problematic soils. Thus the future prospects of MV in Asia appear to be quite positive. These prospects in SSA were overestimated when applied to rice cultivation.

International Organizations under CGIAR (Consultative Group for International Agricultural Researches) such as IITA (International Institute of Tropical Agricultural) and AfricaRice (African Rice Center, formerly called WARDA, West Africa Rice Development Association) were established in the 1970s and were aimed at realizing similar success of the Asian and Latin American Green Revolution (GR) in SSA. Since the success of the research at CIMMYT and IRRI had been done mainly through the development of high yielding variety (HYV) technology, IITA and AfricaRice applied a similar breeding strategy. In terms of sustainable yield increase, GR has not been realized through breeding research and development alone. It is clear from the statistical data (FAOSTAT 2017-2022, AQUASTAT 2019) as shown in Sawah Technology (1) that the rice production of SSA has been increasing exponentially, especially in West Africa. A new-world rice-producing area is being formed. However, a considerable part of this increase in production is mainly due to expansion in cultivated area resulting in forest and soil degradation. Thus, sustainable yield increase and realization of green revolution are the most important current tasks of governments of SSA countries. It is also a core target for sustainable development of the UN 2030 Agenda.

6-2. The core technologies to realize African Green Revolution

Of the three green revolution technologies, breeding research for good high yielding varieties (HYV), through biotechnology, played a central role in Asia. International organizations such as AfricaRice, IITA, and IRRI have conducted research on good HYV for the past 50 years, and have successfully developed many good HYVs. An example is AfricaRice's NERICA variety, which has been available since 2000. The international non-government organization (NGO) of AGRA (Alliance for Green Revolution in Africa), which was founded in 2006 has also spent a large amount of money on the development and dissemination of successful varieties. However, it is now clear that good varieties alone will not succeed in the green revolution in SSA. In Asia, irrigation technology and fertilizer technology were important along with breeding technology. The key technology required will be discussed in Sawah Technology 4 (Principles and Theory).

7. Scientific errors by IITA research (1987/88)

Gadza village is located 5 km south of Bida city. The area surrounded by two light green lines shows the lowland of the Emikpata river (blue line), which joins the Niger river. The geology is Nupe sand stone, and countless springs flow into the Emikpata river during the wet season (August to November).

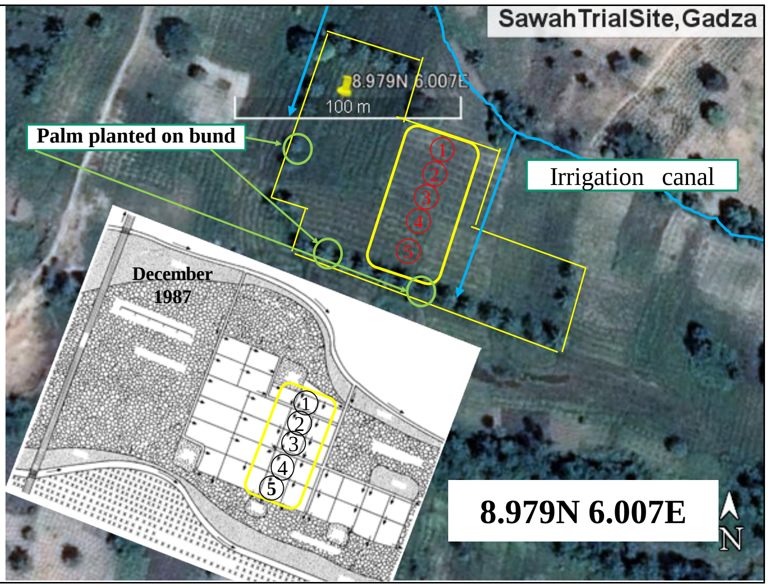

Figure 19. Sawah platform development trial site during 1987–1989 (Google Earth, November 2016): 8.979N 6.007E, which is 1km south from Gadza village. The figure on the right is an enlarged view of the trial site of approximately 1 ha, surrounded by the thin yellow line. Varietal tests were conducted from ① fringe to ⑤ valley bottom within the thick yellow lines along the top sequence. The blue line shows the irrigation canal installed by Niger state ADP before 1987. Irrigation water was introduced from the two blue arrow points.

①Farmer’s rudimentary micro sawah system in 1987, ②Before standard sawah system in August 1987, ④ The same position of ②, after standard sawah system in October, 1987, ③ all sawah plots were puddled and leveled by power tiller, September 1987.

Figure 20 A. ① farmers’ traditional rice farming platform which was either irrigation or rainfed before sawah platform was developed. The traditional systems were commonplace in the inland valleys surrounding the sawah trial site shown in Fig. 19. Photographs ②, ③ and ④ of Fig.20A and ② in the Fig. 20B were taken almost at the same position of the point of ⑤, which location is indicated at the variety trial plot shown in the thick yellow frame of Fig. 19. Note the big tree marked in red circles is common to all photographs. Photograph ② of the Fig. 20A shows the field prior to sawah development (August 1987), photograph ④ shows bund repairing to stop water leaking in post sawah development (September 1987). Photograph③ shows a puddling and levelling operation by a turtle power-tiller made in Philippines (September 1987).

①Various varieties along sawah topo-sequence, the photo taken from bottom to fringe, October 1987, ② Irrigation canal for ® **farmers’ rudimentary micro sawah platform, evolutional stage 3,** and for on-farm sawah system trail, September 1987, ③The same position of ① the photo taken from fringe to bottom in December 1987, ④ Field evaluation of sawah platform trial by IITA’s top management team on December 1987.

Figure 20 B. Photographs ① and ③ shows varietal trial sites, the results of which are shown in Table 5. Photograph ② shows an irrigation canal for trial plots. ® shows local farmers’ rudimentary irrigated micro sawah platform, Photograph ④ shows the field observation by IITA’s top research management team (December 5th 1987). Members are a Board of Trustees, Deputy Director General for Research, Director of Resource and Crop Management Program, and Director of Rice program. A small oil palm seedling planted on the bund can be seen (yellow circle). These are the same palm trees seen in green circles shown in Figure 19. A row of dense canopy of mature oil palm trees (planted on the outer bunds of the newly developed Sawah system) indicates the location of the bunds at the time of the trial, i.e., 29 years ago at 1987.

Table 4 shows topsoil fertility of this topo-sequence from ① fringe to ⑤ bottom position, which location is shown in Figure 19. Soils are extremely sandy, very low in carbon, nitrogen, and effective cation exchange capacity. Levels of available phosphorus (Bray No.1), and exchangeable calcium, potassium and magnesium are very low (Wakatsuki et al.,1989; Issaka et al., 1996; Issaka, 1997; Issaka et al., 1997).

Table 4. Soil fertility characteristics along a topo-sequence of an inland valley at Bida, Nigeria.

Topo-position	T-C (%)	T-N (%)	BrayP1 ppm*	Exchangeble Cations(Cmol/kg) Ca	K	Mg	eCEC	Sand (%)	Silt (%)	Clay (%)
①Fringe	0.17	0.015	0.9	0.47	0.06	0.16	1	94	3	3
②Middle	0.54	0.046	4.8	0.86	0.09	0.27	1.6	81	14	5
③Middle	1.16	0.066	1.2	1.27	0.14	0.46	2.2	66	27	7
④Bottom	0.93	0.068	1.1	1.02	0.1	0.41	2	72	11	17
⑤Bottom	0.72	0.056	1.2	1.13	0.1	0.43	2.1	72	11	17

Note: For the sampling points, please refer to the Google Earth image shown in Figure 19.

As seen from the result shown in Tables 5 and 6, in the early stage of on-farm research (1986-88) it was very clear that if appropriate sawah system platforms were developed and managed at standard levels, farmers could achieve paddy yield higher than 5 t/ha, even in very poor sandy soils in SSA. The exception to this was extremely poor sandy fringe soils such as that of ①, with clay less than 5% (see Table 4), where paddy yields were 2.1-4.9 (mean 3.3) t/ha even under recommended fertilizer application. All of the remaining sawah plots of ②−⑤produced a mean yield of 5–6 t/ha.

Table 5. Rice yields (t/ha at 14% moisture) in newly constructed sawah platforms with irrigation located in different topographical positions, as shown in Figure 17 (Wakatsuki et al. 1987, Wakatsuki et al. 1988, Wakatsuki et al. 1989).

Variety	Fringe ①	Middle ②	Middle ③	Bottom ④	Bottom ⑤	Mean	SD%
ITA 230	4.7	3.6	5.7	6.4	7.6	5.6	24.6
ITA 306	4.9	4.1	4.3	6.6	7.5	5.48	24.4
ITA 312	3	5.5	5.3	6.9	6.9	5.52	25.9
TOX 3109-75-4-1	3.3	4.2	5.4	6.2	5.6	4.94	21.2
TOX 3114-10-1-1	2.6	3.8	2.8	4.7	4.5	3.68	23.2
TOX 3118-2-E2-2	5	5	5.5		6.6	5.53	11.8
TOX 3118-6-E2-3	3.3	6.3	4.7	7.6	7.1	5.8	27.4
TOX 3118-47-1-1	3	5.3	5.2	5.8	6	5.06	21.2
TOX 3118-78-2-1	3	6.4	5.6	5.6	6.5	5.42	23.4
TOX 3133-56-1-3	2.1	5.3	3.4	6.7	6.2	4.74	36.6
ITA308	2.7	5.9	6.9	4.8	5	5.06	27.6
FARO 10	2.1	4.9	4.3	4.8	6.2	4.46	30
Mean	3.3	5.03	4.9	6.01	6.3		24.8
SD%	29.5	17.9	21.5	15.2	14.3	19.7	
*Fertilzer ammount was 90-60-30 kg/ha, N-P2O5-K2O							

Table 6. Paddy yield (ton/ha, at 14% moisture) responses of rice varieties and fertilizer levels in traditional paddy fields and improved paddy (sawah) platform in inland valleys at Bida, Nigeria (IITA 1988, Wakatsuki et al., 1987, 1988, 1989)

