# Comparative studies on rice farming systems in Japan, Bangladesh, Indonesia, Thailand and West African countries

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## Abstract

During 1961–2003, Japan decreased per capita paddy production and consumption from 180 to 84 kg but paddy yield increased 5.3 to 6.4 t $ha^{-1}$. The marked decline of rice cultivated area might relate to the degradation of present Japanese environment through the loss of multi-functionalities of sawah systems. Although per capita paddy production kept constant about 400 kg, since the paddy yield steadily increased 1.8 to 2.6 t $ha^{-1}$ during the same period, Thailand has been major rice exporter in the world. Bangladesh increased paddy yield doubly 1.7 to 3.4 t $ha^{-1}$, but decreased slightly per capita paddy production, 266 to 233 kg during 1961–2000. Although both per capita paddy production and paddy yield increased sharply 120 to 235 kg and 1.9 to 4.5 t $ha^{-1}$ respectively during the same period, since the per capita consumption also increased 145 to 250 kg, Indonesia imported the highest amount of rice in the world in 1997. During the same period, although per capita paddy production increased 5.5 to 14 kg in Ghana, 6 to 30 kg in Nigeria, and 20 to 30 kg in West Africa, since per capita paddy consumption also increased 14 to 38 in Ghana, 9 to 48 in Nigeria, and 26 to 56 in West Africa, the importation of rice increased dramatically in West Africa.

Except for the arsenic pollution problems in Bangladesh, the Green Revolution technology widespread in Asia Developing since the 1970s showed no serious problems on soil fertility degradation at the moment. Long-term monitoring will be important. The Green Revolution, however, not yet occurred in West Africa and Sub-Saharan Africa, the regions with the most serious food and environmental crises in the world. The potential of sawah-based rice farming in West Africa is enormous. Although lowland soils fertility and hydrological conditions in West Africa may be the lowest in the world, since the agro-ecological conditions are quite similar to those of north-eastern Thailand, the sawah-based rice farming can overcome such soil fertility

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problems through the enhancement of the geological fertilization process, conserve water resources, and the multi-functionality of the sawah type wetlands. This is a sawah hypothesis (Hirose and Wakatsuki, 2002). Asian African collaboration with the interfaces of Europe and USA will be a key for sustainable sawah development.

The term sawah refers to levelled and bunded rice fields with inlet and outlet connecting irrigation and drainage. The term originates from Malayo-Indonesian. The English term, paddy or paddi, also originates from the Malayo-Indonesian term, padi, which means rice plant. In order to avoid confusion between the terms rice plant, paddy, and man-made rice growth environment, the author propose to use the term sawah.

*Keywords:* Bangladesh; Ghana; Geological fertilization; Indonesia; Japan; Nigeria; Sawah-based rice farming; Sustainable rice production; Trend of rice production during 1960–2000; Thailand; West Africa

## 1. Introduction

Among the three major cereals, rice has the highest nutritional value. Relative quality of its protein in comparison with egg protein is 66%, while wheat is 53% and maize is 49%, respectively (Juliano, 1985). According to FAO (FAOSTAT, 2004), during past 40 years, world population increased 34 billion (1961–70 mean) to 62 billion (2001–2003 mean), i.e., 184% increase. During the same period, world rice production increased 264 to 586 million ton per year (221% increase), while wheat production was increased from 278 to 574 million ton per year (206% increase). Although the increase of maize production was the highest, 238 to 619 million ton (260% increase) during the period, percentage of feed for domestic animal was about 70%. Therefore rice is the most important cereal as a direct human food.

Total population of Sub-Saharan Africa was 640 million at 2003, of which 30%, about 200million were malnourished. Sub-Saharan Africa is the only region where hunger prevalence is over 30%, and the absolute numbers of malnourished people are increasing last 20 years (Sanchez and Swaminathan, 2005; FAO, 2004). The West Africa is a core region of Sub-Saharan Africa. Food and environmental crises are increasingly serious. Thus the deteriorating environment is threatening the human survival. Apart from natural environmental reasons, the background for this cause can be found in the tragedies many years ago. The slave trade by European countries for as long as 400 years, 16$^{th}$ to 19$^{th}$ century, destroyed African communities. Subsequent colonization continued for additional 150 years until 1960. These are probably the main reason for the continuing poverty and crises facing many parts of this continent

(Hirose and Wakatsuki, 2002).

Thanks to the success of the Green Revolution, most of the Asian countries achieved food self-sufficiency and their crops production exceeded the pace of population growth. This is generally considered to be a basic condition that has brought rapidly expanding economy in Asia now. During the 1960 to 2003, per capita crop production has increased 30% in tropical Asia but decreased 10% in Sub-Saharan Africa. The evaluation of the long-term sustainability of the recent Green Revolution in the Asian countries is the topics of this paper. While to present the strategy and tactics to realize the Green Revolution in Sub-Saharan Africa through the international collaboration, particularly Asia and Africa with the interfaces of Europe and USA, is another topic of this paper.

## 2. Rice production trends in the world, Japan, tropical Asia, Bangladesh, Indonesia, Thailand, Sub-Saharan Africa, West Africa, Ghana, and Nigeria during 1961–2003

Based on the data of FAOSTAT (2004), Ito (2005), and USDA PS & D View (2005), rice production and importation trends were reviewed in the world, Japan, tropical Asia, Bangladesh, Indonesia, Thailand, Sub-Saharan Africa, West Africa, Nigeria and Ghana during 1961 to 2003 (Tables 1–4, Figs 1–3). In those tables and figures, the conversion ratio between paddy and milled rice was used 1:0.65. Some Asian countries, especially Japan, decreased per capita rice production and consumption during the same period because of their change on dietary taste from rice to diverse cereals. According to Ito (2005) and FAOSTAT (2004), relative percentages of Japanese rice, wheat and maize consumptions were 65, 23 and 12%, respectively, in 1961. In 2003, these percentages were changed to 29, 19, and 52%, respectively, in which maize was used mainly for animal feed.

Although per capita rice production in Thailand kept constant, 400 kg in paddy, per capita paddy consumptions decreased 292 kg in 1960s to 234 kg in 2003, the amount of rice export increased 1.3 to 5.8 million tons during the same period. Bangladesh showed slightly decreasing trend in per capita rice production. As a result because of population increase, Bangladesh had to import 1.5 million tons of milled rice and 1million tons of wheat in recent years. On the contrary although per capita paddy production in Indonesia increased 120 to 235 kg, the consumption also increased 145 to 250, the amounts of annual milled rice importation were increased $1\times10^6$ in 1960s to $3–6\times10^6$ tons in 1997–2000 (Ito 2005). Indonesia imported the highest amount of rice in the world in 1997. During 1961-2003, per capita paddy production and consumptions also increased 130 to 154 kg in Asia Developing and 81 to 101 kg in the world.

