The Effect of Green Revolution Technology during the Period of 1970-2003 on 'Sawah' Soil Properties in Java, Indonesia

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Abstract

Many countries reported that the green revolution (GR) technology caused some adverse effects on agricultural lands, but there is no research on the effects of GR in Indonesia. In order to evaluate the effect of GR technology on 'sawah' soil in Indonesia, a comparative study between seed farms, where GR technology has been continuously applied, and non-seed farms was conducted in Java as a pioneer place of GR technology in Indonesia. Soil samples collected by Kawaguchi and Kyuma in 1970 and new samples taken in 2003 from the same sites or the sites close to the 1970 sampling were analyzed and compared. During the period of 1970- 2003 the land use pattern of 'sawah' in seed farms and non-seed farms were not changed but cultivation intensity increased. The result showed total carbon (TC) and total nitrogen (TN) contents significantly increased from 31.90 to 40.42 Mg ha^{-1} and from 3.04 to 3.97 Mg ha^{-1}, respectively and were mostly accumulated in the surface soil layer. Differences in land management practices between seed farm and non-seed farm affected the change of TC and TN content in 0 - 20 cm soil layer during the period of 1970 to 2003. In seed farms, where rice had been planted in monoculture system, the TC and TN contents in the soil layer of 0-20 cm increased from 34.50 to 39.24 Mg ha^{-1} and 3.16 to 3.95 Mg ha^{-1}, respectively. , mean soil pH and exchangeable sodium (Na) decreased from 6.90 ± 0.77 to 5.84 ± 0.90 and from 3.28 ± 2.76 to 1.67 ± 2.06 $kmol_c\ ha^{-1}$, respectively. Exchangeable acidity and available phosphorus (P) significantly increased from 9.32 ± 3.09 to 13.23 ± 3.72 $kmol_c\ ha^{-1}$ and from 136.62 ± 154.72 to 255.75 ± 292.41 kg P_2O_5 ha^{-1}, respectively. The average content of available Si decreased from 1512 ± 634 kg SiO_2 ha^{-1} to 1230 ± 556 kg SiO_2 ha^{-1} and from 6676 ± 3569 kg SiO_2 ha^{-1} to 5894 ± 3372 kg SiO_2 ha^{-1} in the 0-20 cm and 0-100 cm soil layers, respectively. Cultivation intensities' difference between seed farms planted with rice three times a year and non-seed farms rotated rice and upland crop seemed affected the changing rates of available Si within the study period. In the 0 - 20 cm soil layer, the average content of available Si decreased from 1646 ± 581 kg SiO_2 ha^{-1} to 1283 ± 533 kg SiO_2 ha^{-1} (- 22%) and from 1440 ± 645 kg SiO_2 ha^{-1} to 1202 ± 563 kg SiO_2 ha^{-1} (- 17%) in seed farms and non-seed farms, respectively. The demerit of 'sawah' system in Indonesia is mostly because of improper land management and imbalance nutrient input over long period of time.

Key words: chemical characteristics, green revolution, Java, 'sawah', seed farms, total carbon, total nitrogen.

Introduction

Green Revolution (GR) is the term referring mainly to dramatic increases in cereal-grain yields in many developing countries beginning in the late of 1960s. The GR technologies are broadly classified into two majors categories. The first one is the breeding of new plant varieties; the second is the development of new agricultural techniques. The design of hybrid strains was motivated by a desire to, first, increase crop yield, and also to increase durability for transport and longevity for storage. The techniques refined and developed by the GR consisted of extensive use of chemical fertilizers, irrigation, pesticides and herbicides (FAO, 1984).

The GR technology has been criticized on several grounds, but the primary argument is an environmental problem. Runoff and leaching of fertilizer, pesticide and herbicide continue to be significant causes of environmental pollution, killing off beneficial soil microbes and other organisms; erosion of the soil; and loss of valuable trace elements (Pimentel, 1996). Some studies in India found that application of GR technology caused soil degradation and produced scarcity by reducing the availability of genetic diversity of crops (Singh, 2000). Similar conclusions were reported by researchers in Bangladesh (Rahman, 2003), China (Zhang *et al.*, 2003) and Latin America (Redclift, 1989). In case of Indonesia, GR technology was implemented in Java from 1966, by using the new high-yielding varieties (HYVs) of rice (i.e. IR-8) developed by the International Rice Research Institute (IRRI). This island was chosen as a pioneer place in adopting the GR technology, because it has some advantages as compared to the others. Indonesia had about 6 million hectares of irrigated 'sawah' and more than half was located in Java and as the centre of the country, Java was much easier to be monitored. The term 'sawah' refers to levelled rice field surrounded by bunds with inlet and outlet for irrigation and drainage (Wakatsuki *et al.*, 1998). To support the adoption of GR technology, Indonesian government established many research stations for rice (seed farm) throughout Java and supported them with good irrigation facilities, chemical fertilizers, pesticides and also qualified staff. Due to the abundance of cheap labour, mechanization under rice cultivation has not made much progress in Java and Indonesia as a whole. The main function of seed farm was to bridge technology transfer from researchers (mostly from IRRI) to farmers and also as a food security buffer for the country (Indonesian Ministry of Agriculture, 1995).

The GR was not a once-and-for-all change in technology. In the beginning of the period, the new rice cultivation systems consisted of new HYVs of rice, application of chemical fertilizers and pesticides was done in the seed farms. Java had more than 20 seed farms, spreading all over the island (Indonesian Ministry of Agriculture, 1995). Implementation of GR technology caused a lot of changes in rice cultivation systems in Java. Differences in land management practices might have affected soil chemical properties. In seed farm, where rice has been planted continuously using high amounts of chemical fertilizers the trend was different when compared with non-seed farm where farmers used low amounts of chemical fertilizers but in rotation. Kawaguchi and Kyuma (1977) noted that in 1970, all seed farms in Java were practicing GR technology using HYVs of rice, chemical fertilizers and pesticides and produced about 2.5 Mg ha^{-1} of husked rice on average. The productivity of seed farms was almost two folds compared with non-seed farms, where local varieties were planted with traditional management ways. However, since the GR technology started to be adapted to non-seed farms, this wide gap of productivity was gradually eliminated and both of them have been able to produce 5.5 Mg ha^{-1} per cropping season (Indonesian Ministry of Agriculture, 1995).

Although seed farms and non-seed farms were located in one island, their cultivation and land management practices were quite different. Indonesia government supplied seed farms with all their needs for rice cultivation. In order to ensure food security, most of the seed farms planted rice over the whole year, using modern cultivation management systems. On the other hand, rice cultivation in non-seed farms was affected by the non availability of water, and application of chemical fertilizers and pesticides depending on the farmers' budget. Most of the non-seed farms were cultivated by rented farmers that made it difficult to track the history of chemical fertilizers application on those sites. However, according to Lansing *et al.*, (2001), application rates of chemical fertilizers by Java's and Bali's farmers are much lower than government recommendation. During the less rainfall season, from April to September, most non-seed farms planted upland crops, dominated by vegetables such as soybean, green bean, peanuts, chili, maize, cassava and sugarcane in some crop rotation patterns (Nair, 1985).

Differences in cultivation and land management systems between seed farms and non-seed farms might also have affected 'sawah' soil properties. The purposes of this study are to evaluate the effects of GR technology on the changes of 'sawah' soil during the period of 1970 and 2003, in relation to differences in soil properties.

Materials and Methods

Description of study area and sampling sites

Java is the smallest among the five biggest islands in Indonesia archipelago. It lies between 05°52'34" S to 08°46'46" S and 105°12'40" E to 114°35'38" E. Although the total land area of this island is just 132,187 km^2, which is about 7 percent of the total land area of Indonesia, more than half of Indonesian people live here. Figure 1 shows the study area and distribution of sampling sites both in 1970 and 2003 throughout the island. Most of the sampling sites are located in the northern part along the coastal plain, because the southern part of Java is mountainous and difficult to access. Tables 1 gives the brief information on soil and land use pattern both in 1970 and 2003, including the general description in each sampling sites.