Platform level	Farmers Paddy Platform				Improver Paddy(Sawah) Platform				Mean	SD%
Management le	Poor** water condition		Good** water condition		Farmer managed		Researcher managed			
Fertilzer level*	15-15-15	90-60-30	15-15-15	90-60-30	15-15-15	90-60-30	15-15-15	90-60-30		
Local(FARO15)	1.2	1.48	1.86	2.65	3.6	3.3	4.7	6.2	3.1238	51%
ITA212	1.04	1.48	2.12	3.27	3.2	4.6	4.4	4.7	3.1013	43%
ITA306	1.82	2.32	2.55	3.58	4.9	6.8	4.6	6.1	4.0838	42%
FARO29	1.04	1.39	2.43	3.32	3.1	6.1	4	5.3	3.335	49%
Mean	1.275	1.6675	2.24	3.205	3.7	5.2	4.425	5.575	3.4109	46%
SD%	25%	23%	12%	11%	19%	26%	6.10%	11%	17%	
(Max-Min)	0.78	0.93	0.69	0.93	1.8	3.5	0.7	1.5	1.3538	
(Max-Min)/Min%	75%	67%	37%	35%	58%	106%	17.50%	32%	53%	

*Farmer's level=15-15-15Kg/ha of N-P2O5-K2O, Recommended level=90-60-30kg/ha
**Good/poor means fields under water saturation or flooded for a period of less or more than half of the growing period

Table 6 summarizes the results of various trials and on-farm surveys by IITA's resource and crop management program (1986 to 1988), including the above sawah trial results from 1987 to 1989 (IITA 1986, IITA 1987, IITA 1988, Wakatsuki et al. 1987, Wakatsuki et al. 1988, Wakatsuki et al. 1989, Carsky and Masajo 1991). This research suffered from rudimentary but big essential errors in scientific evaluation by IITA's top management team as shown in Figure 21(IITA 1988). IITA's top research managers at the time, who were experts in Western-style upland crop agriculture, probably stemmed from a basic lack of understanding of Asian-style irrigated sawah (paddy) based rice cultivation. Thus, final evaluation confused about the cause and effect of essential agronomic factors in irrigated sawah based rice culture. The work showed a lack of understanding about the basic functions of the sawah (paddy) platform in rice cultivation. Appropriate water control enables effective use of fertilizers, and also serves as a platform for proper weed management (Sawah Technology (4)).
The IITA annual report (1993, in page 34) summarized as follows: "Past research on inland valleys in Africa has focused almost exclusively on rice cropping. Often, the assumption was that irrigated rice paddies of Asia could or should simply be reproduced in Africa to repeat the green revolution. It has been clear from experience for two decades now that this will not happen".

Table 7. Difference between the yields of a farmer's paddy and an improved sawah.

(1) **Between farmers' paddy platform of poor water condition and the improved sawah platform by researcher management:243%difference**
(a)Under farmers' fertilization level of 15-15-15, mean increase was 4.43-1.28=3.2t/ha, 250% increase
(b)Under recommendation level of 90-60-30, mean increase was 5.6-1.67=3.93t/ha, 235% increase
(2) Between farmers' paddy platform of poor water condition and the improved sawah platform by farmers' management:200% difference
(a)Under farmers' fertilization level of 15-15-15, mean increase was 3.7-1.28=2.42t/ha, 189% increase
(b)Under recommendation level of 90-60-30, the mean increase was 5.2-1.67=3.53t/ha, 211% increase
(3) Between farmers' paddy platform of Good water condition and the improved sawah platform by researcher management:86% difference
(a)Under farmers' fertilization level of 15-15-15, mean increase was 4.43-2.24=2.19t/ha, 98%increae
(b)Under recommendation level of 90-60-30, mean increase was 5.58-3.21=2.37t/ha, 74%
(4) Between farmers' paddy platform of Good water condition and the improved sawah platform by farmers' management: mean 64% difference
(a)Under farmers' fertilization level of 15-15-15, mean increase was 3.7-2.24=1.46t/ha, 65% increase
(b)Under recommendation level of 90-60-30, the mean increase was .2-3.2=2.0t/ha, 63% increase

Using the data of the Table 7, the effect of the two different rice cultivation platforms was evaluated as the average paddy yields increased of four varieties of each fertilizer level 15-15-15 and 90-60-30 between the farmers' paddy (Sawah) system and the improved paddy (Sawah) system platform, which gave (250+235+189+211+98+74+65+63)/8=148%

(1) **Calculation Mistake on the Effect of Sawah System Platform:** As Tables 6 and 7 show the effect of sawah improvement by farmer management being 129.3%, which is the mean of (2) and (4) of the Table 7, i.e., (211+189+65+63)/4 and by researchers management being 164.3%, which is the mean of (1) and (3) of the Table 7, i.e., (250+235+98+74)/4. Thus mean effect of paddy (sawah) improvement should be 148%. But IITA's research highlight described 90% as seen in the Figure 21.
(2) **Dramatic increase of improved sawah platform both under 15-15-15 fertilization and 90-60-30 fertilization. The result of (1) and (2) of the Table 7 showed that the increase was 221% = (250+235+189+211)/4.** There was no significant difference between management by a farmer or researcher.
(3) **The water condition of farmers' paddy system (good and poor) led to a mean difference of 84%. (a) Under farmers' fertilizer ratio of 15-15-15, the variety mean increase was 2.24–1.275 = 0.965 t/ha, an increase of 76% was seen, (b) Under recommended fertilizer ratio of 90-60-30, the variety mean increase was 3.21-1.67 = 1.54 t/ha, there was an increase of 92%.** Some farmers' paddy systems have favorable water condition owing to good topographic position, good rain, and an irrigation system as shown in Figure 20A ① and Figure 20 B ®. However, the mean paddy yield was 3.2 t/ha even under the recommended fertilizer ration. This means farmers have no incentive to use the recommended fertilizer ratio.
(4) **The effect of management of improved sawah platform between farmers and researchers: mean**

13.4% difference. (a) Under farmers' fertilizer ratio of 15- 15-15, the variety mean increase was 4.425–3.7 = 0.725 t/ha, an increase of 19.6%. (b) Under the recommended fertilizer ratio of 90-60-30, the variety mean increase was 5.575–5.2 = 0.375 t/ha, i.e., an increase of 7.2%. This suggests that once a proper (standard) sawah platform has been developed, management requirements are less; therefore, an increase in the scale of the technology will be more viable.

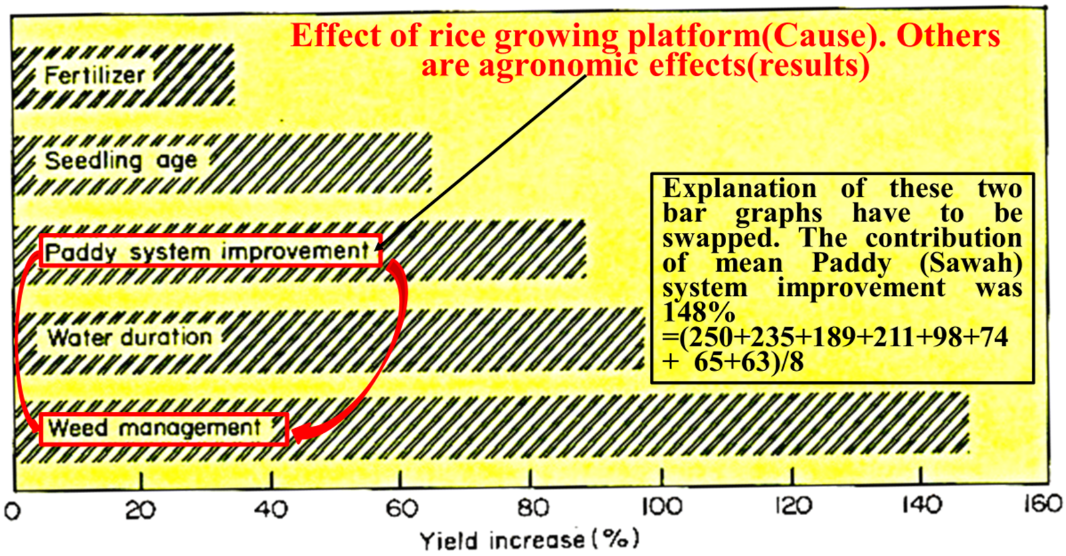

Fig.21. Relative contribution to yield increase (%) in rice by some agronomic factors in Inland Valleys (Cited from IITA Annual Report and Research Highlights 1987/1988, page 60, Figure 13(IITA 1988)

The Figure 21 presentation in IITA's Research Highlight (1987/88) shows the lack of basic understanding of the sawah based rice agronomy. That is, irrigated *Paddy* (Sawah) system platform is a water control platform. Good sawah platform is the basic cause to get good water control. Through the good water control, good weed management (effect 1) as well as other good agronomic practices (effect 2) can operate to get high and sustainable paddy yield (final effects/results). However, the research highlight shown in Fig. 21 is a result of the incompetence of rice scientists at IITA's research management team in 1986/87, who failed to understand the consequences of weeds flourishing due to poor water management platforms, such as sawah(*paddy*) platform.

(5) **Fertilizer and Good variety can perform well only under the good Sawah System Platform**

Table 8 compares the effect of fertilization and variety, of which **1(1)-1(4)** compare the effect of the fertilizer application rates of 15-15-15(farmers' rate) and the recommended rate of 90-60-30 under the farmers' paddy platform and the improved sawah (paddy) platform. Farmer's paddy platform was separately evaluated between the poor water condition, which is an average case, and the good water condition due to irrigation, good geographical location, and or the blessed with rainfall. The difference in the management of sawah (paddy) platform by farmers and by researchers was also examined.

(1) In the case of farmers' paddy platform under poor water condition, the yield increase by increasing 15-15-15 to recommended amount of 90-60-30 was 1.67-1.28 = 0.39t / ha. However under good water condition, the yield increase was 3.2-2.2 = 1t / ha. The fertilization effect was large depending on the difference in water conditions. Mean yield increase was only 0.7kg / ha on for farmers' platforms. The improved sawah (paddy) platform was 5.2-3.7 = 1.5t / ha for farmer management and 5.6-4.4 = 1.2kg / ha for researcher management. The mean yield increase was 1.4kg / ha. The improved Sawah (Paddy) platform has a larger incentive for standard fertilization than the farmers' platform.