Table 1. Population (FAOSTAT, 2004) Unit: 1,000

| Year | 1961–1970 | 1971–1980* | | 1981–1990 | | 1991–2000 | | 2001–2003 | |
|---|---|---|---|---|---|---|---|---|---|
| Ghana | 7,849 | 9,970 | (127) | 13,380 | (170) | 17,689 | (225) | 20,474 | (261) |
| Nigeria | 42,957 | 56,198 | (131) | 75,560 | (176) | 101,388 | (236) | 120,914 | (281) |
| West Africa | 95,749 | 124,204 | (130) | 165,990 | (173) | 220,738 | (231) | 261,861 | (273) |
| Africa South of Sahara (SSA) | 234,782 | 307,466 | (131) | 411,559 | (175) | 544,361 | (232) | 640,376 | (273) |
| Thailand | 31,771 | 41,818 | (132) | 50,941 | (160) | 58,088 | (183) | 62,194 | (196) |
| Indonesia | 108,324 | 136,182 | (126) | 167,800 | (155) | 198,562 | (183) | 217,123 | (200) |
| Bangladesh | 59,400 | 76,251 | (128) | 98,036 | (165) | 124,921 | (210) | 143,808 | (242) |
| Asia Developing | 1,786,958 | 2,251,298 | (126) | 2,732,350 | (153) | 3,252,342 | (182) | 3,568,256 | (200) |
| Japan | 99,469 | 111,749 | (112) | 120,936 | (122) | 125,593 | (126) | 127,468 | (128) |
| World | 3,376,145 | 4,102,728 | (122) | 4,879,539 | (145) | 5,712,586 | (169) | 6,224,835 | (184) |

* Figures in parentheses are relative percentages when 1961–1970 adjust to 100.

Table 2. Per capita rice paddy production + per capita import as paddy equivalent (FAOSTAT, 2004) Unit: kg

| Year | 1961–1970 | 1971–1980 | | 1981–1990 | | 1991–2000 | | 2001–2003 | |
|---|---|---|---|---|---|---|---|---|---|
| Ghana | 5.5+6.9 | 7.9+4.8 | (143+70) | 5.4+6.5 | (97+94) | 10.6+10.2 | (191+148) | 14.2+15.2 | (256+220) |
| Nigeria | 6.1+0.02 | 9.5+2.8 | (154+100**) | 23.3+5.0 | (378+182) | 30.7+5.9 | (500+215) | 30.0+15.2 | (489+553) |
| West Africa | 19.9+5.8 | 22.0+10.3 | (111+178) | 25.8+16.7 | (130+289) | 30.4+16.6 | (153+289) | 29.5+17.6 | (148+306) |
| Africa South of Sahara (SSA) | 17.0+3.9 | 17.9+6.1 | (105+157) | 18.3+9.8 | (108+250) | 19.6+8.9 | (115+228) | 18.7+9.4 | (110+240) |
| Thailand | 379.9+0.0 | 357.1+0.0 | (94+ - ) | 374.4+0.0 | (99+ - ) | 380.9+0.0 | (100+ - ) | 426.5+0.0 | (112+ - ) |
| Indonesia | 132.3+10.4 | 172.0+15.6 | (130+150) | 232.5+2.8 | (176+27) | 246.8+8.4 | (186+81) | 236.5+5.0 | (179+48) |
| Bangladesh | 266.0+8.8 | 236.8+6.6 | (89+75) | 235.8+4.5 | (89+51) | 233.1+5.8 | (88+66) | 260.0+8.3 | (98+94) |
| Asia Developing | 126.2+3.5 | 136.1+3.0 | (108+86) | 151.4+2.3 | (120+64) | 153.4+3.1 | (121+86) | 145.9+3.4 | (116+96) |
| Japan | 172.0+0.0 | 137.5+0.0 | (80+ - ) | 111.1+0.0 | (65+ - ) | 98.3+0.0 | (57+ - ) | 84.1+0.0 | (49+ - ) |
| World | 78.4+2.9 | 85.9+2.9 | (110+103) | 95.5+3.1 | (122+107) | 98.0+3.9 | (125+134) | 94.1+4.3 | (120+149) |

* Figures in parenthesis are relative percentages when 1961-1970 adjust to 100, **Paddy import in Nigeria, 1971-1980 adjust to 100

Table 3. Per capita paddy consumption (FAOSTAT, 2004; Ito, 2005; USDA PS & D View, 2004 ) Unit: kg

| Year | 1961–1970 | 1971–1980 | | 1981–1990 | | 1991–2000 | | 2001–2003 | |
|---|---|---|---|---|---|---|---|---|---|
| Ghana | 14 | 14 | (101) | 11 | ( 82) | 23 | (167) | 38 | (278) |
| Nigeria | 9 | 15 | (171) | 30 | (329) | 37 | (412) | 48 | (530) |
| West Africa | 28 | 33 | (118) | 41 | (145) | 44 | (159) | 56 | (201) |
| Africa South of Sahara (SSA) | 21 | 24 | (112) | 27 | (126) | 27 | (129) | 32 | (153) |
| Thailand | 292 | 288 | ( 98) | 253 | ( 87) | 230 | ( 79) | 234 | ( 80) |
| Indonesia | 161 | 195 | (121) | 248 | (154) | 260 | (162) | 257 | (160) |
| Bangladesh | 282 | 248 | ( 88) | 247 | ( 88) | 248 | ( 88) | 279 | ( 99) |
| Asia Developing | 129 | 139 | (108) | 151 | (117) | 155 | (120) | 154 | (119) |
| Japan | 181 | 149 | ( 82) | 128 | ( 71) | 113 | ( 63) | 104 | ( 58) |
| World | 81 | 89 | (110) | 97 | (120) | 100 | (124) | 101 | (125) |

* Figures in parenthesis are relative percentages when 1961-1970 adjust to 100.