The present land use patterns in each seed farm and non-seed farm were almost similar compared to 1970, but cultivation intensity increased. Most of the seed farms grew rice three times a year and non-seed farms planted with rice and upland crops in rotation patterns. Although rice is still the major crop in Java, the area of 112,000 hectares 'sawah' decreased during the period 1984-2000 or about 7000 ha every year (Verburg *et al.*, 1999). Among 46 sampling sites in 1970, four of them (site number 2, 4, 5, and 40) were not sampled in 2003 because land use changed to non-agricultural purposes and two sites (number 15 and 30) changed to other crop cultivation were also excluded in this study. For the remaining 40 sites in 2003, twenty-five of them were identified as the original sites with 1970's (Table 1) consulting with the description sheets made by Kawaguchi and Kyuma and/or information from the landowners and old farmers near the sites. Since 15 sites could not be confirmed as the original sites due to land use changes and lack of information, soil was collected from the closest site to 1970's sampling areas. Among 40 sites in 2003, twenty-two sites were located in non-seed farm 'sawah' and the other eighteen were in seed farms. Inceptisols and Vertisols were the main two soil types in the sites, dominating 24 and 14 locations, respectively. The other two, number 8 and 10 belonged to Ultisols and Alfisols (Table 1).

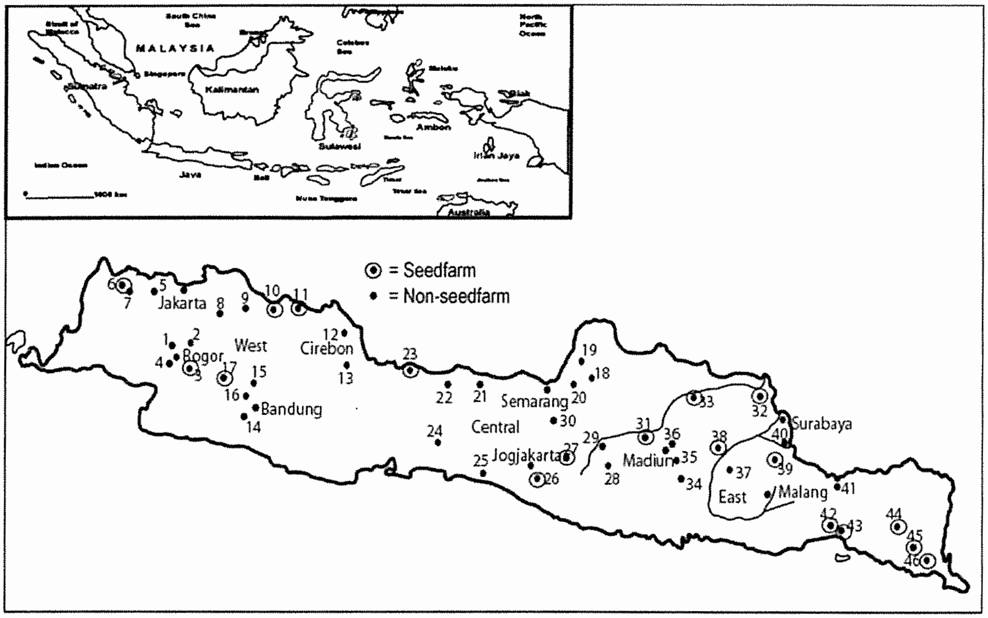

Figure 1. The map of Indonesia showing the Java Island with the main cities and distribution of sampling sites both in 1970 and 2003

Soil sampling and interview

The study used soil samples taken by Kawaguchi and Kyuma in 1970 as references. These soil samples had been air dried and kept in sealed plastic bottles in a storage room. The second sampling was done in April and December 2003 from the same or closest to original sites in 1970. Soil samples were collected from each horizon in a profile at the respective sites by using 100 cm^3 core samplers to determine the bulk density of soil. Composite soil samples from the each horizon were also collected as well for chemical analyses. To ensure the reliability of 1970 soil samples, our analytical data and the original data from Kyoto University was compared. Both analytical results were found to be very similar with less than 5% difference (data not published).

In order to get the latest information about the changes in rice cultivation systems and productivity in seed farms and non-seed farms during the period of 1970 and 2003, we interviewed seed farms staff and farmers on the respective sites assisted by the counterparts as interpreters.

Laboratory analyses.

Total Carbon and Nitrogen. Air-dried soil samples were ground and passed through a 2 mm sieve and stored in plastic boxes for laboratory analyses. Soil samples from both 1970 and 2003 were treated similarly. A total of 349 soil samples (165 for 1970 and 184 for 2003) were analyzed for total carbon (TC) and total nitrogen (TN) contents. Finely ground soil samples were oven dried at 80°C for about 24 hours. Total carbon and nitrogen were determined by dry combustion method (Nelson and Sommers, 1982) using Yanaco CN Corder Model MT-700 (Yanagimoto MFG. Co. Ltd., Kyoto, Japan).

Available Nitrogen. Six grams of soil in a glass tube was submerged with distilled water and covered with rubber stopper. These tubes were incubated at 30 °C for 28 days. After incubation, the inorganic nitrogen in soil was extracted with 2 M KCl and the content was determined by steam distillation method with MgO and Devarda alloy (JSSPN, 1986).

Bulk density. Bulk density is necessary for converting carbon and nitrogen contents on a weight basis to content on the volume basis (e.g. Mg ha^{-1} to the 100 cm depth). Bulk density of a soil was calculated by using the sample in a 100 cm^3-core. After oven drying at 105°C for about 72 hours, the weight of soil per core sample volume (100 cm^3) was measured. The bulk density values in 2003 were used to calculate the carbon and nitrogen contents for both samples taken in 1970 and 2003, since the bulk density of 1970's samples was not determined.

Chemical properties of soils. The air-dried soil samples were ground and passed through a 2-mm sieve. Soil pH was measured using the glass electrode method with a soil: water ratio of 1:2.5 (IITA, 1979; Mclean 1982). Exchangeable acidity was determined by first extracting with 1 M KCl and titrating with NaOH (Mclean, 1965). Exchangeable base cations (Ca, Mg, K and Na) were extracted by 1 M neutral ammonium acetate (Thomas, 1982) and then exchangeable Ca and Mg were determined by using Inductively Coupled Plasma-Atomic Emission Spectroscopy (Shimadzu ICPS 2000) and exchangeable K and Na determined by Atomic Absorption Spectrophotometer (Shimadzu AS 680). Effective cation exchange capacity (eCEC) represents the sum of the amount of exchangeable bases and the exchangeable acidity. Available P was extracted by Bray 2 method and the content was determined by colorimetry with UV/VIS Spectrophotometer (Jasco V-530, Tokyo-Japan) (Bray and Kurtz, 1945).

Calculation and statistical analyses

The calculation method of soil carbon and nitrogen content. The depths of the identical horizons were not perfectly the same but very similar in the 1970 and 2003 (Figure 2 and 3). The carbon and nitrogen contents were estimated on per hectare basis using the equation below (Ali *et al.*, 1997). For an individual profile with n horizons, the calculation of the total carbon and nitrogen contents on a volume basis was as follow:

$$\sum = nipiPiDiTd1 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where, Td = total content of carbon or nitrogen (Mg ha^{-1}) at a depth d, pi = bulk density (Mg m^{-3}) of horizon i, =Piproportion of carbon or nitrogen (g kg^{-1}) in horizon I, Di = thickness of the horizon *(cm)*. Similar calculations were also applied for other soil characters.

Statistical analyses. To examine the effect of land management differences on the change patterns, all data was analyzed by SPSS (Version 11.0 for Windows). Paired-samples T-test was used for comparing means of TC and TN contents using land management differences referring to seed farm and non-seed farm as blocks

Results and Discussion

Change in carbon and nitrogen stocks in 'sawah' soil during the period of 1970 - 2003.

Table 2 describes the mean and changes in TC and TN contents in each site. Change in TC content ranged from -29.5 % (site number 8) to 137.9 % (site number 27), but at most sites change was greater than 25%. Change in TN content ranged from - 26.3 % (site number 45) to 121.3 % (site number 24), with the change at most sites also being greater than 25 %. Figure 2 and 3 show the profile distributions of TC and TN contents in 1970 and 2003 in seed farms and non-seed farms, respectively. TC and TN contents highly varied among the sites. Mean TC content for seed farms sites increased throughout the soil profile from 8.23 ± 5.06 g kg^{-1} to 9.81 ± 5.01 g kg^{-1} during the period of 1970 to 2003; while in non-seed farms TC changed from 8.37 ± 5.11 g kg^{-1} to 10.27 ± 6.26 g kg^{-1}. Mean values of TN content in seed farms increased from 0.85 ± 0.46 g kg^{-1} to 1.05 ± 0.46 g kg^{-1} and 0.91 ± 0.42 g kg^{-1} to 1.04 ± 0.52 g kg^{-1} in non-seed farms sites.

Table 1. Descriptions of sampling sites and land use pattern during the period between 1970 and 2003 Java, Indonesia.