(2) The most significant increase was the difference between the farmers' paddy platform and the improved sawah (paddy) platform. At the fertilizer application ate of 15-15-15, the average yield increase was (3.7 + 4.43) / 2- (1.28 + 2.24) /2=2.31t/ha. At the standard fertilizer rate of 60-60-30, the average yield increase was (5.2 + 5.58) / 1- (1.67 + 3.2) /2=2.96 kg / ha. The fertilization efficiency increased remarkably. On the other hand, in the farmers' paddy platform, when the water conditions are poor, the difference in the amount

of fertilizer application between 15-15-15 and 90-60-30 was only 0.39t / ha. It is clear that there is no incentive to increase the fertilization rate under farmers paddy platform. On the other hand, if farmers can grow rice on the improved sawah (paddy) platform, farmers have strong reason to increase the amount of fertilizer application from 15-15-15 to 90-60-30, since the yield will increase by 5.2-1.28 = 3.92kg / ha.

Table 8 Effects of fertilizer amount and variety difference

1. Effect of fertilizer: 35% increase =(31+43+41+26)/4, which is based on the following calculation using the data of Table 7

(1) In farmers' paddy system of poor water condition:
fertilizer increase gave 1.6675-1.275 = 0.39t / ha, 31% increase

(2) In farmers' paddy system of good water condition:
fertilizer increase gave 3.205-2.24 = 0.97t / ha, 43% increase

(3) In improved sawah platform by farmer management:
fertilizer increase gave 5.2-3.7= 1.5t / ha, 41% increase

(4) In improved sawah: platform by researcher management:
fertilizer increase gave 5.576-4.425 =1.151t/ ha, 26% increase

2. Effects of varieties: The range of increase in the following 4 water management systems and total variation of fertilizer application rates 15-15-15 and 90-60-30 was 17.5-106% with an average increase of 53%.

(1) In farmers' paddy system of poor water condition:
The maximum increase by variety was 1.82-1.04=0.78t/ha, **75% increase under 15-15-15 fertilization**
The maximum increase by variety was 2.32-1.39=0.93t/ha, **67% increase under 90-60-30 fertilization**

(2) In farmers' paddy system of good water condition:
The maximum increase by variety was 2.55-1.86=0.69t/ha, **37% increase under 15-15-15 fertilization**
The maximum increase by variety was 3.58-2.65=0.93t/ha, **35% increase under 90-60-30 fertilization**

(3) In improved sawah platform by farmer management
The maximum increase by variety was 4.9-3.1=1.8t/ha, **58% increase under 15-15-15 fertilization**
The maximum increase by variety was 6.8-3.3=3.5t/ha, **106% increase under 90-60-30 fertilization**

(4) In improved sawah: platform by researcher management
The maximum increase by variety was 4.7-4.0=0.7t/ha, **17.5% increase under 15-15-15 fertilization**
The maximum increase by variety was 6.2-4.7= 1.5t/ha, **32% increase under 90-60-30 fertilization**

Table 8-**2(1)-2(4)** compares the differences of 4 rice varieties at both fertilizer ratios of 15-15-15 (farmers') and 90-60-30 (recommended) under the farmers' and improved sawah platforms.

(a): In the case of farmers' paddy platform under poor water condition, the maximum yield difference under 15-15-15 fertilization was 1.82-1.04 = 0.78t/ha, under 90-60-30 fertilization it was 2.32–1.39 = 0.93 t/ha.

(b): In the case of good water conditions, yield difference was 2.55-1.86 = 0.69 t/ha at 15-15-15 fertilization ratio, and 3.58-2.65 = 0.93 t/ha under 90-60-30 ratio.

(c) In the case of the improved sawah platform under farmers' management, yield difference was 4.9-3.1 = 1.8 t/ha at 15-15-15 fertilization ratio and it was 6.83.3 = 3.5 t/ha at 90-60-30 fertilization rate. The research-managed sawahs yield difference was 4.7-4 = 0.7 t/ha at 15-15-15 fertilization ratio, and under 90-60-30 ratio was 6.2-4.7 = 1.5 t/ha.

(d) The most significant increase was the difference between the paddy platforms. Under 15-15-15 fertilizer ratio, mean yields of the 4 varieties were 1.28 t/ha under farmers' paddy of poor water condition, 2.24 t/ha (75% increase) under farmers' paddy of good water condition, and 3.7 t/ha (189% increase) under improved sawah of farmers' management, 4.43 t/ha (246% increase). Under 90-60-30 recommended fertilization, variety difference was more significant, i.e., mean yields of the 4 varieties were 1.67 t/ha under farmers' paddy of poor water condition, 3.21 t/ha (92% increase) under farmers' paddy of good water condition, 5.2 t/ha (211% increase) under improved sawah of farmers' management, 5.58 t/ha (237% increase) under improved sawah of researcher management.

(e)It has been long argued in the last 50 years that increasing the fertilizer application rate is the way forward for the green revolution in SSA, but this study suggests otherwise. Another assumption is that good high-yielding varieties are crucial, but this is also not supported by the data. Major improvement in rice yield in SSA will come when the lack of proper agricultural sawah platform and its management is recognized.

8. Mean paddy yield of 23 rice cultivars in irrigated sawah, rain-fed sawah and non-sawah platforms under high input as well as low input cultivation (Ofori et al., 2005)

Table 9. Mean paddy yield of 23 rice cultivars in three major rice platforms under low input and high input agronomic practices, i.e., (IS): Irrigated sawah platform, evolutional stage 4 or 5, (RS): Rainfed sawah platform, evolutional stage 2 or 3, and (UBLL): unbunded/unleveled lowland non-sawah platform, evolutional stage 1, 2, or 3*

Entry		Irrigated Sawah Platform(IS)		Rainfed Sawah Platform (RS)		Non sawah Platform(UBLL)	
No.	Cultivar	High input**	Low input***	High input**	Low input***	High input**	Low input***
				(Mg ha $^{-1}$)			
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	2.1	2	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	1.8	0.4
6	BOAK189	7.0	3.8	3.7	2	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	2.3	2.3	0.6
9	IR5558	7.9	4.0	3.8	2	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	2.2	1.9	0.4
12	C123Cu	8.9	4.1	4.2	1.9	2	0.4
13	CT9737	6.3	4.0	4	1.7	1.9	0.6
14	CT8003	7.3	3.8	3.8	1.7	2	0.5
15	CT9737-P	8.2	4.0	4.3	1.8	1.2	0.5
16	WITA 1	7.6	3.6	3.3	1.8	0.9	0.3
17	WITA 3	7.6	3.5	4.1	2	1.3	0.5
18	WITA 4	8.0	4.1	3.7	2.1	1.5	0.3
19	WITA 6	8.0	3.5	4	2.3	1.4	0.3
20	WITA 7	7.3	3.7	3.8	2.2	2	0.4
21	WITA 9	7.6	4.4	4.5	2.8	2	0.6
22	WITA 12	7.6	4	3.8	1.9	1.8	0.4
23	GK88	7.5	3.8	3.5	2	1.8	0.5
	Mean n=23	7.2	3.8	3.8	2	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

Entry 1-7: Early-maturing cultivars, Entry 8-23: Medium-maturing cultivars.
***Cited from Ofori et al (2005), **High input level:45-45-45(N-P2O5-K2O) as basal application and 45kgN at panicle initiation with herbicides (Propanil and Weedon) application and manual weeding at 42DAT (days after trans planting. ***Low input level: 20kg N after manual weeding approximately 40days after sowing (DAS) with manual weeding at approximately 30DAS. Both IS and RS were ploughed, puddled and transplanted. UBLL were slash and burn as well as direct sowing by dibbling.**

Table 9 shows the mean paddy yield of 23 rice cultivars under major three rice cultivation platforms used in SSA: irrigated sawah (IS: evolutional stage 4 or 5), rainfed sawah (RS: evolutional stage2 or 3), and upland rice style, non-bunded and non-leveled, non-sawah lowland platforms (UBLL: evolutional stage 1or 2 or 3). The entries No.1-7 are early maturing cultivars of 80-130 growing days. Entries No. 8-23 are medium maturing cultivars of 130-160 growing days. Yields under both high input and low input agronomic practices were compared. These farm trials were conducted in an inland valley of the Biem river (Figure 6) near Biemso No.2, (Google location is 6.9011N 1.8654W), Kumasi, Ghana, and were done in the same manner as in Fig. 19–20 at Gadza Bida, Nigeria. The results of Table 9 support those of Table 8. The effects of various agronomic practices, including varieties, are basically limited by the quality (evolutional stage) of the rice cultivation platform available to farmers. In the upland cultivation environment, it is difficult to increase the yield higher than 2 t/ha even with high-input agronomy. Fertilizer efficiency is very low, and water control is impossible, thus weed management are difficult. Even with high input agronomy using high-yielding varieties, it is difficult to achieve 4t/ha under a rain-fed cultivation platform.
The yield of 4t/ha or more, which is the basic target of the green revolution, can be achieved only by standard

rice agronomical practices under the standard sawah platform. What is clearly shown in sections 7 (Table 6) and 8 (Table 9) is that international research institutes concur that rice yield improvement in SSA should be facilitated by improving rice varieties. However, the development of Eco-technology, such as sawah technology will maximize the yield of such varieties. In other words, the misunderstanding that Asian success strategy should be valid in SSA, still has a universal understanding in SSA. This study has shown that, historically, improvements in rice production have focused on breeding for high yielding varieties. However, improvements in sawah platform design and skills for development and management are crucial in SSA to maximize the advantages of breeding strategies. It seems that international research organizations were (are?) not recognizing this need for synergy.