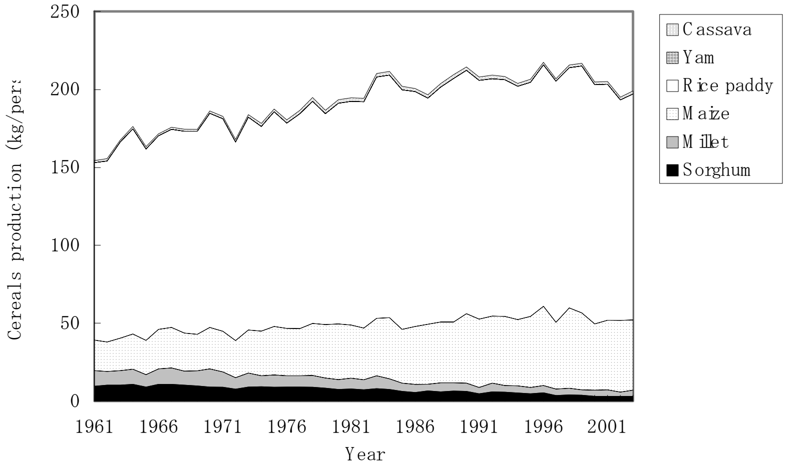


Fig. 1. Asia developing countries, cereals production in kg per person (FAOSTAT, 2004).

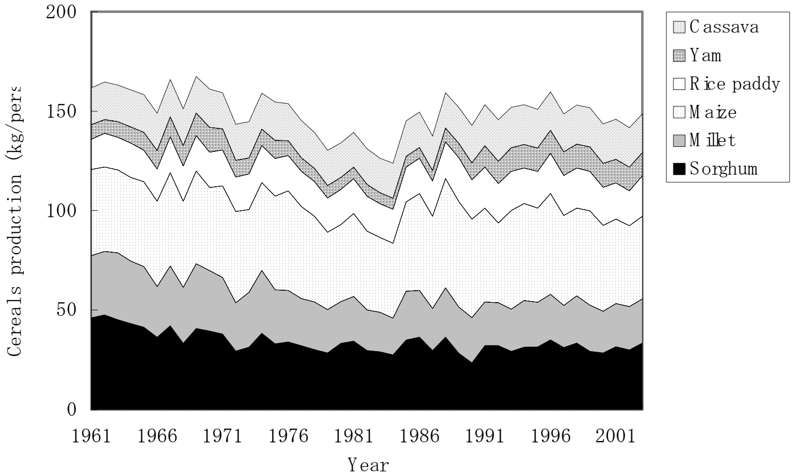


Fig. 2. Sub-Saharan Africa, cereals production in kg per person (FAOSTAT, 2004).

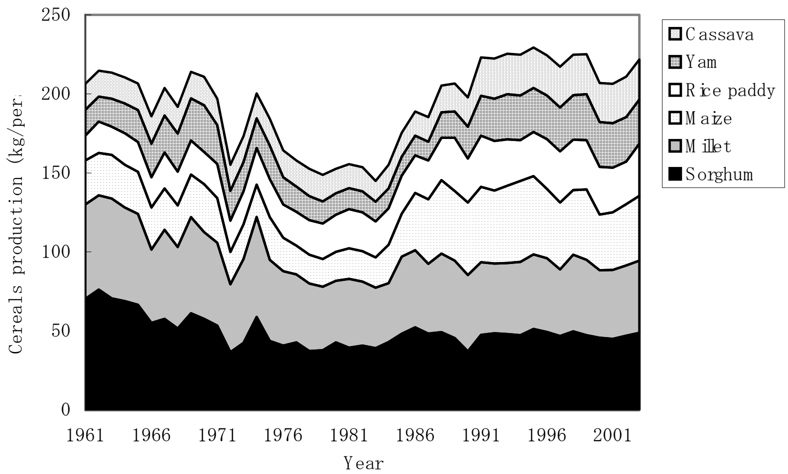


Fig. 3. West Africa, cereals production in kg per person (FAOSTAT, 2004).

Table 4 Paddy yield (FAOSTAT 2004) Unit: kg ha$^{-1}$

| Year | 1961-1970 | 1971-1980 | | 1981-1990 | | 1991-2000 | | 2001-2003 | |
|---|---|---|---|---|---|---|---|---|---|
| Ghana | 1,114 | 915 | ( 82) | 1,109 | (100) | 1,866 | (168) | 2,135 | (192) |
| Nigeria | 1,255 | 1,690 | (135) | 2,080 | (166) | 1,686 | (134) | 1,094 | ( 87) |
| West Africa | 1,074 | 1,209 | (113) | 1,469 | (137) | 1,665 | (155) | 1,348 | (126) |
| Africa South of Sahara (SSA) | 1,294 | 1,357 | (105) | 1,508 | (117) | 1,646 | (127) | 1,482 | (115) |
| Thailand | 1,811 | 1,845 | (102) | 2,026 | (112) | 2,366 | (131) | 2,561 | (141) |
| Indonesia | 1,910 | 2,745 | (144) | 3,961 | (207) | 4,346 | (227) | 4,465 | (234) |
| Bangladesh | 1,685 | 1,813 | (108) | 2,234 | (133) | 2,839 | (169) | 3,418 | (203) |
| Asia Developing | 2,016 | 2,478 | (123) | 3,250 | (161) | 3,779 | (187) | 3,928 | (195) |
| Japan | 5,280 | 5,811 | (110) | 6,055 | (115) | 6,212 | (118) | 6,356 | (120) |
| World | 2,106 | 2,516 | (119) | 3,221 | (153) | 3,738 | (178) | 3,880 | (184) |

* Figures in parenthesis are relative percentages when 1961-1970 adjust to 100.

As shown in the Tables 1–4, during 1961 and 2003, the most dramatic increases of paddy production, consumption and importation were appeared in Ghana, Nigeria, and West Africa. During the same period, although per capita paddy production increased 5.5 to 14 kg in Ghana, 6 to 30 kg in Nigeria, 20 to 30 kg in West Africa, and 17 to 19 kg in Sub-Saharan Africa, since per capita paddy consumption also increased 14 to 38 in Ghana, 9 to 48 kg in Nigeria, 26 to 56 kg in West Africa, and 21 to 32 kg in Sub-Saharan Africa, the importation of rice, paddy equivalent, increased 0.05 to 0.3 in Ghana, trace to 1.5 in Nigeria, 0.5 to 4.5 in West Africa and 0.7 to 6.5 million tons in Sub-Saharan Africa.