Sampling Code	Location name	GPS reading		Elevation	Land use pattern		USDA Taxonomy	Note
		South	East		1970§	2003		
In-1	Kedung Halang, Bogor	S 06°33'0.6.3"	E 106°48'26.4"	213 meter	rice-upland crop	upland crop	Aeric Epiaquepts	B-NS
In-3	Bendungan Ciawi, Bogor	S 06°39'43.2"	E 106°51'40.4"	529 meter	rice-rice	rice-rice-upland crops	Aeric Epiaquepts	A-SF
In-6	Kebun Percobaan Singamerta, Ciruas	S 06°07'14.7"	E 106°14'36.5"	26 meter	rice-rice	rice-rice-rice	Typic Epiaquepts	A-SF
In-7	Petung Sentul, Kragilan Serang	S 06°07'52.0"	E 106°16'16.5"	31 meter	rice-upland crop	rice-rice-upland crops	Typic Halaquepts	B-NS
In-8	Pasir Gombong Lemahabang, Bekasi	S 06°07'52.0"	E 106°16'16.5"	31 meter	rice-upland crop	rice-rice-upland crops	Typic Kanhapludults	B-NS
In-9	Palawad, Karawang	S 06°17'30.0"	E 107°21'13.6"	32 meter	rice-rice	rice-rice-upland crops	Vertic Epiaquepts	B-NS
In-10	Balitpa Sukamandi, Subang	S 06°21'27.1"	E 107°38'38.2"	31 meter	rice-rice	rice-rice-rice	Aeric Endoaqualfs	A-SF
In-11	LPPP Pusakanegara, Subang	S 06°16'43.0"	E 107°52'26.6"	22 meter	rice-rice	rice-rice-rice	Vertic Epiaquepts	A-SF
In-12	Sudikampiran, Sliyeg Indramayu	S 06°29'00.7"	E 108°22'44.4"	22 meter	rice-rice	rice-rice-upland crop	Vertic Endoaquepts	B-NS
In-13	Sampora, Cilimus Kuningan	S 06°51'32.3"	E 108°29'26.1"	452 meter	rice-upland crop	rice-rice-upland crops	Typic Dystropepts	B-NS
In-14	Pamoyanan, Ketapang Bandung	S 06°00'08.5"	E 107°33'10.1"	685 meter	rice-rice	rice-rice-upland crops	Typic Endoaquepts	B-NS
In-16	Warungkaweni Cipageran, Cimahi	S 06°51'17.4"	E 107°32'54.1"	825 meter	rice-upland crop	upland crop	Mollic Fragiaquepts	B-NS
In-17	LPPP Ciheya, Ciranjang, Cianjur	S 06°50'15.7"	E 107°16'26.5"	209 meter	rice-rice	rice-rice-rice	Aeric Epiaquerts	A-SF
In-18	Medini, Undaan Kudus	S 06°55'04.6"	E 110°47'43.7"	22 meter	rice-upland	rice-rice-rice/upland crops	Vertic Endoaquepts	A-NS
In-19	Mayong Lor, Mayong Jepara	S 06°45'41.7"	E 110°45'08.4"	25 meter	rice-upland crop	rice-rice-upland crops	Aquic Eutropepts	B-NS
In-20	Katonsari, Demak	S 06°54'42.2"	E 110°36'59.0"	17 meter	rice-upland crop	rice-rice-upland crops	Typic Calciaquepts	A-NS
In-21	Kartoharjo, Buaran Pekalongan	S 06°55'19.5"	E 109°40'16.5"	14 meter	rice-upland crop	rice-rice-upland crops	Aeric Epiaquerts	A-NS
In-22	Sirandu, Pemalang	S 06°54'11.5"	E 109°22'53.2"	25 meter	rice-upland crop	rice-upland crop	Aeric Epiaquerts	A-NS
In-23	Seedfarm Bulakamba, Brebes	S 06°21'27.1"	E 108°57'07.0"	11 meter	rice-rice	rice-rice-upland crops	Typic Natraquerts	A-SF
In-24	Bojong, Purbolinggo	S 07°24'44.4"	E 109°22'31.0"	45 meter	rice-upland crop	rice-rice-upland crops	Typic Endoaquepts	B-NS
In-25	Lajer Ambal, Kebumen	S 07°44'45.6"	E 109°43'28.8"	22 meter	rice-upland crop	rice-rice-upland crops	Vertic Endoaquepts	A-NS
In-26	Seed farm Wonocatur, Bantul	S 07°48'02.5"	E 110°24'27.3"	118 meter	rice-rice	rice-rice-rice	Aeric Epiaquepts	A-SF
In-27	Humo Seed farm, Semangkak	S 07°42'29.5"	E 110°35'51.6"	159 meter	rice-rice	rice-upland crop	Aeric Epiaquepts	A-SF
In-28	Jumapolo, Karanganyar	S 07°42'29.5"	E 111°00'04.8"	339 meter	rice-upland crop	rice-rice-upland crops	Typic Dystrustepts	B-NS
In-29	Papahan, Tasikmadu Karanganyar	S 07°42'38.2"	E 111°17'17.2"	182 meter	rice-upland crop	rice-rice-rice/upland crops	Typic Epiaquerts	A-NS
In-31	LPPP Ngale, Paron Ngawi	S 07°24'37.6"	E 111°22'18.3"	68 meter	rice-rice	rice-rice-upland crops	Typic Calciaquerts	A-SF
In-32	BPMD Sukodadi, Lamongan	S 07°05'28.0"	E 112°19'41.7"	26 meter	rice-upland crop	rice-rice-upland crops	Typic Epiaquerts	A-SF
In-33	BPMD Brenggolo, Bojonegoro	S 07°07'39.4"	E 111°45'21.1"	37 meter	rice-upland crop	rice-rice-upland crops	Aeric Endoaquerts	B-SF
In-34	Kresek Wungu, Madiun	S 07°41'47.9"	E 111°36'58.0"	277 meter	rice-upland crop	rice-rice-upland crops	Aeric Epiaquepts	B-NS
In-35	Banjarsari, Dagangan Madiun	S 07°41'01.5"	E 111°35'49.2"	214 meter	rice-upland crop	rice-rice-rice	Typic Calciaquerts	B-NS
In-36	Patang, Nglames Madiun	S 07°35'31.1"	E 111°32'51.6"	74 meter	rice-rice	rice-rice-upland crops	Typic Epiaquerts	A-NS
In-37	Pelem, Parce Kediri	S 07°45'58.8"	E 112°10'02.4"	113 meter	rice-upland crop	rice-rice-upland crops	Typic Epiaquepts	B-NS
In-38	Seed farm Waung, Baron Nganjuk	S 07°35'51.7"	E 112°02'03.3"	56 meter	rice-upland crop	rice-rice-upland crops	Aeric Epiaquepts	A-SF
In-39	LPPP Mojosari, Mojokerto	S 07°30'27.9"	E 112°31'36.6"	33 meter	rice-upland crop	rice-rice-rice	Aeric Epiaquepts	A-SF
In-41	Maron Kulon, Maron Probolinggo	S 07°50'48.8"	E 113°21'02.2"	78 meter	rice-upland crop	rice-rice-rice/upland crops	Typic Epiaquepts	A-NS
In-42	Labruk Kidul, Lumajang	S 08°08'45.4"	E 113°12'18.6"	89 meter	rice-rice	rice-rice-rice/upland crops	Typic Epiaquerts	A-SF
In-43	BPMD Yasowilangun, Lumajang	S 08°12'58.8"	E 113°18'06.7"	30 meter	rice-upland crop	rice-rice-rice	Aeric Endoaquerts	A-SF
In-44	Balai benih Srimurni, Arjasa Jember	S 08°07'10.4"	E 113°44'47.9"	181 meter	rice-upland crop	rice-rice-rice	Fluvaquentic Epiaquep	A-SF
In-45	LPPP Genteng, Banyuwangi	S 08°22'47.4"	E 114°08'37.0"	159 meter	rice-rice	rice-rice-rice/upland crops	Aeric Epiaquepts	A-SF
In-46	Seed farm Sukorejo, Banyuwangi	S 08°29'30.7"	E 114°08'13.3"	93 meter	rice-upland crop	rice-rice-rice	Typic Calciaquerts	A-SF

Note: A = original sites; B = close to original sites; SF = seedfarms; NS = non-seedfarms; §= data from Kawaguchi and Kyuma (1977)

Table 2. Changes in TC and TN (Mg ha^{-1}) content in topsoil layer of each sampling sites in Java, Indonesia (1970-2003) and Bangladesh (1967-1995).