9. The trend of irrigation in SSA during 1961-2012 and the irrigation potential in SSA

The distribution of flat wetland soils in Africa (Figure 22, cited from Van Dam and Van Diepen (1982), world distribution of rain fall (Figure 23), and current and potential of world regional irrigated agriculture (Figure 24) are shown. It is worth mentioning here that the irrigation potential of Sub Sahara Africa is more than 10-20 times higher than the current level, which is comparable to South Asia, 50 million ha for rice and 50 million ha, for other crops and vegetables (Figure 24).

Figure 22 shows only large-scale wetlands, such as the flood plains and inland as well as coastal basins (deltas) in Sub-Saharan Africa (SSA). Van Dam and Van Diepen (1982) and Andriesse (1986) published the area estimation as follows, i.e., 108 million ha for inland basins (deltas), 30 million ha for floodplain, and 17 million ha for coastal swamps. However, there are numerous small inland swamps and valleys in all agro-ecological zones of SSA. Its total area is estimated to 85 million ha (Van Dam and Van Diepen 1982, Andriesse, 1986)

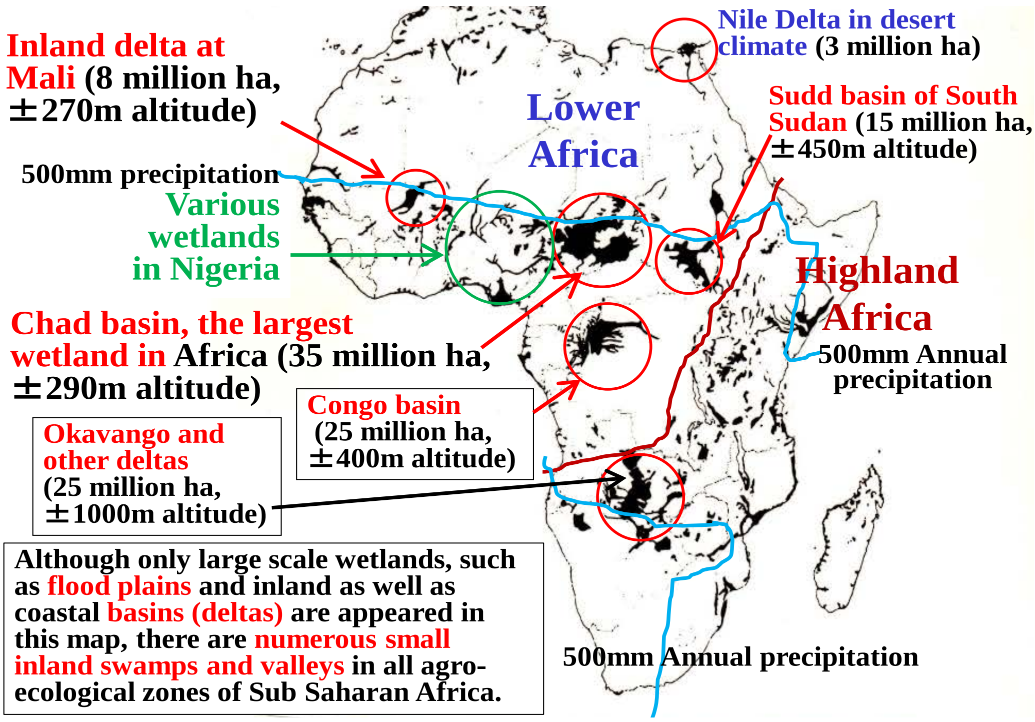

Fig. 22. Distribution of flat wetland soils in Africa (van Dam and van Diepen 1982, cited by Andriesse 1986) All explanations of the red, blue, brown, black and green areas are added by the authors.

Based on the "Soil maps of Africa" (FAO-unesco 1977) types of soils and areas of distribution suitable for irrigated sawah platform development can be estimated. Previous development performance in those soils is compared with image analysis from Google earth and other sources. A time series quantitative assessment of the extent to which these lowland soils can be sustainably developed as a platform for irrigated sawah can give up potential area of irrigated sawah platform. Some of the results are presented in Sawah technology (3): evolution of Sawah platforms, Sawah technology (5) practice and potential and Sawah Technology (6): Kebbi rice revolution..

Total range of total area for irrigated 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 146 (97 million ha for irrigated and 49 million for rain-fed) sawah based annual rice cultivation area in Asia (mean paddy yield 4.76 t/ha in 2017), thus 3617 km^3 of available water in Africa may support about 50 million ha of both irrigated and rain-fed sawah area in Africa (Oki et al 2009, FAOSTAT 2015). If mean paddy yield 5t/ha 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.

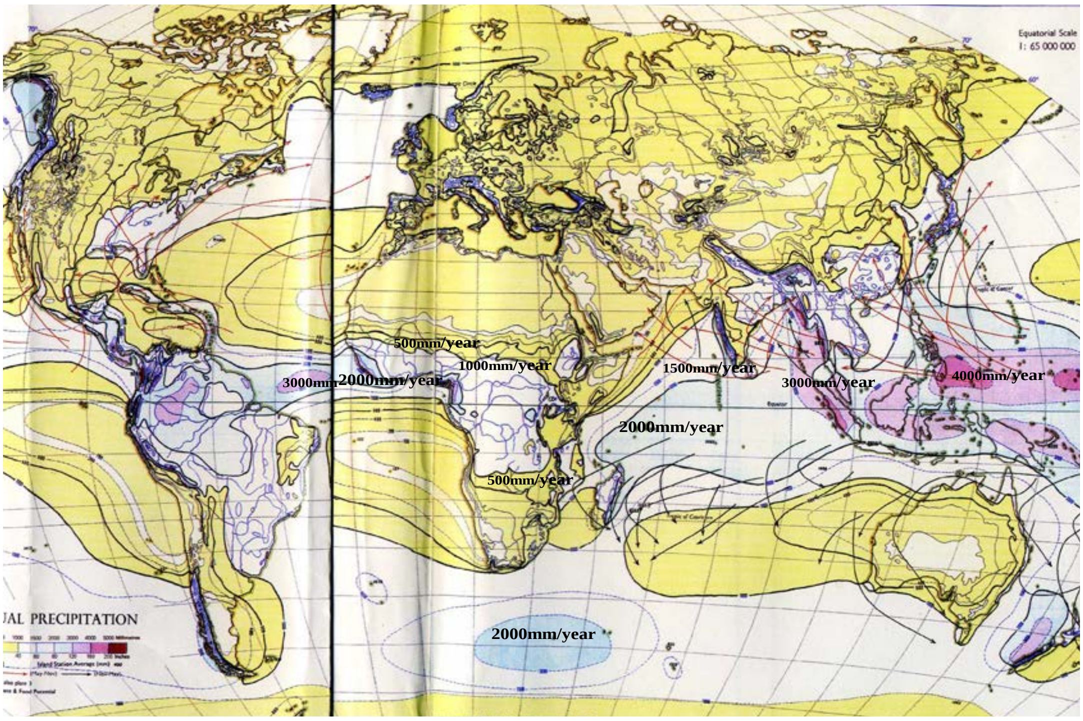

Fig. 23. Distribution of world precipitation (The Times Comprehensive Atlas of the World 2007).

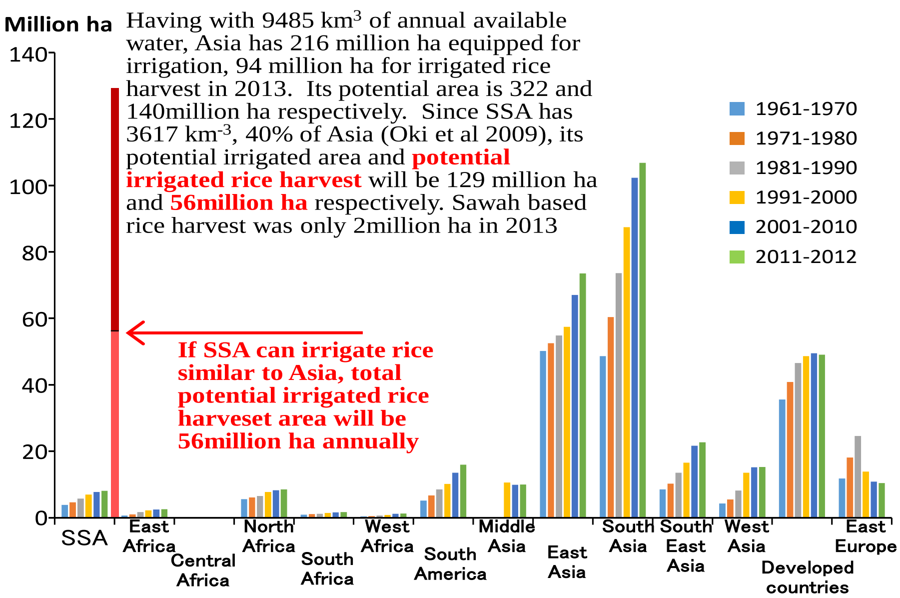

Fig. 24. Trends of harvest areas of irrigated crops in major world regions during 1971–2012 and potential harvest area of crops and rice harvest in SSA (FAOSTAT 2019, AQUASTAT 2019).

10. Compare the fertility of rice soils in West Africa with the fertility of "pre- and post-Green Revolution" rice soils in tropical Asia.