Figs 1, 2, and 3 show per capita major food crops production trends comparatively in Sub-Saharan Africa, West Africa and developing countries of Asia (FAOSTAT, 2004). Since the nutritional values of cassava and yam are quite low in terms of protein and mineral contents (Kiple and Ornelas, 2000; Sanchez, 1976), cereal equivalents of cassava and yam were calculated by dividing 8 and 5, respectively, in those figures. Clear contrast is divers food crops consumption in Sub-Saharan Africa and rice domination in Asia developing. The most important contrast is, however, the decreasing trend in Sub-Saharan Africa while increasing trend in Asia developing. In 1960s per capita cereals production was about the same 150 kg both in Asia developing and Sub-Saharan Africa, but less than 150 kg in Sub-Saharan Africa and more than 200 kg in Asia developing in 2000s. Although Sorghum and millet showed decreasing trend in the regions, West Africa showed somewhat more positive trends than whole Sub-Saharan Africa, especially after 1990s. Both per capita maize and rice production showed clear increase in West Africa, mainly through the contribution by Ghana and Nigeria.

The historical trends of paddy yields were shown in Figs 4 and 5. In Japanese rice history there were four major technological innovation stages to increase rice yield. The first step was the development of small-scale irrigated sawah systems, Jouri and other systems in Japanese, during 7 to 16s centuries. The second stage was the development of large-scale irrigated sawah systems based on the development of civil engineering technologies during 16 to 19 centuries. These technologies were developed and derived from technologies for fighting during the Warring State Period, Sengoku Jidai during 1467 to 1616. Paddy yield up to 2.5 t ha$^{-1}$ can be reached by these irrigated sawah systems (Tabuchi and Hasegawa, 1995). The third step was based on the integration between scientific breeding and farmers varietal selection coupling with newly introduced fertilizer technologies originated from Europe and USA. The integration of technical innovations and introduction was accelerated since Meizi Restoration in 1868. Japanese farmers bred and selected varieties with semi-dwarf gene both in rice and wheat. The semi-dwarf gene, named sd1, is known common in all high yielding varieties, HYV, in rice, wheat and maize (Sakamoto et al., 2004). The sd1 gene in semi-dwarf wheat, Nourin 10, was bred by Dr. Gonjiro Inazuka, which was collected at 1946 by Dr. S.C. Salmon, technical advisor of US army of Japanese occupation (Peitz and Salmon, 1968). The Nourin 10 was the gene source for the Green Revolution initiated by Dr. Norman Borlaug. The fourth stage was structural reform, reclamation and land consolidation of sawah systems for mechanization as well as lowland rice and upland crop rotations (Takase, 2003).

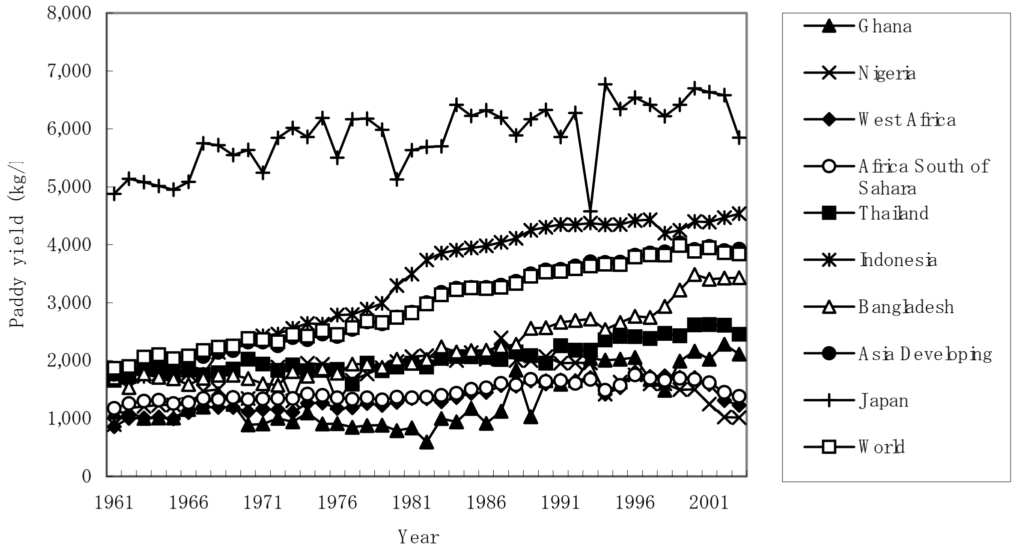


Fig. 4. Paddy yield (FAOSTAT, 2004).

As shown in Fig. 4, using the Green Revolution technology, majority of Asian countries, except for Thailand, increased rice yield rapidly since. These increases are started during 1960–80s and still ongoing. These recent yield increases in Asian countries can be compared to the achievement in Japanese rice history last 500 years as shown in Fig. 5. We have to examine this kind of very rapid yield increases are sustainable or not in long-term. As seen in Fig. 5, the rapid yield increase started at Stage 3, 1880, in Japan and although very gradual the increasing trend is still continuing during 1960-2003 in Japan as seen in Fig. 4, we may foresee some more yield increase continues in Asia developing in future. Yield stagnation and decline in IRRI's rice field reported recently have to make clear (Olk et al., 2004). Thailand shows very stable but gradual increase of rice yield. On the other hand, Sub-Saharan Africa, West Africa, and Nigeria have no clear trend of yield increase during the last 40 years. Although Ghana showed some indication of yield increase, Green Revolution technologies have not yet reach to this region.

### 3. Ecological foundation of rice farming: Geological fertilization theory

What causes the extremely great differences in population density in the areas as shown in Fig. 6. In this figure, the areas with a concentration of black dots are densely populated ones. It is clear from the figure that densely populated areas are restricted by precipitation (or water supply from rivers). In the temperate zones, high population densities are observed only in the areas where the yearly precipitation is 500–1,000 mm or more, and in the tropics, they exist only in the regions with an annual rainfall of 1,000–2,000 mm or more. But in the tropics having much rain, population density differs greatly from area to area.

As Fig. 6 shows, tropical Asia has a higher density than tropical Africa on the whole but has substantial differences in population according to region. The density reaches 1,000 persons per $km^2$ or more in the delta of the Ganges and other large rivers, on such volcanic islands as Java and Bali and on basaltic lava flow plateau like the Indian Deccan highland. By contrast, Borneo's population density is as low as about 10 persons per $km^2$. In tropical Africa, while the Zaire basins have a low density, the Ethiopian Plateau, volcanic ash zones around Lake Victoria in East Africa, the Hausa area in northern Nigeria and the Yoruba and Ibo areas in southern Nigeria have hundreds of people or more per $km^2$. These densely populated areas are all those blessed with fertile soil and abundant water resources. Whether a region has a plentiful water resource or not is dependent on the distribution of rainfall and topographical features. On the other hand, the distribution of fertile soils is determined by geological fertilization, one of the workings of the earth. 'Geological fertilization' is here defined as the earth's activity of supplying new starting materials to the weathering of rocks and soil formation actions, which are irreversible processes, and thus restoring (renewing) soils (Fig. 6).