Profile no./location	Total Carbon (Mg ha^{-1})			Total Nitrogen (Mg ha^{-1})			Bulk density
	1970[a]	2003[b]	% change	1970[a]	2003[b]	% change	(Mg m^{-3})
1. Kedunghalang Bogor	39.29	39.15	-0.4	3.77	3.88	2.8	1.11
3. Bendungan Ciawi	43.93	48.55	10.5	4.37	5.27	20.5	1.15
6. Singamerta Ciruas	38.70	37.76	-2.4	4.01	4.20	4.6	1.18
7. Petung Sentul	11.22	12.61	12.4	1.10	1.60	45.9	1.10
8. Pasir Gombong	40.41	28.50	-29.5	1.94	3.15	62.7	1.21
9. Palawad Karawang	48.14	39.95	-17.0	4.01	4.09	2.0	1.18
10. Balitpa Sukamandi	24.93	34.74	39.4	3.15	3.80	20.7	1.21
11. LPPP Pusakanegara	41.33	50.33	21.8	3.28	5.38	64.2	1.26
12. Sudikampiran Sliyeg	20.09	29.13	45.0	3.72	3.25	-12.7	1.24
13. Sampora Cilimus	21.18	39.00	84.1	2.86	3.92	37.3	1.19
14. Pamoyanan Ketapang	52.92	58.63	10.8	5.80	5.63	-2.9	1.26
16. Warungkaweni Cipageran	38.56	48.91	26.9	3.81	4.86	27.7	1.19
17. LPPP Ciheya	40.25	45.62	13.4	4.13	4.58	10.9	1.29
18. Medini Undaan, Kudus	30.21	71.63	137.1	4.10	6.03	47.1	1.28
19. Mayong Lor Jepara	27.82	28.33	1.8	2.68	2.77	3.2	1.22
20. Katonsari Demak	29.97	54.43	81.6	4.57	5.23	14.5	1.27
21. Kartoharjo Buaran	20.99	46.65	122.2	2.56	4.24	65.6	1.28
22. Sirandu Pemalang	24.70	38.47	55.8	2.02	4.08	102.2	1.26
23. Bulakamba Brebes	27.90	33.54	20.2	2.05	4.10	100.0	1.28
24. Bojong Purbolinggo	33.92	70.05	106.5	2.95	6.53	121.3	1.22
25. Lajer Ambal, Kebumen	35.70	46.36	29.9	2.86	4.29	50.2	1.19
26. Wonocatur Bantul	18.64	18.88	1.3	1.65	2.51	52.2	1.18
27. Semangkak Klaten	18.41	43.79	137.9	2.12	4.67	119.7	1.18
28. Jumapolo Karanganyar	19.72	26.21	32.9	1.62	2.82	73.5	1.16
29. Tasikmadu Karanganyar	13.46	30.67	127.9	1.78	3.26	83.2	1.27
31. LPPP Ngale	34.58	48.00	38.8	2.66	3.75	40.8	1.33
32. BPMD Sukodadi	32.23	31.03	-3.7	1.83	2.69	46.8	1.31
33. BPMD Brenggolo	46.70	58.05	24.3	3.61	4.91	35.9	1.29
34. Krese Wungu	38.84	45.64	17.5	3.74	4.23	12.9	1.22
35. Banjarsari Dagangan	30.99	39.34	27.0	1.78	3.61	102.8	1.27
36. Patang, Nglames	34.27	60.19	75.6	3.02	5.08	68.1	1.26
37. Pelem Paree	16.42	21.65	31.8	1.83	2.04	11.1	1.19
38. Waung Baron Nganjuk	27.38	37.32	36.3	2.60	3.61	39.2	1.18
39. LPPP Mojosari	23.13	24.25	4.9	2.12	2.46	15.8	1.18
41. Maron Kulon	26.14	34.75	32.9	2.18	3.00	37.7	1.21
42. Labruk Kidul Lumajang	37.00	38.85	5.0	3.50	4.28	22.4	1.25
43. BPMD Yosowilangun	50.55	46.60	-7.8	5.33	4.69	-12.0	1.27
44. Srimurni Arjasa	27.38	32.26	17.8	2.60	3.32	27.9	1.18
45. LPPP Genteng	47.34	34.60	-26.9	4.88	3.60	-26.3	1.22
46. Sukorejo Bangorejo	40.57	42.20	4.0	3.02	3.26	7.8	1.26
Mean Java, Indonesia	31.9	40.4***	26.7	3.0	3.96***	30.6	1.22
Mean Bangladesh §	23.7	21.1	-11.0	2.5	2.2	-11.8	1.45

[a] Calculated base on the bulk density in 2003
[b] Paired samples T-test; *** significant at 0.001 level
§ data from Ali et al. (1997)

Variations in changing rates of TC and TN content among the sampling sites could have been affected by management practices in each site. For instance, although site number 45 was a seed farm that was planted with rice over the whole year, TC content decreased by - 26% while TC content at site 18 that was non-seed farm increased by more than 100 %. This disparity might be due to the differences in harvesting practices between these two sites. At site 45, whole rice straw was always taken away from the 'sawah' by farmers to feed their cattle. On the other hand farmers at site 18 only took out the rice grain and left the plant residues decomposed in the field, which was the typical harvesting management practice in Java. Lansing *et al.*, (2001) indicated that most of Java's and Bali's farmers thresh the rice stalks in situ and remove only the grain, leaving the rest of the plant to be ploughed under or burnt.

The application of GR technology in Java caused the accumulation of TC and TN in 'sawah' soils with a changing rate of about 30% between 1970-2003. On the other hand, within a similar period, Bangladesh decreased by -11% for these two parameters (Table 2). The differences in changing rate of 'sawah' productivity in these two regions could be a reason for these results. During the period of 1966 to 1996, rice production increased from 1.8 Mg ha^{-1} to 4.5 Mg ha^{-1} (150%) in Indonesia, which was much higher compared with that in Bangladesh which recorded a marginal increase (65%) from 1.7 Mg ha^{-1} to 2.8 Mg ha^{-1} (Otsuka, 2000). The farming systems were also different. Rice cultivation was predominant in Indonesia, which might accumulate more organic matter as main resources of carbon and nitrogen in the soils compared with those in Bangladesh, where the upland crop dominated (Ali *et al.*, 1997). The amount of carbon stored in 'sawah' system is greater than upland because of different biochemical processes and mechanisms mainly caused by the presence of flooded water in 'sawah' (Guo and Lin, 2001). The fraction of remaining carbon from total quantities added is higher under flooding than under non-flooding conditions. Both decomposition and mineralization rates of organic matter in anaerobic condition are considerably retarded compared with those under aerobic condition. Therefore, 'sawah' has a tendency to enhance carbon and nitrogen accumulation in the soil (Zhang and He, 2004).

Vertical distribution of carbon and nitrogen under different land use management

Figures 2 and 3 show the effect of GR on the profile distribution of TC and TN contents in respective sites in seed farms and non-seed farms between 1970 and 2003. It was clear that the changes and accumulation of TC and TN contents in each site were predominantly found within the topsoil. In the deeper layers, TC and TN contents of soils in 1970 were not so different compared with samples collected in 2003 for both seed farms and non-seed farms. This means that differences in land use management practices did not affected TC and TN distribution in the deeper layers of these soils. The International Rice Research Institute (IRRI-1986) and Zhang *et al.*, (2003) reported that intensive use of 'sawah' would form compacted and impermeable layer below the puddle layer that will protect the movement of nutrient and water to the deeper soil layer. This accounted for TC and TN accumulation in mostly the topsoil. The greater accumulation of TC and TN in top soil layers could be explained by increased input of plant residues, reduced decomposition rate of organic matter and increased nitrogen fixation in the 'sawah' systems (Kundu and Ladha, 1995; Roger and Ladha, 1992).

There were no significant differences both in TC and TN distribution between Inceptisols and Vertisols. The long-term intensive use of 'sawah' already eliminated the differences in the original characteristic of Inceptisols and Vertisols in 1970. Vertisols are clayey soil characterized by the ability to form deep cracks under dry conditions and the surface soils rich in nutrients move down through the crack (Kirby *et al.*, 2000 and Tomar *et al.*, 1996), so that TC and TN were expected to be distributed more in the deeper horizons in Vertisols as compared to the other soil type. However, under 'sawah' condition it seemed that phenomenon did not occur frequently. As shown in Table 1, most Vertisols were found in seed farms sampling sites, where intensive rice cropping kept the soil always in wet condition and probably prevented Vertisols from forming deep cracks and therefore prevented the movement of nutrients including carbon and nitrogen to the deeper horizon.

Effects of land management on the changes of total carbon and nitrogen.