10-1. Survey trips of rice cultivation system in West Africa and rice soil fertility

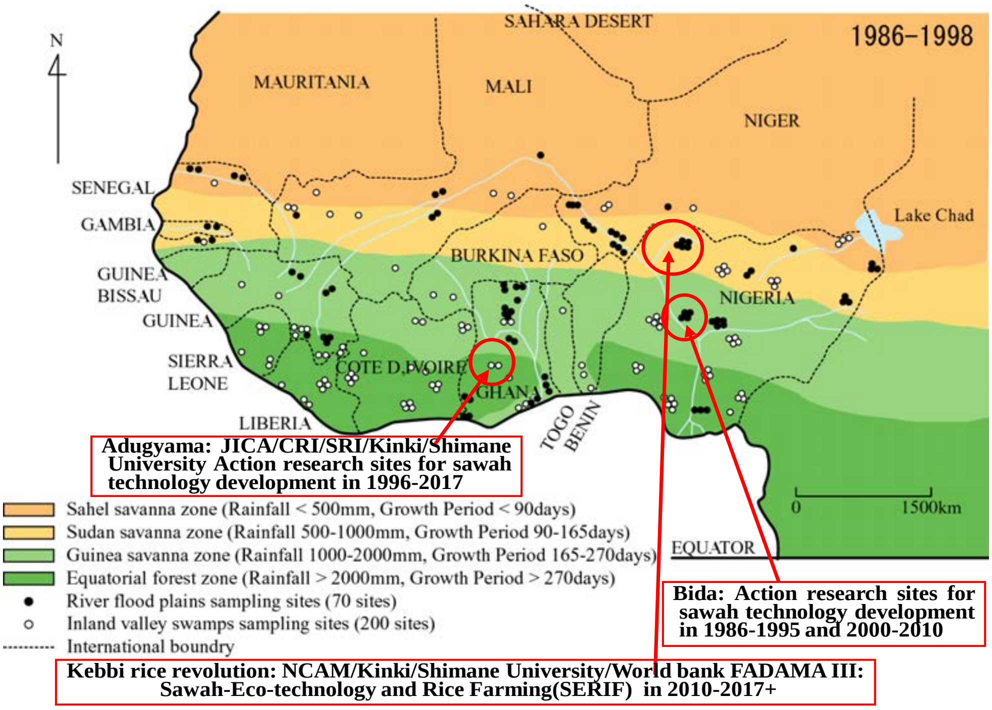

Figure 25. West Africa map showing selected sampling sites of lowland soils of inland valleys and flood plains (Wakatsuki et al. 1989, Issaka et al. 1999, Buri et al. 2000, Hirose and Wakatsuki 2002, Abe et al. 2006).

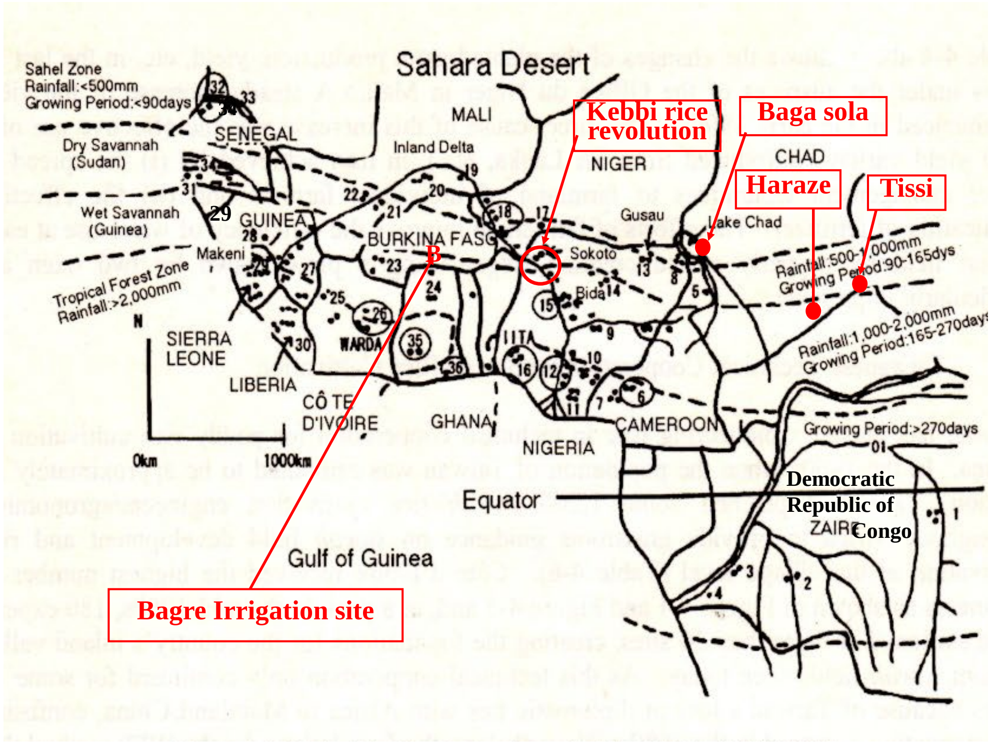

Figure 26. Map showing sites of soil sampling and rice ecologies surveyed in Western and parts of Central Africa during 1986-2006. The circled numbers are the sites that Japan-assisted irrigated rice projects. Red B shows Bagre irrigation project site at Burkina Faso assisted by Taiwan, European, mainly French, and Arabic donors. Three red marks show IOM-Chad/NCAM sawah project sites at Baga sola (Nigeria border), Tissi (Sudan/Central Africa/Chad tri-national border), and Haraze (Central Africa border) area in 2015-17 (IOM 2016, Ademiluyi et al 2017).

Note 1: Apart from basic soil fertility research studies, on-farm action research for sawah technology development was carried out in the three red-circled benchmark sites in Figure 25. In the small inland valleys (Gara and Gadza valleys) near Bida in central Niger State, Nigeria, the research was carried out lead by one of the authors of this paper, T. Wakatsuki, who was a sawah rice research specialist (*Suidn Inasaku Senmonnka in Japanese)* dispatched by JICA to IITA in 1986-89 and later by JSPS Grants-in-Aid for Scientific Research from 2000-2010, as part of the farmer's self-help on-farm action research for the development of irrigated sawah platform through farmers' self-help efforts was carried out. In some Inland valleys near Adugyama village near Kumashi city in the Ashanti Region of Ghana, the proto-type of sawah technology for farmers' self-help irrigated sawah platform development was completed in 1996-2001 through a JICA-supported joint research project between CRI and SRI under the Ghana CSIR (Wakatsuki et al 2001). This prototype technology continued to be improved both in Ghana and Nigeria under the JSPS Grants-in-Aid for Scientific Research 2002-2011 and was transferred as the base technology for AfricaRice's SMART-IV (Sawah, Market Access, and Rice Technology for the Inland Valley: 2009-2019) (Wakatsuki et al 2010, Buri et al 2011, Abe et al 2012, Africa rice 2013-2016, 2018-19, and 2022). Meanwhile, the technology was improved and transferred via sawah team of NCAM (National Center for Agricultural Mechanization, Nigeria) to World bank's Fadama III project in 2010-2015 and became the base technology for the rice revolution in Kebbi State, Northwest Nigeria (World bank 2016, Sawah Technology (6): Kebbi rice revolution). The location of Kebbi State is indicated by the red circles in Figures 25 and 26.

Note 2: Figures 25 and 26 are the West African and central African maps showing selected sampling sites of lowland soils of inland valleys and flood plains (Wakatsuki et al. 1989, Issaka et al. 1999, Buri et al. 2000, Hirose and Wakatsuki 2002). Figure 24 shows some additional surveys in central African countries, such as Cameroon and Democratic Republic of Congo during 1987–1988. These western and central African soil and rice ecological surveys were carried out during 1986–2006.
Major survey sites soil sampled and rice ecology observed are as follows, **(1) Kindu**: traditional slash and burn upland rice, **(2) Kikwit**: Inland valley weir irrigated sawah rice project of by Taiwan in 1966-1972, **(3) Knshasa**, Flood plain dam irrigated sawah rice by Taiwan 1966-1972), **(4) Mbanza Ngungu:** Inland valley weir irrigated sawah rice project of by Taiwan in 1966-1972, **(01) Bumba:** only Taiwan's information, not visited (Hsieh 2003 and 2001, Committee of International Technical Cooperation of Taiwan 1997 and 1990): The date of ravel :27 December 1987-12 January 1988.**(5) Yagou, Maga, and Kousseri** project sites of SEMRY(Societe d'Expansin de Modernisasion de la Rizculture). The Yagoua project, 4,800ha, pumps water 3-4m from the Logone river flowing along the border of Chad. The Maga project has 27km long dyke to the lake Maga, 36,000ha, to irrigate 5,300ha sawah. The Kousseri project is near the lake Chad. One thousand ha of sawah is irrigated by pumping water from the Logone rice with ahead of 8-10m. **(6)Baigon plain,** Model weir irrigated sawah, 100ha, constructed by Nippon Koei, potential area may 3,000ha, but because of elevation is 1,000m, cold damage exist, **(7)Ndop and Mbo** plains, potential area for irrigated sawah may reach 20,000ha with dams and weirs. The date of travel: 2-12, March, 1987. **(8)South Lake Chad Irrigation Project**: Failed 50,000ha pump irrigation using huge oil money. Technical assistance was provided by Pakistan: The date of travel: 4-13, August, 1986, 19-29 November 1987, **(9) Makurdi:** Pump irrigation of 200ha, but pump was broken. The date of travel: 16-21, June, 1987. **(11) Bende**: High population area 500/km^2.Rice has been cultivated in inland valley bottom without sawah system. At the end of 1970s, Word Bank implemented a small scale weir based irrigated rice project for about 1,000ha without proper sawah platform: The date of travel:5-11, June 1986, 17 September -16 October, 1990, **(12a) Adani-Adarice**: The development of weir based irrigation for 500ha of poor sawah system by World bank and another 500ha of standards sawah system by Nihon Koei, which had been completed by the end of mid 1980s.**(12b) Lower Anambra Irrigation Project site at Uzo Uwani**: A Yen loan project of a Japanese consortium consisting of Nihon Koei, Taisei Corporation and Itoh C (around 1983-1988), which was followed by project type technical cooperation of ICA (1989-1994). It was not possible to sustainably manage a huge and powerful pump that had a water head difference of 30 m or more to irrigate 4,000ha irrigated sawah platform. Thus at the time my last visit on 1998, the irrigation system was no more function: The date of travel: 5-11, June 1986, 17 September -16 October, 1990, 25 July-9 September 1998. **(13) Gashua, Sokoto, and Arugungu:** Non sawah African Rice cultivation had been wide spread before 2000. The construction Goronyo and Bakalori dams have been contributed severe flooding of the Rima/Sokoto river. This may a part of the reason of Kebbi Rice Revolution in 2010-2020. The date of travel: 4th -19th December, 1987, April-May and September 2011, June 2015,