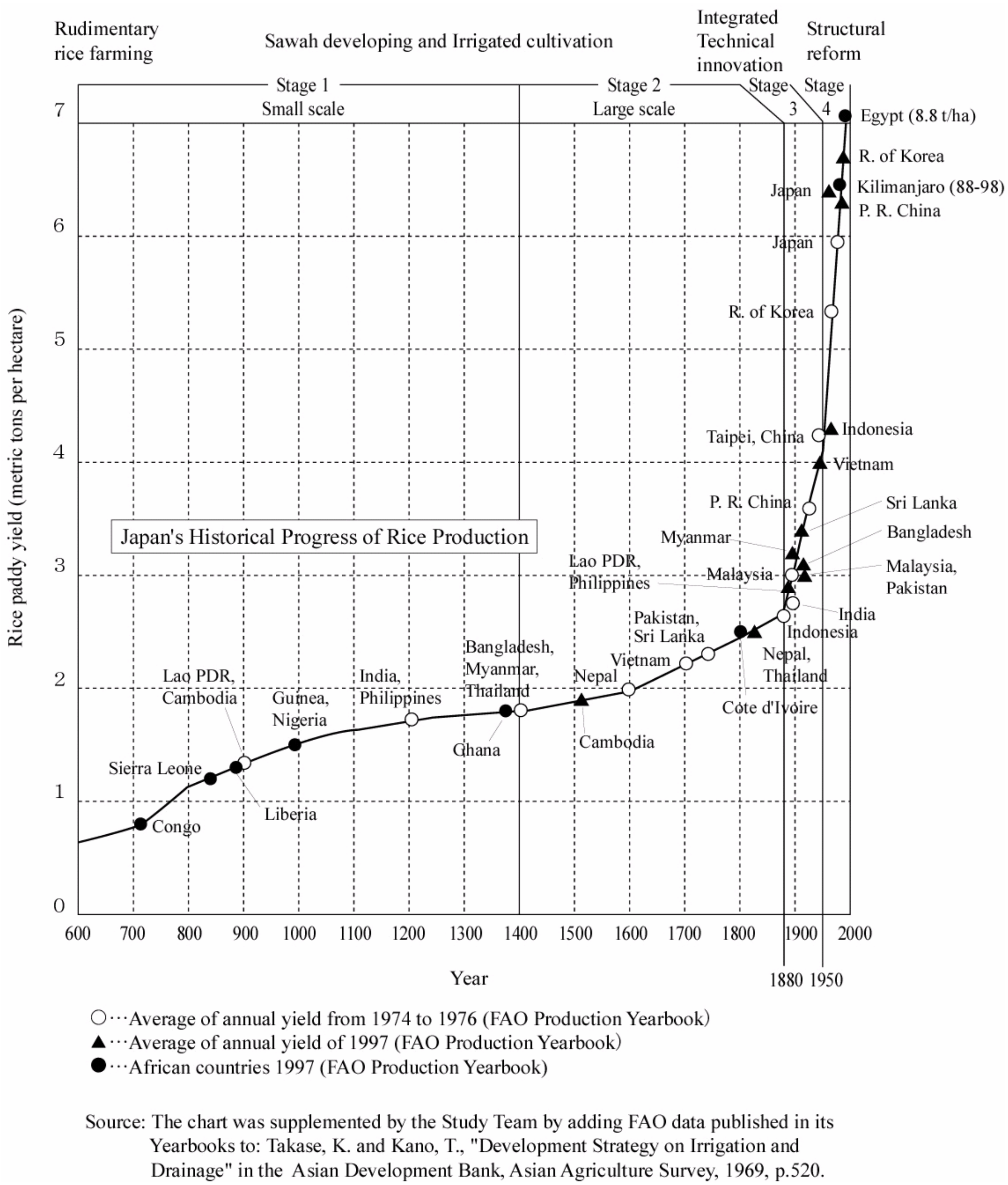


Fig. 5. Rice yields in Asia and Africa: Comparison with historical path of rice production in Japan.

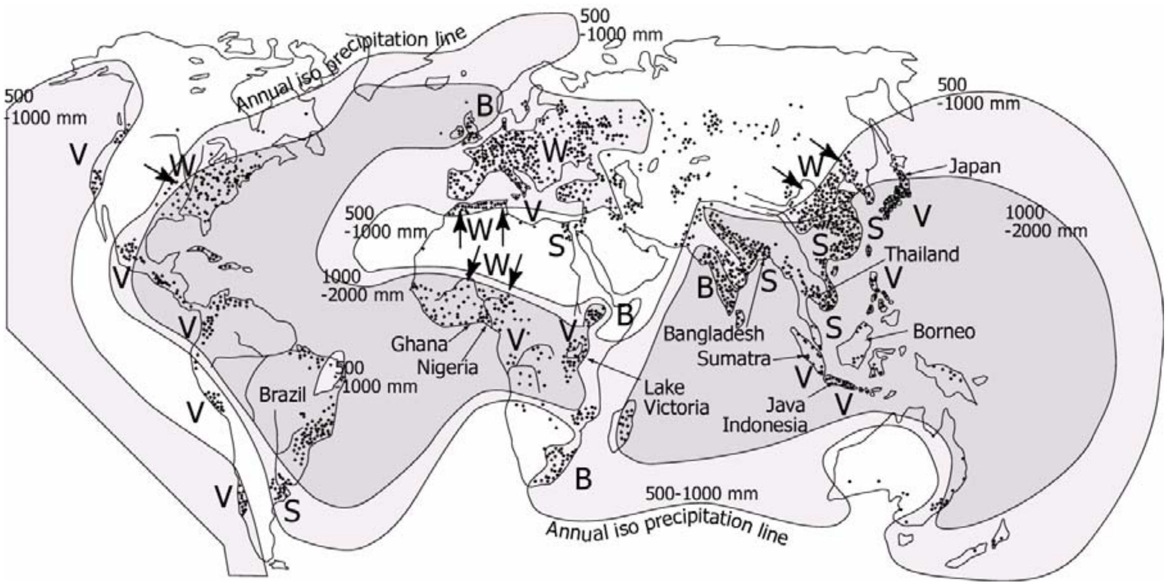


Fig. 6. Global distribution of geological fertilization soils and population density. Dense dots show the area of dense population. Global distribution of fertile soils is related to following four geological fertilization processes. (1) S: sediments by river, (2) V: volcanic, (3) W: loess deposition by wind, (4) B: dynamic balance between soil formation and erosion on base rich parent material.