Table 3 shows how differences in management practice bewteen seed farms and non-seed farms influenced the changing rates of TC and TN contents in 0–20 and 0–100 cm soil layers. The mean value of TC in seed farms increased from 34.50 to 39.24 Mg ha^{-1} (13.7% change) in the 0–20 cm soil layer and from 92.68 to 112.83 Mg ha^{-1} (21.7% change) in the 0–100 cm soil layer, respectively. Within the same period TC content in non-seed farms significantly increased from 29.77 to 41.37 Mg ha^{-1} and from 79.6 to 114.8 Mg ha^{-1} in 0 – 20 cm and 0 – 100 cm the soil layer, respectively, with a relative change of about 40% in both soil layers. In the case of TN, seed farms and non-seed farms increased from 3.16 to 3.95 Mg ha^{-1} (25.0% change) and 2.94 to 3.98 Mg ha^{-1} (35.4% change) in the 0–20 cm soil layer, which was significantly different at 0.01 and 0.001 levels, respectively. And within the 0–100 cm soil layer, TN content changed by 28% at both sites (Table 3). Although, TN contents in seed farms were much higher as compared to those in non-seed farms in 1970, they were found to be similar in 2003 (Table 3).

Kawaguchi and Kyuma (1977) reported that in 1970 seed farms and non-seed farms sites produced rice husk about 2.5 Mg ha^{-1} and 1.5 Mg ha^{-1}, respectively, but from 1990's both of them have been able to produce about 5.5 Mg ha^{-1} of rice husk per cropping season (Indonesian Ministry of Agriculture, 2001). It means that the increasing rate of rice productivity during the period between 1970 and 2003 in non-seed farms was more than three folds, which was much higher than that in seed farms. The increase of rice productivity probably related with the increase of TC and TN contents in both sites. Increase of the rice production augmented the amount of plant residues such as straw, leaf and root remained in 'sawah' field, especially in non-seed farms in which residues were usually left in the field. This might have contributed to the increase of TC and TN in both seed farms and non-seed farms. Tiessen *et al.*, (1994) reported that increase of plant production would increase the organic matter input to the soils as a major source of carbon and nitrogen in the soils.

Table 3. Changes in TC and TN (Mg ha^{-1}) content in 0–20 cm and 0–100 cm soil layer in seed farms and non-seed farms (1970 - 2003) in Java, Indonesia.

Total Carbon (Mg ha^{-1})

	Seedfarm				Non-Seedfarm			
	0 - 20 cm		0 - 100 cm		0 - 20 cm		0 - 100 cm	
	1970	2003	1970	2003	1970	2003	1970	2003
n	18	18	18	18	22	22	22	22
mean	34.50	39.24	92.68	112.83	29.77	41.37	79.60	114.86
SD	9.95	9.70	39.47	40.91	10.88	15.12	28.07	40.50
mean change		4.74		20.15		11.60		35.26
% change		13.7		21.7		39.0		44.3
T-test		*		***		***		***

Total Nitrogen (Mg ha^{-1})

	Seedfarm				Non-Seedfarm			
	0 - 20 cm		0 - 100 cm		0 - 20 cm		0 - 100 cm	
	1970	2003	1970	2003	1970	2003	1970	2003
n	18	18	18	18	22	22	22	22
mean	3.16	3.95	9.34	12.03	2.94	3.98	8.93	11.44
SD	1.07	0.89	4.01	4.10	1.15	1.24	3.16	3.30
mean change		0.79		2.69		1.04		2.51
% change		25.0		28.8		35.4		28.1
T-test		**		***		***		***

n = number of sampling sites
Significant level: * ? 0.05 < ** ? 0.01 < *** ? 0.001

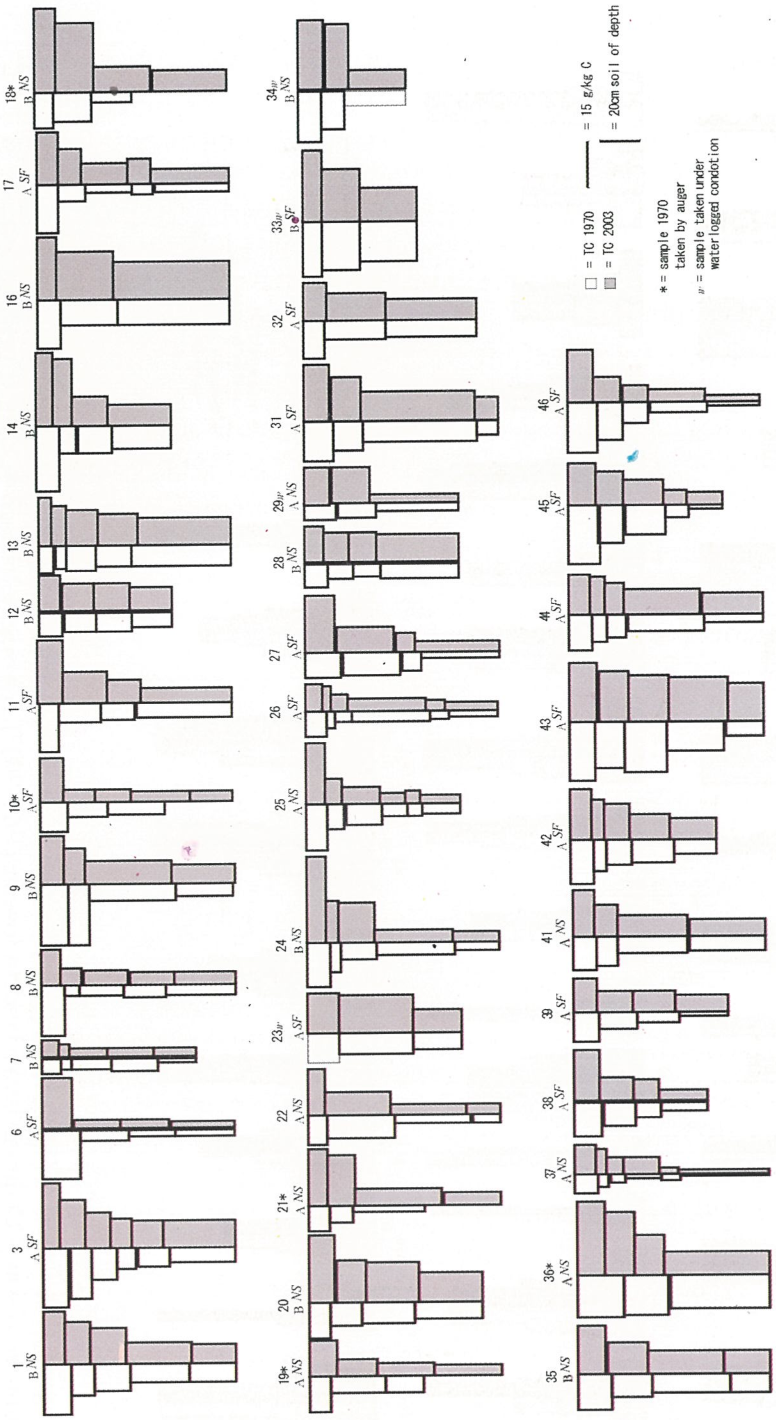

Figure 2. The effect of GR technology application on the profiles distribution of TC (g kg^{-1}) content of soil in seed farm (*SF*) and non-seed farm (*NS*) sites in Java Island, Indonesia (1970-2003). A = original sites; B = closest to original sites.