(14) Kaduna: Inland valley bottom non sawah rice cultivation. Fonio had been cultivated on degraded upland. The date of travel: 17 September -16 October, 1990, **(15) Bida area**: Various bench mark sites of IITA's Wetland Utilization Research Project (1984-1991), Hirose project (JSPS Kakenhi in 1992-2008) including WIN2001 and AICAF, and Sawah Projects in collaboration with NCRI and NCAM (2003-2020). All types of rice cultivation platforms of both rain-fed and traditional/official irrigation in both inland valleys and flood plains have been practiced. The date of visit: April 1986- March 1988, January 1989, September- October 1990, August 1992, Periodical visit 1-3 times per year during 1993-2017 and 2019. **(16) IITA**: Rain-fed and irrigated sawah system of experimental station, paddy yields can be possible 2-4t/ha in rain-fed valley bottom, 5-10t/ha in irrigated sawah platform. The 10 t/ha was realized on strong sunshine month of dry season harvest in March-April or November harvest (IITA 1981 and 1982), Date of visit: April 1986-March 1988, **(17) On the road side between Birnin Konni and Dogondoutchi**: Semi-cultivation of African Rice. The date of visit: 4-19 December, 1987, **(18) Niamy:** Taiwan assisted irrigated sawah platform total 1,569ha on the Niger river flood plain. About 100ha of irrigated sawah platform was developed at Koutoukale by the assistance of Japan. The date of visit: 30 December 1988-21 January 1989, **(19) Gao**: African rice cultivation on the flood plain of the Niger river (around 14.479N 4.197W) 7Jan1989 sampled, **(20) Mopti**: African rice (around 16.218N 0.0364W) 9Jan1989 sampled and revisited on 7Jan1998, **(21) San**: African rice (around 13.328N 4.902W) 9 Jan 1989, **(22) Niono irrigation area**: Office du Niger site (around 14.253N 5.95W) and **Massina (Macina)** non sawah site (13.99N 5.378W): sampled on 10 Jan 1989 and revisited 10Jan1998. About 2000ha of official irrigation with sawah platform had completed after 2001 at Massina. Niono site had 40,000ha of irrigated sawah platform in 1989, but in 2020 it might expand to about 100,000ha, **(23) Vallee Du Kou**(11.376N 4.396W), flood plain at Bobo Dioulasso, and **Red B of Bagre** (11.4585N 0.5317W), both of which are Taiwanese irrigated sawah platform, **Kiribina,** inland valley, INERA's Banfora station: sampled on 15April 1987 and visited in December 2004 and January 2006, **(24)Tono irrigation site, 2500ha**, flood plain and **Nyankpala Agric Experimental Station, Inland valley bottom**, Tamale, sampled on 3 and 4 of Feb1988, **(25)Daloa, Gagnoa, (26)Katiola, WARDA/AFricaRcie at Mbe, Sakasso, Djebonoua**: Majority of nation-wide standard Sawah platforms have been originated by massive on-the-job training and development by Taiwanese team in 1962-73:Sampled and visited Feb 1988, September 1998, August 2002, **(27)-(28)**Various samplings along the Niger river flood plains such as **Siguiri, Kankan, and Faranah**, but majority rice sites are inland valleys, such as **Nzerekore, Gueckedou, Kissidougou, Kilissi and Kindia.** Majority sites have no irrigated sawah platform, except for the Taiwanese influences in border areas of Liberia and Sierra Leone. North Korea has been irrigated sawah program at Kindia since 1988: Sampled February 1988 and January 1989 and visited August 2002, **(29) Makeni, Kabala**: Inland valley bottom irrigated sawah platform developed by Taiwan are still seen in many places although some had degraded. A sawah rice experimental station called **Chinese farm exists at Bo** (7.963N 11.751W), by 1992, **Rokupr** had mangrove rice research station (9.01N 12.955W) of WARDA/AfricaRice: sampled and surveyed July1986, February 1988, **(30) Monrovia/WARDA, Suakoko/CARI**, **Gbarnga**, Taiwan team's irrigated sawah platform can be observed by Google earth at Suakoko (7.001N 9.569W) and Gbarnga (7.013N 9.459W): Sampled on April 1987 and January 1989, **(31) Ziguinchor/Nyaguis** (12.573N 16.14W)/**Tanaf** (12.655N 15.45W), Inland valley Taiwanese assisted Sawah platform and ridge rice to avoid salt water, sampled on 2 and 3 May 1987, **(32)Debi**(World bank assisted) **and Ntiago/M'bane** (Taiwan and Japanese assisted, 16.405N 15.724W)**, and (33) Fanaye, WARDA station** (16.537N 15.196W) sampled on 1May 1987 and 1-3 August 1998. During 1964-1973 and 1996-2005, Taiwan implemented 3,200ha irrigated sawah platform and trained 4000 farmers at 14 locations along the Senegal River and in Casamance region. This has been the basis for the promotion of rice cultivation in Senegal, which leads the green revolution of in West Africa. **(34) Kuntuar/Wassu**: Taiwan assisted tidal irrigation project, visited on 31July1998, **(35) Adugyama**(6.8864N1.879W)**/Biemso No.1**(6.8835N 1.851W):JICA/CRI sawah project site in 1996-2001, then JSPS Kakenhi sawah projects in 2002-2009, which target was endogenous sawah platform development. However MOFA/Africa Development Bank have been doing by poor skilled contractor/bulldozer based sawah platform development (IVRDP) in 2009-2019. These two sites are very good study sites on the land degradation, restoration and sustainable development using the location coordinates and time series of Google earth image during 2001-2020.
(36) Ashiaman(5.6985N 0.055W):Taiwan Assisted site during 1968-1972, then JICA 's small scale irrigated project sites during 1999-2004

10-2. Rice Soil Fertility of West Africa in comparison to Tropical Asia

One of the authors, T. Wakatsuki, was seconded to the headquarters of IITA, Ibadan, Nigeria, as a JICA (Japan International Cooperation Agency) expert between 1986 and 1989. During this period and in 1998, he made extensive field surveys of soils, topography, irrigation and river systems, as well as African systems of rice farming in major rice growing areas of Nigeria, Benin,Togo, Niger, Burkina Faso, Mali, Guinea, Ghana, Cote d'Ivoire, Liberian Sierra Lone, Gambia, Senegal, Cameroun and Zaire (Democratic Republic of Congo), stretching across central and western Africa (Figure 25 and 26) from the Sahel zone to the mangrove forests along the coast of the Gulf of Guinea. Since Kawaguchi & Kyuma (1977) and Kyuma (2004) completed the fertility evaluation of sawah soils in tropical Asia, our sawah team's first target was to evaluate fertility data of the West African lowland soils to compare with the tropical Asian sawah soils.

Table 10 shows the general topsoil (0–30 cm) fertility characteristics sampled from both inland valley swamps (IVS) at 185 points and 62 points from flood plains in West Africa. As can be seen from the distribution of sampling points shown in Table 10 and Figures 25 and 26, IVS is mostly distributed in the Guinea savanna zone and the equatorial forest zone, and the floodplains are distributed largest in the Sudan savannah zone, followed by the Guinea savanna zone, and the Sahel savannah zone. There is not much distribution in the Equatorial forest zone. The number of samplings for IVS is approximately 1 per 190,000 ha because the distribution area of inland lowlands in West Africa is about 36 million ha, and 1 per 310,000 ha for floodplains because the distribution area of floodplain is about 19 million ha (Windmeijer and Andriesse 1993). In the case of the trace element surveys as shown in Figures 25-27, the sampling density was 200 points for IVS and 70 points for Flood plain, and thus 1 point per 180,000 ha for IVS and 1 point per 270,000 ha for Flood plain.

As shown in Table 10, the lowland soils in the inland valleys of West Africa, especially in the Guinea savanna zone, are very sandy, have low clay content, low CEC (cation exchange capacity), low clay activity, low exchangeable bases (Ca, Mg, K), low available phosphate content, and low total carbon and nitrogen contents. Soil fertility is at the lowest level in the world. Carbon, nitrogen and available phosphate contents of the inland valley soils in the equatorial forest zone were at a higher level. West African floodplain soils have a relatively higher fertility than those of inland valley soils, but below the fertility levels of lowland soils in tropical Asian countries (Wakatsuki et al. 1989, Oyediran 1990, Wakatsuki 1997, Issaka 1997, Issaka et al. 1996, Issaka et al. 1997, Buri 1999, Buri et al. 1999, Buri et al. 2000, Abe et al. 2006).

The effects of climatic zones on the fertility of lowland soils in West Africa tend to be regular. Sahel and Sudan Savana zones are suitable for rice cultivation. Despite having a lower carbon content, they are more alkaline, and have a high eCEC and clay content. These soils, when sufficient water is available, are more suitable than those in the Guinea Savanna zone. However, as Table 10 shows, exchangeable sodium is slightly high. This means it will be necessary to treat alkalinity problems including deficiency of micronutrients such as zinc and sulfate as shown in Figure 27. In both inland valleys and flood plains, more than 60% of the top-soils are deficient in available sulfate and zinc. Sulfate correlated positively and significantly with total T-C, available phosphorus, eCEC and clay for flood plains, but only with T-C, available phosphorus and eCEC for inland valleys. Available zinc showed a similar relationship with T-C and available phosphorus, but a negative correlation with eCEC for both river flood plains and inland valley swamps.

Table 10 shows that in order to realize the SSA's Green Revolution, the current level of available phosphorus (Bray No.2 method) needs to be increased to at least 50 mg/kg within the next 10 years. Such investment in this is crucial, particularly by individual farmers. Good quality sawah platforms owned by individual farmers make this possible. Alternatively, large-scale investment by governments or international organizations may also be required. In the 1960s and 1970s, Kawaguchi and Kyuma measured the available phosphorus (Bray No2.) of the top soils of sawah plots of 410 sites in nine major tropical Asian countries, including areas where use of high-yielding varieties and chemical fertilizers had already begun. The average level was 16.9 mg/kg. The West African survey was conducted between 1986 and 1998. Therefore, available phosphorus level in tropical Asian topsoils was slightly higher than West Africa. Both West Africa and tropical Asia were very low compared to the sawah soils of Japan in the 1960s.