Geological fertilization can be divided into the following four categories as shown in the Fig.6:

(1) S: Action of water (rivers' transporting and alluvial action): Floods occur once in several years to several decades and form fertile lowland soils (Inceptosol). In Africa, the delta of the Nile Delta is a typical example. The Nile Delta also benefits from the volcanic ash soils distributed in the Ethiopian Plateau and around Lake Victoria in the upstream sections.

(2) V: Volcanic activity (supply of volcanic ash and basic lava): Supplied once in several hundred to several thousand years, volcanic ash causes catastrophic disasters in the short term but restores soils and forms fertile volcanic soils (Andisol) full of nutrition and vitality. Soil fertility is high on the Ethiopian Plateau and in the countries around or near Lake Victoria (Kenya, Uganda, Rwanda, Burundi and far eastern parts of the Democratic Republic of the Congo) because volcanic ash and basic lava provide these regions with geological fertilization.

(3) W: Action of winds (supply of loess): Natural deserts are needed to the formation of fertile soils. Harmattan dust from the Sahara is rich in bases and fertile. Northern Nigeria has Harmattan winds from the Sahara in December and January in the dry

season every year, which bring a large quantity of loess. Loess-derived soils are widely distributed in the granaries of Western countries, too. The eastern parts of China enjoy the benefit of dust from the Gobi Desert, loess plateaus, etc. Dust from deserts also possibly helps prevent global warming by supplying iron to the ocean, which in turn promotes $CO_2$ absorption by algae.

(4) B: Dynamic equilibrium between weathering/soil formation and soil erosion (soil metabolism or prevention of soil ageing): The Deccan Plateau in India is a basaltic lava flow plateau having a history of tens of millions of years. Using these soils as parent materials, fertile Regul soils (Vertisol) were formed extensively. But since it is estimated that the maturing period of Vertisol does not exceed tens of thousands of years, the Vertisol in the Deccan Plateau clearly keeps a dynamic equilibrium between soil erosion and soil genesis. But as discussed later, care should be taken because a soil erosion-genesis balance achieved in the natural environment is easily changed into excessive erosion, soil degradation and desertification as a result of improper farming activities. If soil erosion is much less than soil formation, soil nutrients leach and are exhausted in the long run, forming aged soils (Oxisol).

## 4. Sawah system as multi-functional wetlands

The upper part of Fig. 7 shows a concept of macro scale ecological engineering, i.e., watershed ecological engineering. The soils formed in uplands and the nutrients released during rock weathering and soil formation processes in uplands are accumulated in lowlands (geological fertilization). Watershed agroforestry through the integration of upland forestry, upland farming and lowland sawah systems in a watershed is a typical model of watershed ecological engineering. The optimum land use pattern and landscape management practices optimize the geological fertilization through the control of optimum hydrology. This is an eco-environmental basis for long-term intensive sustainability of sawah-based rice farming in Asia. World scale sediment delivery data from various river basins in ton $ha^{-1}$ $yr^{-1}$ were reported by Walling (1983). Asian monsoon area showed the highest delivery of sediments by soil erosion where have the major distribution of sawah-based rice farming. For upland farming, such soil erosion destroys farming productivity, however for lowland sawah-based rice farming such eroded sediments are the parent materials of lowland sawah soils.

The lower part of the Fig. 7 shows the micro scale mechanisms of intensive sustainability of the sawah system. The sawah systems can be managed as multi-functional constructed wetlands. Submerged water can control weeds. Under submerged condition, because of reduction of ferric iron to ferrous iron, phosphorous