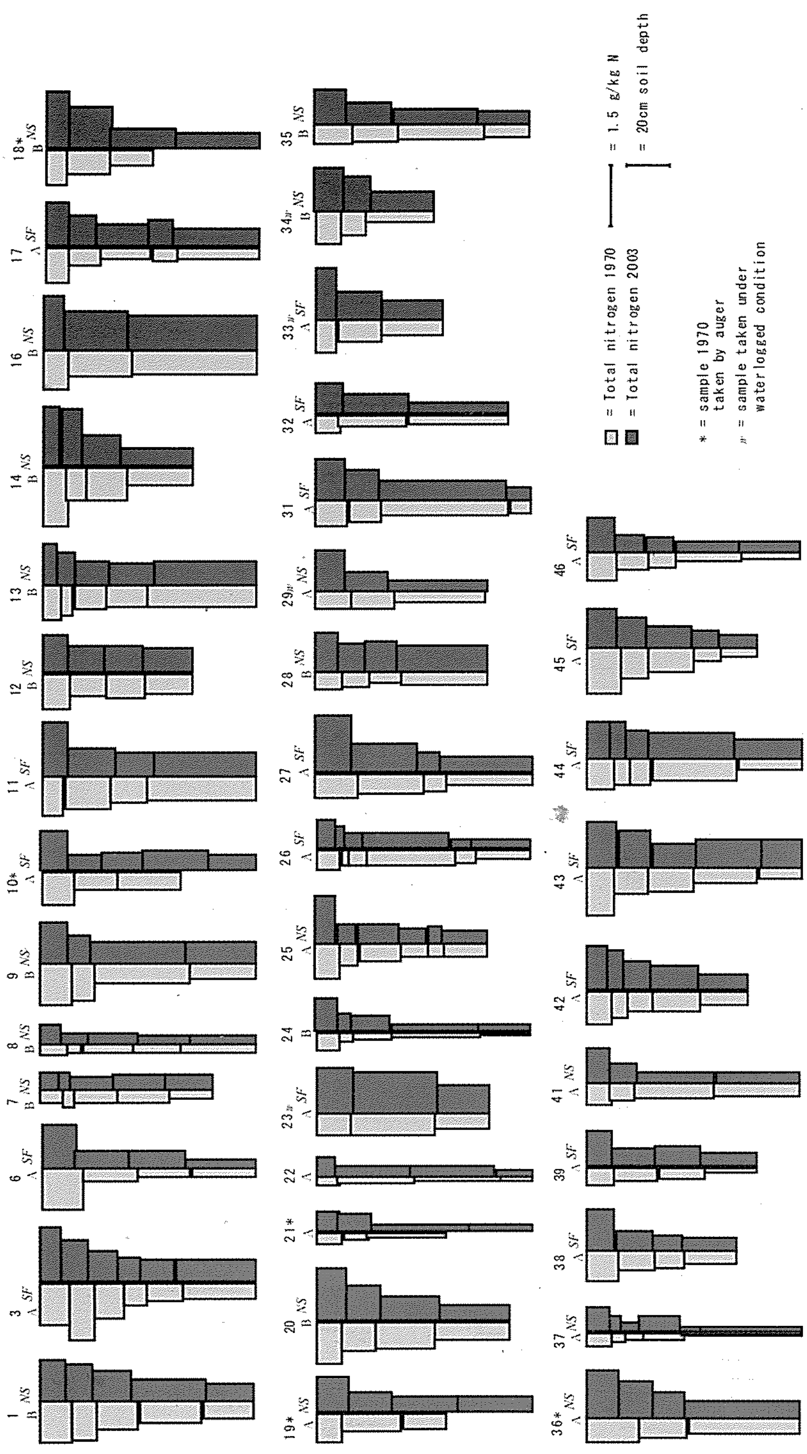

Figure 3. The effect of GR technology application on profiles distribution of TN (g kg^{-1}) content of soil in seed farm (*SF*) and non-seed farm (*NS*) sites in Java Island, Indonesia (1970-2003). A = original sites; B = closest to original sites.

Table 4. The effects of land management on the changes of some chemical properties of 'sawah' soil in 0 – 20 cm and 0 – 100 cm soil layers in seed farm and non-seed farm sites during the period of 1970 - 2003 in Java, Indonesia

0 - 20 cm

Soil properties	Seedfarm				Non-seedfarm			
	n	mean±SD 1970	mean±SD[a] 2003	Change (%)	*n*	mean±SD 1970	mean±SD[a] 2003	Change(%)
pH H?O (1:2.5)	18	7.13±0.66	5.88±1.02***	-1.25(-17)	22	6.71±0.81	5.81±0.81***	-0.90(-13)
Exch. Acidity (kmolc ha^{-1})	18	8.68±3.40	12.80±4.60***	4.11(47)	22	9.84±2.78	13.60±2.90***	3.26(38)
Exch. Ca (kmolc ha^{-1})	18	60.10±52.20	64.20±61.60^{ns}	4.15(7)	22	61.90±49.50	66.80±64.20^{ns}	4.92(8)
Exch. Mg (kmolc ha^{-1})	18	18.80±10.80	19.30±11.70^{ns}	0.49(3)	22	13.20±9.20	14.70±9.30*	1.58(12)
Exch. K (kmolc ha^{-1})	18	1.62±0.84	1.75±1.13^{ns}	0.14(8)	22	1.27±0.56	0.98±0.67*	-0.30(-23)
Exch. Na (kmolc ha^{-1})	18	3.49±2.63	2.07±2.88*	-1.42(-41)	22	3.11±2.91	1.34±0.96***	-1.77(-57)
ECEC (kmolc ha^{-1})	18	92.70±56.40	100.20±66.80^{ns}	7.47(8)	22	89.30±57.10	97.50±67.50^{ns}	8.19(9)
Available P (kg P_2O_5 ha^{-1})	18	198±211	393±382***	194(98)	22	86±49	143±105**	57(67)

0 - 100 cm

Soil properties	Seedfarm				Non-seedfarm			
	n	mean±SD 1970	mean±SD[a] 2003	Change (%)	*n*	mean±SD 1970	mean±SD[a] 2003	Change(%)
pH H?O (1:2.5)	18	7.26±0.46	6.38±0.64***	-0.89(-12)	22	7.01±0.70	6.28±0.72***	-0.72(-10)
Exch. Acidity (kmolc ha^{-1})	18	29.70±12.00	41.40±16.00***	11.67(39)	22	35.10±17.90	43.80±13.40**	8.75(25)
Exch. Ca (kmolc ha^{-1})	18	267.1±179.1	278.5±196.7^{ns}	11.45(4)	22	303.8±268.5	261.0±224.4*	-42.8(-14)
Exch. Mg (kmolc ha^{-1})	18	98.70±58.60	99.60±53.10^{ns}	0.85(1)	22	62.70±40.70	60.00±40.20^{ns}	-2.66(-4)
Exch. K (kmolc ha^{-1})	18	7.94±3.20	7.14±4.74^{ns}	-0.80(-10)	22	6.01±2.13	4.05±2.56***	-1.96(-33)
Exch. Na (kmolc ha^{-1})	18	15.50±4.90	10.60±12.20*	-4.88(-31)	22	13.20±7.80	6.98±5.09***	-6.24(-47)
ECEC (kmolc ha^{-1})	18	419.0±196.6	437.3±216.5^{ns}	18.28(4)	22	420.8±299.9	375.9±243.0^{ns}	-44.9(-11)
Available P (kg P_2O_5 ha^{-1})	18	654±690	1198±1148***	544(83)	22	301±255	436±379*	135(45)

[a] Paired samples T-test [b] Independent-samples T-test between changes of the mean values from 1970 to 2003 of seedfarms and non-seedfarms

Significant level: * = 0.05 < ** = 0.01 < *** = 0.001; ns = not significant

As an essential macro nutrient, K had been added to the soil as potassium chloride (KCl) fertilizer in seed farms, but not in non-seed farms (Lansing *et al.*, 2001). The chemical fertilizer used in non-seed farms sites mostly depended on the farmer's budget condition, and among the three kinds of chemical fertilizers (Urea, Super-phosphate and KCl), KCl was less frequently used by farmers (personal communication).The removal of K through harvest or leaching without enough replacement might have contributed to the decrease of exchangeable K in non-seed farms where the application of K fertilizers was not as much as in seed farms.

Available P content (Table 4) in seed farms significantly increased from 198.5 ± 211.1 to 393.0 ± 382.3 kg P_2O_5 ha^{-1} (98%) and from 653.6 ± 690.5 to 1198.2 ± 1147.9 kg P_2O_5 ha^{-1} (83%) from 1970 to 2003 in 0–20 cm and 0–100 cm soils layers respectively, while in non-seed farms it increased from 86.0 ± 49.3 to 143.5 ± 105.6 kg P_2O_5 ha^{-1} (67%) and from 301.3 ± 254.8 to 436.3 ± 378.6 kg P_2O_5 ha^{-1} (45%) in respective soil layers. The rate of increase was higher in seed farms as compared to non-seed farms (Table 4). The results were obviously influenced by differences in land management practice such as fertilizer application, between seed farms and non-seed farms. Seed farms, which were planted with rice and P fertilizer applied following the government recommendation after the GR technology started, accumulated more available P than did in non-seed farms, where the application of P fertilizer was not as much. The excess of available P in Java 'sawah' soils, especially in seed farm, seemed to create an environmental problem. Water flow through run-off and drainage brought dissolved P into water bodies downstream. During the field research in this study, evidence of the water pollution was observed as aquatic plant grew and covered the water surface on the drainage canals in lowland areas. According to Brady and Weil (2002), runoff, leaching and erosion from agricultural land will move some phosphorus into the streams, lakes, ponds and reservoirs, triggering the process of eutrophication. Lansing *et al.*, (2001) found the concentration of P in the streams increasing gradually from upper to lower areas in Bali. Those results were also in agreement with Zhang *et al.*, (2003) who reported that P losses from 'sawah' is one of the potential factors relating to water eutrophication because P content in runoff and leachate were detachable, even when 'sawah' received low doses of P fertilizer.