About 50 years after by the survey of Kawaguchi and Kyuma, 5 of the 10 tropical Asian countries, namely Thailand, Philippines, and Malaysia were surveyed in 2015-17, at the same sampling points by Kyuma and

Kawaguchi. Indonesia had its same site surveyed in 2003. Bangladesh was surveyed in 1994-5 and 2015-17. The analytical methods applied were the same as those of Kawaguchi and Kyuma (1977).

Table 10. Comparison of topsoil (0–15/30 cm) fertility of inland valleys (IVS) and flood plains (FLP) in West Africa in the 1980s, Philippines and Thailand (1) in the 1960s and (2) in the 2010s, Japan in the 1960s, and SSA in the 2010s.

Location	No.of sites	T-C (%)	T-N (%)	Available-P (P mg/kg)*	pH H_2O	Exchangeble Cations(Cmol/kg) Ca	K	Mg	Na	eCEC	Sand (%)	Silt (%)	Clay (%)	eCEC /Clay
IVS	**185**	**1.28**	**0.11**	**8.7**	**5.3**	**1.89**	**0.25**	**0.88**	**0.19**	**4.2**	**69**	**19**	**12**	**29.2**
CV(%)***		95	82	85	4	98	85	119	115	81	27	68	97	72
Guinea	98	0.73	0.07	6.5	5.3	1.33	0.2	0.51	0.11	2.66	67	20	13	20.5
Forest	79	2.04	0.166	11.8	5.3	2.28	0.27	1.24	0.26	5.72	65	15	20	28.6
FLP	**62**	**1.1**	**0.1**	**7.7**	**5.4**	**5.61**	**0.49**	**2.69**	**0.77**	**10.4**	**40**	**14**	**46**	**24.2**
CV(%)***		78	69	50	15	81	96	79	176	64	61	61	47	65
Sahel	12	0.62	0.071	7.3	5.7	5.86	0.56	3.81	1.56	12.12	50	13	37	33
Sudan	24	0.83	0.088	7.3	5.4	7.26	0.57	3.08	0.55	12.34	34	12	54	23
Guinea	19	1.63	1.33	8	5.5	3.92	0.47	1.93	0.75	7.8	40	26	35	23
Forest	7	1.44	0.086	9.8	5.2	4.11	0.14	1.47	0.35	7.03	34	26	39	18
Madagascar	**8**	**2.75**	**0.24**	**9**	**5.2**	**2.2**	**0.17**	**1.01**	**0.13**	**3.51**	**60**	**18**	**22**	**16**
SSA(2010s)	**42**	**1.3**	**0.12**	**3.8**	**5.6**	**5.3**	**0.25**	**2.33**	**0.38**	**8.77**	**50**	**26**	**24**	**34.4**
CV(%)***		91	90	133	16	95	88	133	139	105	53	64	72	114
T. Asia	**410**	**1.41**	**0.13**	**16.9**	**6**	**10.4**	**0.4**	**5.5**	**1.5**	**17.8**	**33.9**	**28**	**38**	**46.4**
CV(%)***		91	85	279	18	85	95	96	96	65	77	50	56	no data
Phillipines(1)	**37**	**2.06**	**0.17**	**11**	**6.4**	**13.6**	**0.46**	**8.2**	**1.86**	**24.2**	**28.7**	**31**	**40**	**64**
Phillipines(2)	**37**	**1.85**	**0.18**	**65.2**	**6.6**	**18.9**	**0.4**	**8.6**	**0.57**	**28.5**	**22.3**	**44**	**33**	**85.2**
Thailand(1)	**65**	**1.24**	**0.1**	**3.2**	**5.2**	**7.7**	**0.21**	**3.66**	**0.74**	**12.3**	**39.4**	**25**	**36**	**34.2**
Thailand(2)	**65**	**1.73**	**0.15**	**42.8**	**5.8**	**8.8**	**0.31**	**3.11**	**0.88**	**13.1**	**42.8**	**252**	**32**	**40.9**
Japan(1960s)	**84**	**3.33**	**0.29**	**57.3 ****	**5.4**	**9.3**	**0.4**	**2.8**	**0.4**	**12.9**	**49.2**	**30**	**21**	**60.8**
Available-P, Indonesia (Java 44sites), 5.5 (1970s) to 10 (2003), Malaysia (40sites),16(1960s) to 137(2010s)														

***Available-P (P g/kg) by Bary No.2, **In Japan, Application of P_2O_5 fertilizer was about 20kg/ha at 1950, then gradually increased to 110-115 kg/ha at 1970, after 1987 it decreased to70-60kg/ha in 2010s（Nishio 2002, MAFF 2017). Sampling years: 1986-1998 for IVS & FLP in West Africa, 1963-1974 for Thailand, Philippines, Japan by Kawaguchi and Kyuma (1977). Data sources: Buri et al(1999, 2000) for flood plains, Issaka et al(1996 and 1997) for IVS. Philippines (2) and Thailand (2) by Yanai et al (2021 and 2022). Indonesia in 2003 by Darmawan et al (2006a, b), Madagascar by Tsujimoto et al (2010), Tsujimoto (2015), Nishigaki et al (2020) and Johnson et al(2019).**

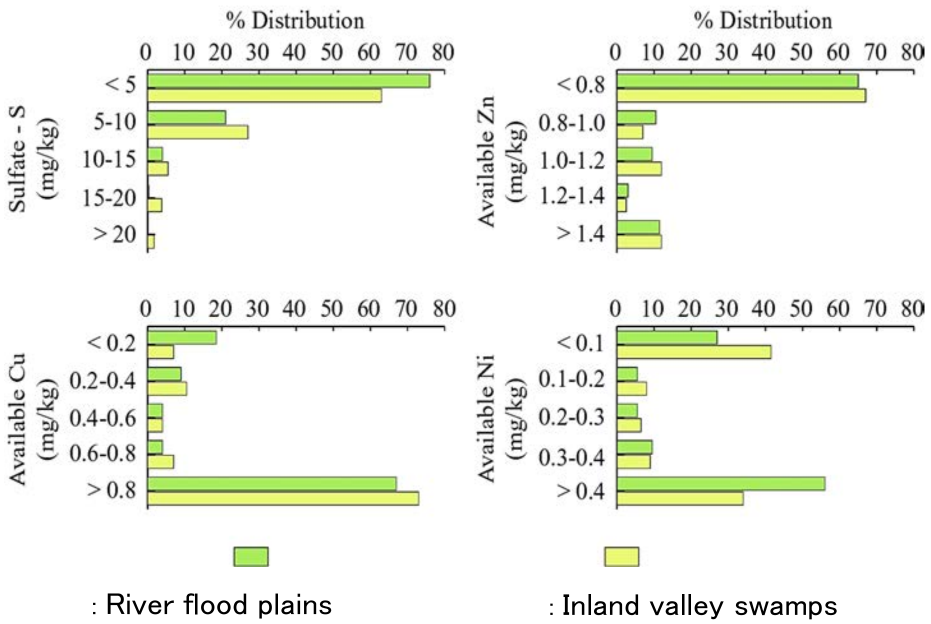

Figure 27. Frequency distribution of available sulfur, zinc, copper and Nickel in topsoils (0–15 cm) in West Africa lowlands (Buri et al. 2000).

Of significance is the five- to ten-fold increase in concentration of available phosphorus in tropical Asian sawah soils in the green revolution period of 1960s to 2010s. This increase correlates with the increase in the average paddy yield and the increased accumulation of fertilized phosphate by country over the past 50 years (Figure 2). This increase was supported by the increase in annual fertilizer application as shown in Figures 27 and 29. As long as the SSA has a sawah platform, it will be possible to increase the amount of fertilizer applied in the same way as in tropical Asia. In the case of Japan, the data show the soil fertility during the period when the improvement in paddy yield was significant between 1950 and 1970. Phosphate chemical fertilizers were not applied to sawah (paddy) soils in Japan before World War II, and it is thought that the available phosphorus was at the same level in tropical Asia in the 1970s. **Thus, Available phosphorus (Bray No. 2) level, > 50 mg/kg of sawah topsoil, is important target to intensive and sustainable paddy production in SSA (a part of Sawah hypothesis 2, which is described in details in Sawah Technology (4): Principles and Theory)**

11. Fertilizer use in SSA

Except for southern Africa, the average application rate of inorganic fertilizer on arable land in Sub Saharan Africa is about 15 kg/ha, and are mainly nitrogen fertilizers. This value is much lower than the 141 kg/ha in South Asia, 154 kg/ha in the European Union, 175 kg/ha in South America, and 302 kg/ha in East Asia as shown in Figures 24–27 (FAOSTAT 2020, Cedrez et al. 2020). SSA has no significant indication of increased fertilizer use by 2005. However, since 2005 nitrogen fertilization has been increasing gradually (Figure 29), particularly in West Africa. As shown in sections 7 and 8, the fertilizer use needs a proper agricultural land platform.