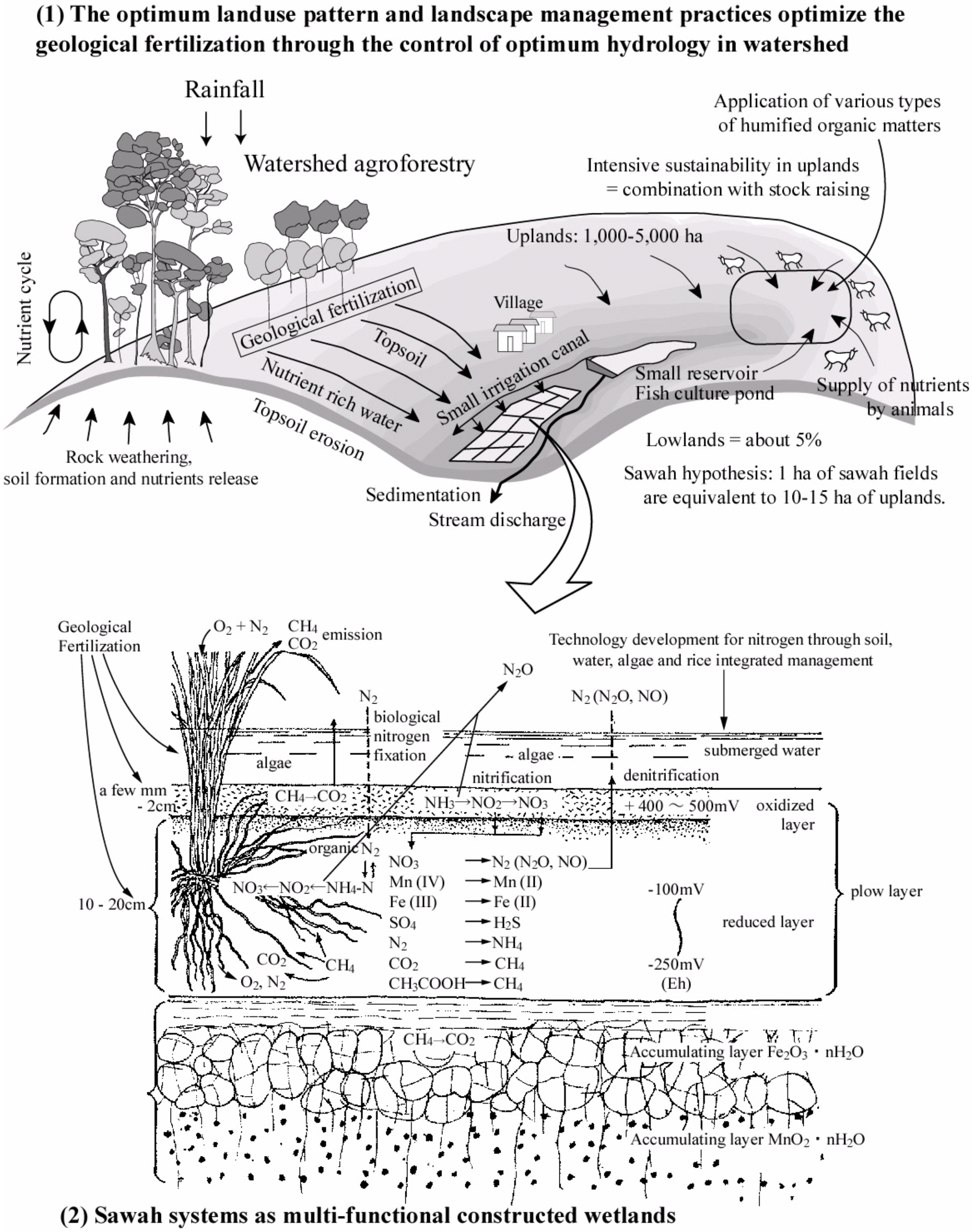


Fig. 7. Macro- and micro-scale ecological mechanisms of intensive sustainability of lowland sawah systems: (1) Geological fertilization through watershed ecological engineering, and (2) Multi-functional constructed wetlands for enhanced supply of N, P, Si, and other nutrients.

availability is increased and acid pH is neutralized, hence micronutrients availability is also increased (Kyuma, 2004). These eutrophication mechanisms encourage not only the growth of rice plant but also encourage the growth of various algae and other anaerobic microbes that increase the nitrogen fixation. The quantitative evaluation of nitrogen fixation in sawah systems including the role of algae will be important future research topics. It is not yet well evaluated the nitrogen fixation amount of soil microbes under a submerged sawah systems which could reach 20–100 kg $ha^{-1}$ $yr^{-1}$ in Japan and 20–200 kg $ha^{-1}$ $yr^{-1}$ in the tropics depending on the level of soil fertility and water management (Hirose and Wakatsuki, 2002).

## 5. Restoration of degraded inland valley watersheds in West Africa by sawah type ecological engineering through farmers' participation and self-support efforts

Why has the Green Revolution not yet occurred in West Africa and Sub-Saharan Africa? The ecological environment of soil and water conditions in this region is very severe. Lowland soil fertility in West Africa may be the lowest among major tropical areas in the world as seen in Table 5. The main cause of food and environmental crises in West Africa, however, may be due to the under development of lowland agriculture. Environmentally creative technology, or ecological engineering technology, such as sawah-based farming, which are common in Asian countries, are not traditionally practiced in West Africa. Irrigation and drainage without farmers' sawah farming technologies has proved inefficient or even damaging because of accelerated erosion. Thus, the development of irrigation has been slow. In the absence of water control, fertilizers cannot be used efficiently. Consequently, the high yielding varieties perform poorly and soil fertility cannot be sustained. Hence, the Green Revolution cannot take place. Sawah-based rice farming for enhancement of the geological fertilization process, conserve water resources, and the multi-functionality of the sawah type wetlands. This is a sawah hypothesis (Hirose and Wakatsuki, 2002). According to the agroecological survey (Windmeijer and Andriesse, 1993), there are wide distributions of lowlands in West Africa, 21–51 million ha of inland valleys, 12–25 million ha of flood plains, and 4.2–8.8 million ha of deltas, coastal lowland s and boliland. Potential total areas for irrigated sawah is estimated 10 to 20 million ha (Hirose and Wakatsuki, 2002; Wakatsuki, 2003), of which 0.6 million ha had developed as irrigated sawah in West Africa in 1999 (WARDA, 2000).

The term sawah refers to levelled and bunded rice fields with inlet and outlet connecting irrigation and drainage. The term originates from Malayo-Indonesian. The English term, paddy or paddi, also originates from the Malayo-Indonesian term, padi, which means rice plant. In order to avoid confusion between the terms rice plant,

Table 5**.** Regional and some historical changes of soil fertility of lowland rice soils in West Africa, Tropical Asia, Japan and Mediterrenian countries**.**

| Location | pH | Total C | Total N | Available Si | Available | Exchangeable Cation (cmol/kg) | | | | | Sand | Clay | CEC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | (%) | (%) | (ppm) | P (ppm)* | Ca | K | Na | Mg | eCEC | (%) | (%) | /Clay |
| IVS-WA 1980s (1) | 5.3 | 1.3 | 0.11 | - | 9 | 1.9 | 0.3 | 0.2 | 0.9 | 4.2 | 60 | 17 | 25 |
| FLPWA 1980s (1) | 5.4 | 1.1 | 0.10 | - | 7 | 5.6 | 0.5 | 0.8 | 2.7 | 10.3 | 48 | 29 | 36 |
| T. Asia 1970s (2) | 5.6 | 2.1 | 0.17 | 111 | 13 | 10.4 | 0.4 | 1.5 | 5.5 | 17.8 | 23 | 41 | 43 |
| Japan 1970s (2) | 5.4 | 3.3 | 0.29 | 91 | 57 | 9.3 | 0.4 | 0.4 | 2.8 | 12.9 | 49 | 21 | 61 |
| Japan 1979 (3) | 5.7 | 2.5 | 0.22 | -- | 11** | 8.7 | 0.5 | --- | 2.4 | --- | -- | -- | -- |
| Japan 1997 (3) | 5.6 | 2.3 | 0.21 | -- | 14** | 8.9 | 0.6 | --- | 2.2 | --- | -- | -- | -- |
| Thailand 1970s (2) | 5.2 | 1.1 | 0.09 | 57 | 6 | 7.2 | 0.3 | 1.4 | 4.3 | 13.2 | 38 | 37 | 36 |
| Bangladesh 1967 (2,4) | 6.1 | 1.2 | 0.13 | 60 | 17 | 7.8 | 0.3 | 0.9 | 2.7 | 12.1 | 28 | 30 | 40 |
| Bangladesh 1995 (4) | 5.9 | 1.1 | 0.09 | --- | 15 | 6.9 | 0.2 | 0.9 | 2.5 | 11.1 | --- | --- | --- |
| Indonesia 1970 (2) | 6.6 | 1.4 | 0.13 | 294 | 11 | 17.8 | 0.4 | 1.5 | 6.3 | 26.0 | 23 | 51 | 51 |
| Indonesia 2000s (5) | 5.6 | 1.6 | 0.16 | --- | 19 | 21.3 | 0.2 | 0.5 | 7.1 | 29.1 | --- | --- | --- |
| Mediterranean 1970s (2,6) | 6.8 | 1.8 | 0.16 | 112 | 32 | 15.9 | 0.6 | 1.0 | 4.6 | 22.1 | --- | --- | --- |