Effects of rice cultivation intensity on available silica decrease

The effects of rice cultivation intensity between seed farms and non-seed farms on the decreasing rate of available Si during the period 1970 to 2003 in Java 'sawah' soils presented in Table 5. Available Si in seed farms decreased with higher statistical level ($p < 0.01$) than in non-seed farms ($p < 0.05$). It is clear that seed farms sites lost more available Si than non-seed farms. In the 0–20 cm soil layer, average content of available Si in seed farms decreased from 1646 ± 581 kg SiO_2 ha^{-1} to 1283 ± 533 kg SiO_2 ha^{-1} (-22%) while in non-seed farms it decreased from 1440 ± 645 kg SiO_2 ha^{-1} to 1202 ± 563 kg SiO_2 ha^{-1} (-17%). In the 0-100 cm soil layer the average available Si in seed farms decreased from 7853 ± 4187 kg SiO_2 ha^{-1} to 6906 ± 4024 kg SiO_2 ha^{-1} (-14%) while in non-seed farms decreased from 5710 ± 2700 kg SiO_2 ha^{-1} to 5063 ± 2528 kg SiO_2 ha^{-1} (-12%) as shown in Table 5.

Although, the available Si content in Java 'sawah' soils is the highest among the Southeast Asian countries (Kawaguchi and Kyuma, 1977), intensive rice cultivation has been mining Si and exporting it through harvesting processes. Due to this transport of Si out of the field, seed farms where rice is cultivated with higher intensity showed higher decreased rate of available Si than non-seed farms (Table 3). Ma and Takahashi (2002) stated that rice husk accounts for about 20% of the weight of rice grain and up to 20% consists of SiO_2. Assuming rice productivity in seed farms and non-seed farms was similar (about 5.5 Mg husked rice per hectare per cropping season), seed farms sites where rice is planted three times a year lost silica in SiO_2 form about 660 kg ha^{-1} every year. This is much higher than in non-seed farms. Within the study period, seed farms and non-seed farms had exported 21780 kg SiO_2 and 14520 kg SiO_2, respectively out of 'sawah' through harvesting processes. These values were much higher as compared with the decreasing rate of available Si in soils. Table 3 shows that available Si content in the 0–20 cm soil layer decreased by 363 kg SiO_2 ha^{-1} and 238 kg SiO_2 ha^{-1} in seed farms and non-seed farms, respectively. The contribution of other natural silica resources such as irrigation water seemed to play important roles in maintaining available Si content in the soil. Kawaguchi and Kyuma (1977) found that the average Si content in river water (which are the dominant sources for irrigation) in Java was 29.82 mg SiO_2L^{-1}. Although average Si content measured in irrigation water was much lower than in river water (14.00 mg SiO_2L^{-1}), Si input from this resource could possibly decrease the rate of available Si in 'sawah' soil (Table 4).

Conclusion

The application of the GR technology from 1970 to 2003 has changed some soil properties of 'sawah' soil in Java, Indonesia. TC and TN contents in 'sawah' soils increased both on seed farms and non-seed farms. Non-seed farms which were planted with rice and upland crops in rotation accumulated higher TC and TN than

Table 5. The effects of cultivation intensity between seed farm and non-seed farm on the changes rate of available silica (kg SiO_2 ha^{-1}) during the period of 1970-2003 in Java 'sawah' soil, Indonesia.

	Seedfarm				Non-seedfarm			
	0 - 20 cm		0 - 100 cm		0 - 20 cm		0 - 100 cm	
	1970	2003	1970	2003	1970	2003	1970	2003
n	18	18	18	18	22	22	22	22
Mean± SD	1646± 581	1283± 533	7853± 4187	6906± 4024	1440± 645	1202± 563	5710± 2700	5063± 2528
Change mean		-363		-947		-238		-647
% change		-22		-14		-17		-12
T-test		**		*		*		*

Significant level: * ≤0.05; ** ≤0.01

seed farm sites where rice was planted in a monoculture system over the whole study period. Application of chemical fertilizer without any consideration of the natural supply from the soils or (irrigation) water resulted in a considerable variation in the changes of soils properties among the sites within the study period in both seed farms and non-seed farms site. This study also shows how decreasing rate of available Si is affected by cultivation intensity of rice and topographical position. Seed farms site planted with rice at higher intensity lost more Si than non-seed farms. Within similar land management practices and cultivation intensity, sampling sites located in upland positions decreased in available Si higher than those in lowlands. The adverse effect of the GR in Indonesia is mainly due to improper land management over long period of time.

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"Sawah" Eco-technology: Farmers' Personal Irrigated "*Sawah*" Systems to Realize the Green Revolution and Africa's Rice Potential.

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Abstract

Among the 250 million ha of lowlands in Sub Sahara Africa (SSA), only about 10% are estimated as appropriate sites for sustainable irrigated *sawah* system development because of hydrological, topographical, and pedological limitations. Of all lowland types, inland valleys are the priority because of relatively easy water control. However, it has also became clear that some huge flood plains in Guinea savannah zone can also be given priority if appropriate cropping calenders can be selected. Both large-scale and small-scale irrigation projects, typically Official Development Assistance (ODA) assisted, have been very costly because of major dependency on heavy engineering works by outside expertise. Due to their high construction costs, economic returns remain negligible or negative for long periods (20-30 years), project ownership remains with the government (engineers) rather than with the farmers and therefore neither the development nor management is sustainable. Site specific farmers' personal irrigated *sawah* system development (sawah eco-technology) offers low cost irrigation and water control for rice intensification, with sustainable paddy yield of 4-6 t ha^{-1}. If improved agronomic practices are applied, such as System of Rice Intensification (SRI), based on the *sawah* systems, paddy yield can be higher than 10t ha^{-1}. African lowlands are quite diverse and variable and therefore careful site-specific *sawah* development and management technologies have to be researched, developed and disseminated. To develop and manage *sawah* systems by local farmers, self-propelled efforts and small-scale equipment such as hydro-power tillers are needed. After many trial and error processes (1997-2011), the *sawah* eco-technology has been successfully tested in Ghana and Nigeria, especially in locations where appropriate sites were selected and local leading farmers trained and supported by proper backstopping. This paper discusses the main targets to realize sustainable dissemination of sawah eco-technology which are composed of four important skills and technologies: (i) site selection and site specific *sawah* system design, (ii) skills for efficient and cost effective *sawah* systems development using hydro-power tiller, (iii) rice farmers' empowerment for successful development and management of sawah systems, and (iv) sawah-based rice farming to realize at least sustainable paddy yields > 4t ha^{-1} and 20 ton annual paddy production per one set of power tiller for at least three years after the initiation of new sawah development. Establishment of institutional training and dissemination systems for *sawah* eco-technology and basic research to get sustainable paddy yields > 10t ha^{-1} are also important. Since rice farmers have to master relatively wider range of skills including ecological engineering,

intensive on-the-job training is very important and necessary. Once mastered, however, the skills can be transferred from farmer-to-farmer for scaling out activities and faster adoption. Examples of successes which require scaling out are Ashanti in Ghana and Bida, Kebbi, Abakaliki, Akure, Zaria and Adani in Nigeria.

Introduction

As described in earlier publications (Wakatsuki, et al, 1998; 2011; Hirose and Wakatsuki, 2002; Wakatsuki and Masunaga 2005), the sawah eco-technology is the missing technology to improve soil and water management as well as the income generation base of rural society in sub-Saharan Africa (SSA). Among the 250 million ha of lowlands in SSA (Windmeijer and Andriesse, 1993), only about 10% (20 million ha) are estimated to be appropriate sites for sustainable irrigated *sawah* system development, of which 9-20 million ha are in small inland valleys, 8-15 million ha in floodplains, 4-9 million ha in coastal deltas, and 1-5 million ha in inland basins as shown in Table 1 (Wakatsuki et al. 1998, Abe and Wakatsuki 2011).

Table 1. Distribution of lowlands and potential irrigable 'sawah' area in SSA

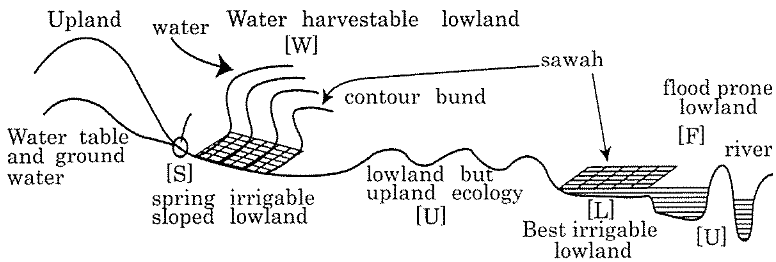
Classification	Area (million ha)	Area for potential 'sawah' development (million ha)	
Coastal swamps	17	4-9	25-50%
Inland basins	108	1-5	1-5%
Flood plains	30	8-15	25-50%
Inland valleys	85	9-20	10-25%

Source: Andreisse & Windmeijer, 1993, Wakatsuki, 2002

Note:

Even though the priority area is inland valleys, some flood plains can be highly suitable such as in the Sokoto and Kebbi states of Nigeria.