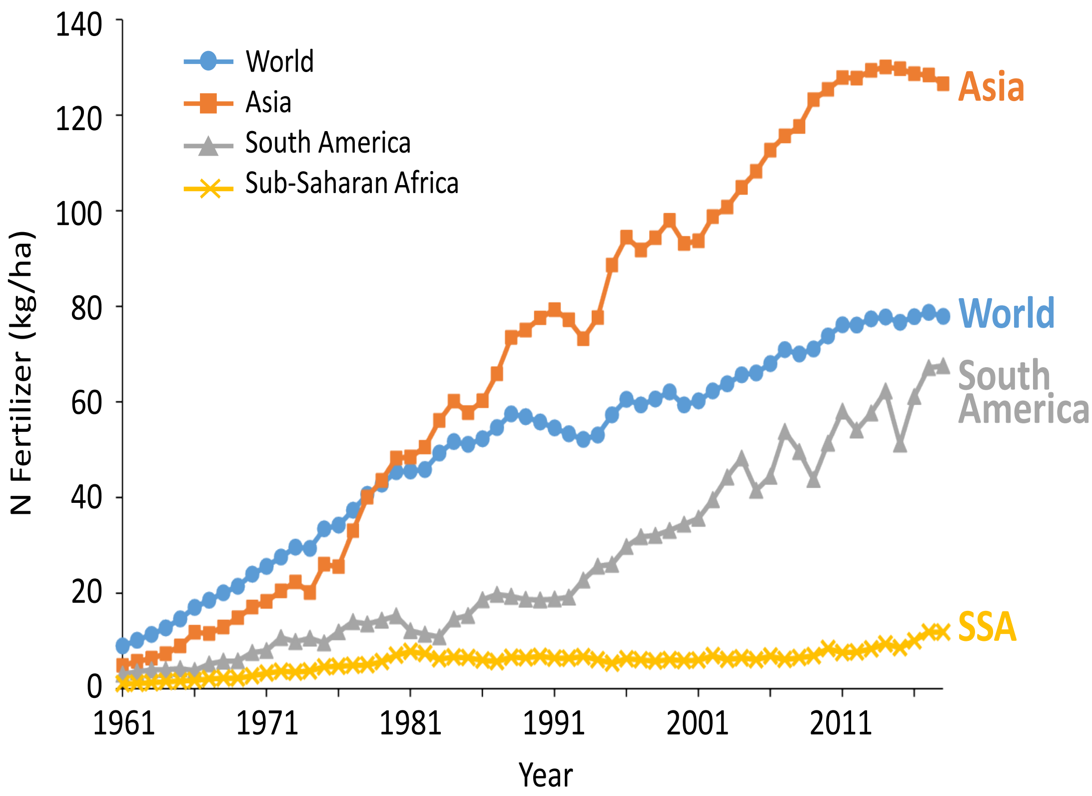

Figure 26. Trends of nitrogen fertilization during 1961-2018 (FAOSTAT2020).

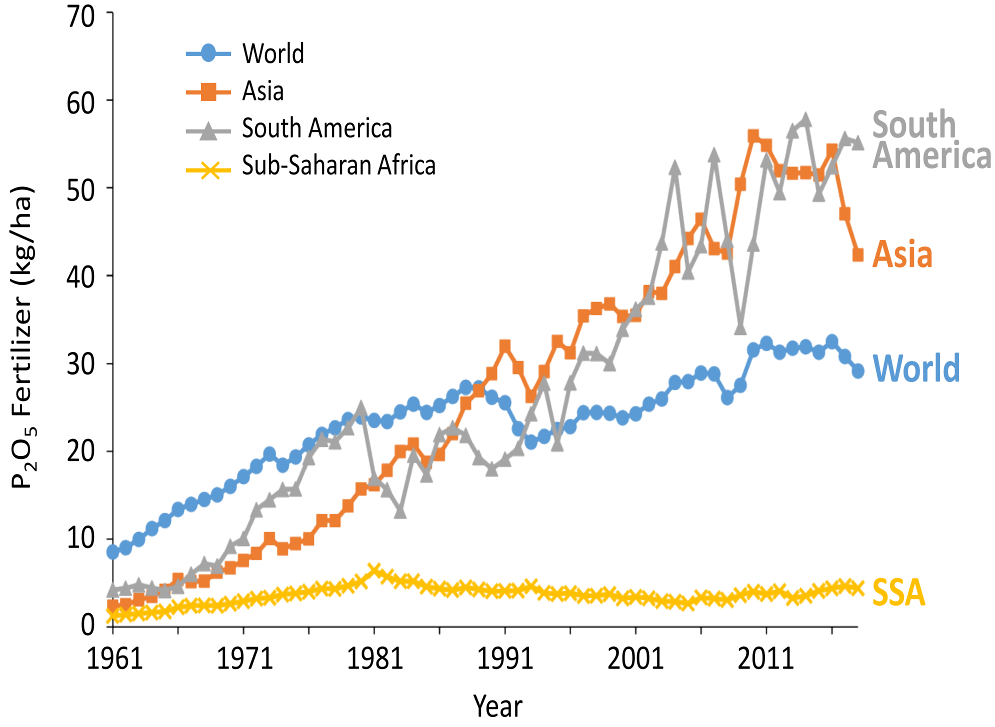

Figure 27. Trend of phosphate fertilization during 1961-2018 (FAOSTAT2020).

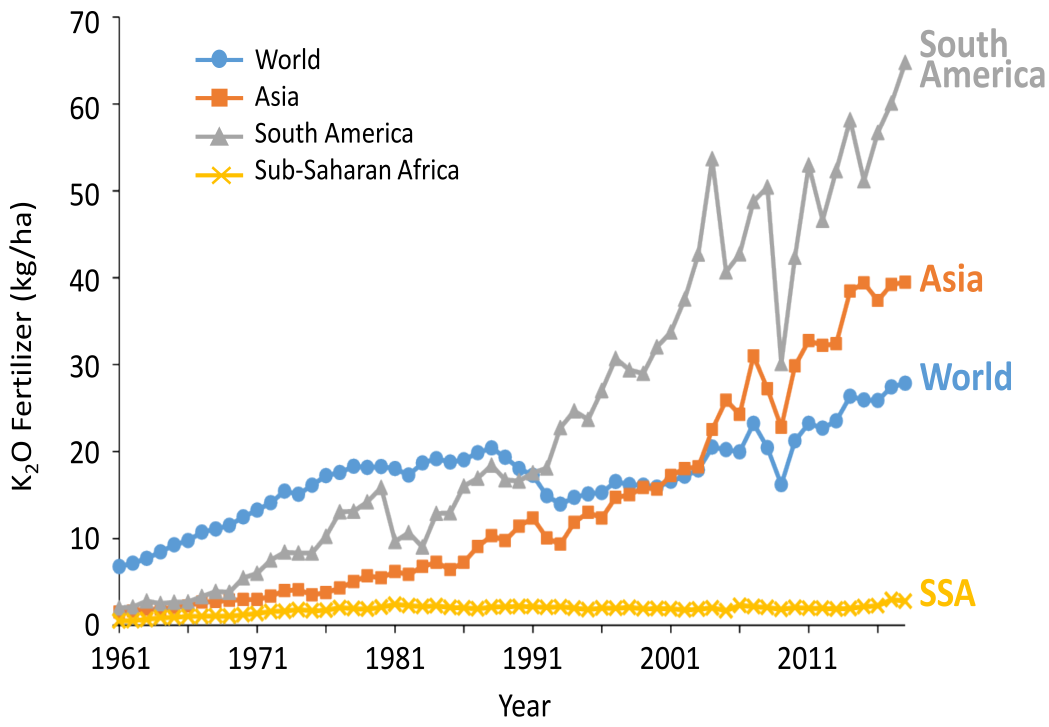

Figure 28. Trend of potash fertilization during 1961-2018 (FAOSTAT 2020).

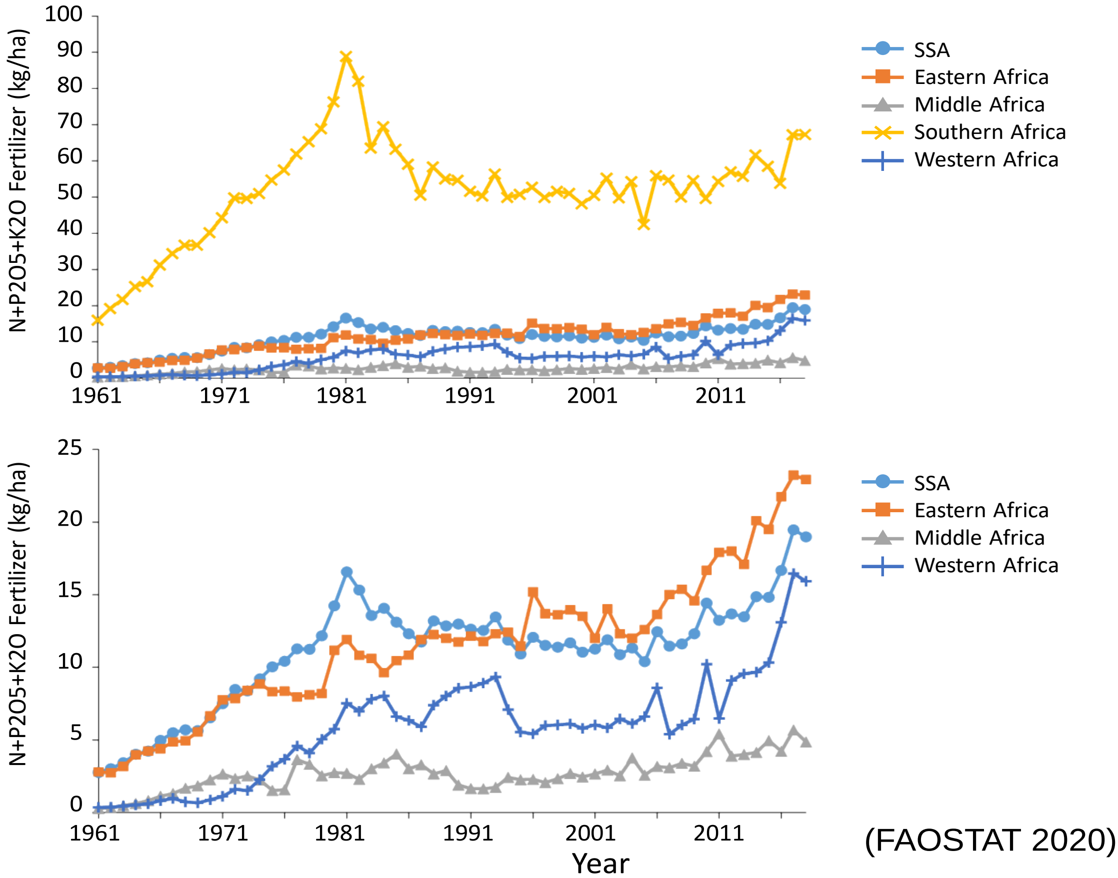

Figure 29. Trends of N-P_2O_5-K_2O Fertilization in Southern, Eastern, Western and Middle Africa in1961-2018.

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