* Bray 2, **Truog, (1) IVS-WA, means of 185 sites of Inland valley soils, FLP-WA, means of 62 sites of flood plain soils in West Africa by Hirose and Wakatsuki **(**2002**)**, (2) means of 529 sites of lowland rice soils in tropical Asian countries by Kyuma 2004, (3) means of 8706 sites of lowland rice soils in Japan collected at the same sites in both 1979 and 1997 by Obara and Nakai 2003, Nakai and Obara 2004, (4) means of 53 sites of lowland rice soils collected at the same sites in both 1967 and 1995 by Mohsin et al., 1997a, b, 1998, (5) means of 46 sites collected at the same sites in both 1970 and 2003 by Darmawan 2004, (6) means of 62 sites of lowland rice soils in 1973 from Portugal, Spain and Italy by Kyuma (2004).

paddy, and man-made rice growth environment, the author propose to use the term sawah.

The term, Ecological Engineering Technology, is defined here as an ecology-based sustainable farming technology viable to local socio-cultural systems to increase farming productivity and to improve the environment. The ecotechnologies control water and helps conserve water and soil. Levelling, bunding, and construction of canal and head dyke are the examples of such ecotechnologies, which can be practiced as an extension of agronomic practices using locally available tools and materials. The ecotechnology will be the key technology to attract local farmers' active participation or even self-support efforts for the improvement of basic agricultural infrastructure, such as irrigation and soil conservation measure.

According to the recent data by WARDA (2000), the percentage of area under rice is as follows: 31% for upland, 47% for lowland, 16% for irrigated 5% and for deep water rice ecology. The percentages of upland rice area and production were dramatically decreased in the last 15 years, 1984–1999 (57 to 31%) and (4 to 25%) respectively. Rice cultivation in West Africa was traditionally an extension of upland farming. However, following the pioneering technical cooperation of Taiwanese teams regarding to wide spread and intensive sawah-based farming for some 10 years in the 1960s and 1970s, the number of rice farmers who are consciously conducting water management is steadily increasing throughout the last 30-40 years (Hsieh, 2003). Such management involves the introduction of bunding, levelling, construction of dams, dykes and weir and extension of water canals. Consequently, there are now many types of rice cultivation in terms of water control, ranging from upland rice to irrigated lowland sawah (Wakatsuki et al., 2005).

In the past 16 years the authors group had continuously selected various areas of benchmark watersheds, from 100 to 10000 ha for basic agroecological survey and intensive field testing for participatory and self-supports approach for low cost sustainable sawah development under the JSPS and JICA projects with collaboration from Ghanaian and Nigerian counterparts at Guinea Savanna zone of Nigeria and Forest Transitional zone of Ghana (Wakatsuki et al., 1998; Hirose and Wakatsuki, 2002), which proposed loan based strategy by farmers' self-support efforts on sawah development in West Africa.

## 6. Present major problems for the sustainable rice farming systems in Japan, Thailand, Bangladesh, Indonesia, Ghana and Nigeria

Table 5 shows regional soil fertility data as well as some historical changes of soil fertility of lowland rice soils in West Africa, tropical Asia, Japan, and some

Mediterranean countries. These fertility evaluations were made based on the extensive soils samplings to reach general characteristics in each country or region (Buri et al., 1999, 2000; Issaka et al., 1997; Issaka and Wakatsuki, 1996; Kyuma, 2004; Hirose and Wakatsuki, 2002, Obara and Nakai, 2003; Nakai and Obara, 2004; Mohsin et al., 1997a, b, 1998, 2003a, b; Darmawan, 2004).

As seen in the Table 5, rice soil fertility in Japan is in good condition and has no indication of decline in terms of soil organic matter status, exchangeable potassium and other bases, and available phosphorous. However, Japanese rice faming is under crises. Total areas of sawah for rice cultivation decreased 3.4 to 1.7 million ha during the last 40 years. Because of ample food importation there are no short-term food crises in Japan. The most serious problems related to the decline rice cultivation are related the loss of multi-functionalities of sawah systems, such as (1) water and soil pollution, (2) landscape deterioration, especially in rural watersheds, Sato-Yama in Japanese, and (3) the deterioration of traditional Japanese community. Controlled release fertilizer (Saigusa, 2004) is the promising technology to reduce nitrate pollution. Although cadmium contamination of Japanese sawah soils can be restore by new remediation technology (Ishikawa, 2004), general imbalance of nutrients in many watersheds in Japan, deficient of Si to N and P in irrigation water, river, lake, and sea, is now basic ecological problems. Hydrological changes by dam constructions and eutrophication during 1960-2000 may be major reason such imbalance of Si to N and P (Harashima, 2003).

Indonesian rice soil fertility may be one of the highest in Asia developing. Although rice yield increased dramatically the last 20 years because of the Green Revolution (Fig. 4), there are no indications of decline of soil fertility as seen in Table 5 (Kyuma, 2004; Darmawan, 2004). Phosphorus fertilizer increased available phosphorous level considerably. However, long-term soil fertility monitoring will be important to sustain multi-functionality of beautiful sawah-based rice cultivation in Java (Indonesian Soil Research Institute, 2004). Rice yield of Bangladesh increased last ten years followed by Indonesia as seen in Fig. 4. Although soil fertility decline is not clear, organic matter contents and base status showed some indication of decline. Arsenic pollution due to heavy utilization of ground water and possible relation to nitrogen fertilizer is very serious problem under expanding (Ahmed et al., 2004). At the moment rice soil contamination is not so clear (Mohsin et al., 2003a, b).

Although soil fertility of Thailand is not so high, especially available phosphorous was low in 1970s as seen in Table 5. However, as seen in the case of Indonesia, phosphorous fertilization might increase the available phosphorous level, as seen the steady increase of rice yield. Thailand has diverse rice farming systems in terms of irrigation and soil fertility management (Tabuchi and Hasegwa, 1995). Since agroecology of north-eastern Thailand, so-called Isan region, has quite similar agro-ecology settings in majority of West Africa, experiences in sawah development and rice farming in the Isan area will be very useful for the sustainable development sawah-based rice farming in West Africa which as the most sever agroecology for rice cultivation in terms of soil fertility and hydrological condition. However, the benefit by geological fertilization and multi-functionality of the sawah system can overcome these constrains in West Africa. Asian African collaboration with the interfaces of Europe and USA for sustainable sawah development will be key (Hirose and Wakatsuki, 2002).

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