As shown in Figure 1, appropriateness is affected by hydrological, topographical, and pedological considerations (Hirose and Wakatsuki 2002). Of all the lowland types, inland valleys are the priority for the application of the sawah eco-technlogy because controlling water in them is relatively easy. However, during the 2011 growing season (April-September), it has now become clear that some huge flood plains within Guinea savannah zone, such as Sokoto or Kebbi states in Nigeria can also be given high priority if appropriate cropping calenders can be selected. Both large-scale and small-scale irrigation projects, typically created under Official Development Assistance (ODA), have been very costly (FAO, 1998; Wakatsuki et al., 2001; JICA, 2008; MOFA and AfDB, 2008) because of dependence on heavy engineering works and outside expertise (Table 2). Due to high construction cost, economic returns remain negligible or negative for long periods (20-30 years). Project ownership remains with the government (engineers) rather than with the farmers, because farmers cannot develop the systems by themselves. Therefore, neither the development nor management is sustainable.



Irrigation options : Sawah to sawah / contour bund water harvesting, spring, seepage, river by dam and dyke, peripheral canal, interceptor canal, tank, pump

Lowland sawah development priority
[S] > [L] > [F] > [W] > [U]

Figure 1. Diversity in topography and hydrology of inland valley in Sub-Saharan Africa. Topography and hydrology are also changed in various agro-ecological zones. Pedological characteristics are changed depending on geology, climate, topography, and vegetation

The *sawah* eco-technology offers low-cost irrigation and water control for rice intensification with sustainable paddy yield of more than 4t ha^{-1} within sufficiently large area of 5-10 ha using one power tiller per farmer or farmers' group. Although the sawah team at Kebbi state Fadama III and ADP, Nigeria, got more than 7t ha^{-1} in 2011 using standard sawah technology. If improved agronomic practices, such as the System of Rice Intensification (SRI) or others with the *sawah* systems are applied, paddy yield can reach more than 10t ha^{-1} (Tsujimoto et al. 2009).

However, African lowlands are quite diverse and different from Asian lowlands as shown in Figure 1. Therefore careful site-specific *sawah* development and management technologies must be researched, developed, and disseminated through intensive On-The-Job training (OJT). The development and management of *sawah* systems requires that local farmers be self-motivated and have access to small-scale equipment, such as hydro-power tillers. After many trial-and-error processes (1997-2011) and the addition of numerous innovation processes, the *sawah* system has since been successfully tested in Ghana and Nigeria, especially in locations where appropriate sites were selected, local leading farmers trained and proper backstopping mechanisms provided by scientists (Hirose and Wakatsuki 2002; Wakatsuki et al. 2001; Wakatsuki and Masunaga 2005; Oladele et al. 2010; Abe and Wakatsuki 2011).

Table 2. Comparison of farmers' sitespecific personal irrigated *sawah* system development with large- and small-scale ODA-based developments, and traditional rice cultivation system in inland valleys of Ghana and Nigeria.

	Large-scale development	Small-scale development	*Sawah* approach	Traditional system
Development cost ($/ha)	20,000–30,000	10,000–30,000	1,000–3,000	30–60
Gross revenue ($/ha)†	2,000–3,000	2,000–3,000	2,000–3,000	500–1,000
Yield (t/ha)	4–6	4–6	4–6	1–2
Running cost, including machinery ($/ha)†	600–800	600–800	400–600	200–300
Farmer participation	Low	Medium–High	High	High
Project ownership	Government	Government	Farmer	Farmer
Adoption of technology	Long, difficult	Slow, relatively easy	Medium to short, needs intensive demonstration and on-the-job training (OJT) program	Low technology transfer
Sustainable and endogenous development based on innovation and adaptive evolution	Low(contractors' heavy machinery used by contractors in development)	Low - medium	High (farmer-based and small power-tiller used in development and management)	Medium
Adverse environmental effect	High	Medium	Low	Medium

† Assuming 1 ton paddy is worth US$ 500; one power-tiller costs $3,000-9,000 in West Africa depending on the brand quality and accessories (2010 values). Selling prices, however, are $1,500-$4,500 for farmers in Asian countries.

The *sawah* approach involves four important skills and technologies (Table 3): (i) site selection and site-specific *sawah* system design, (ii) skills for cost-effective *sawah* system development using a small hydro-power tiller, (iii) rice farmers' empowerment for successful development and management of sawah systems, and (iv) *sawah*-based rice agronomy, including best variety selection and management to realize at least the sustainable paddy yield of more than 4t ha^{-1}. The establishment of institutional training and dissemination systems for *sawah* eco-technology transfer (Buri et al. 2009) is necessary. The co-ordination of farmers' group formation and land-tenure arrangements for secured rent (Oladele 2010) to sustain sawah development are very important and necessary. Training of leading *sawah* farmers is key. Leading sawah farmers who are properly trained can train other farmers or farmer-groups (farmer to farmer training) to develop *sawah* and manage *sawah*-based rice farming by themselves. This is the final goal of sawah eco-technology.

In 2011, the sawah eco-technology has reached the stage of making a strong impact for farmers to realize the Green Revolution. If farmers properly grasp the four components of the *sawah* eco-technology, they can develop their personal irrigated sawah systems and realize 20-50 tons of paddy production per season using one power tiller within three years after the initiation of new *sawah* development. The technology can be transferred from farmer to farmer. This means if 500 leading farmers are trained, the technology can spread like wild fire for the realization of the long-awaited Green Revolution in Africa. Obtaining only high yield is not enough. Rice farmers need to cultivate enough area of *sawah* in order to generate enough income.

Specific target is to train more than 500 qualified leading sawah farmers who can develop their personal irrigated sawah systems and realize 20-50 ton of paddy production per season, which is equivalent to $10,000 - $25,000 gross, using one power tiller, which costs $3000-$5000 per set, within three years after the initiation of new sawah development. This will result in new irrigated rice field of 2500 - 5000 ha in inland valleys and other major lowlands. Traditional ODA-based development of such 2,500-5,000ha irrigation systems for rice cultivation cost $50 - $100million only for development without any training for management. In addition the development is done by outside experts and not local experts or farmers. Therefore the system cannot be expanded if ODA stops. "*Sawah*" eco-technology, however, will provide the same scale of development with only $3 - $5million as described below with sustainable development as a result of the on-the-job training of 500 qualified leading *sawah* farmers at the same time. These farmers will be able to develop new *sawah* fields endogenously.

At this stage, large scale action research and dissemination actions both in inland valleys and flood plains are needed in the major agro-ecological zones of all 10 regions in Ghana and at least 20 major states in Nigeria, to make adaptive evolution and endogenous development of prototype Sawah eco-technology for scaling up the past and current successful results achieved during MEXT project (2007-2011) and JIRCAS project (2008-2011) to the whole of Ghana and Nigeria as primary target, as well as Togo and Benin under the SMART-IV Project. Finally the whole of West and Sub Saharan Africa can make a real impact towards the realization of the rice Green Revolution.

Table 3. Four important skills for *sawah* eco-technology (approach) required by farmers' to develop and manage site-specific Personal irrigated *sawah* systems and sawah based rice farming (SERIF) through their own efforts.

(1) Skills for Site Selection and *Sawah* system design

(a) Water sources & quality
(>10 L/s, >5 months/year)
Stream/River, Spring, Seepage, Flood, Rainfed

(b) Topography and soil
Ongoing & potential rice area >10ha,
Slope <1 -2%,
surface roughness
Soil texture
Soil fertility

(c) Socio - economics
Strong will
Market access
Land tenure
Secured lent

(d) *Sawah* system design
Sawah layout and total potential area
Shape & sawah size
Water intake, distribution and control to sawah, and
Spring & sawah diversion canal
Stream/seepage
Simple dyke & diversion canal
Weir and Canal
Fish pond, dam lake
Pump irrigation
Interceptor canal
Contour bund system
Flood control by drainage or dam
Drought control by pond/water -harvest
Soil movement and quality of leveling
Bund layout and quality

> Action research & on -the -job training on site - specific *sawah* development & management
>
> On the job collaboration between farmers & scientists, engineers, and extension office is essentially important
>
> Farmers know site specific hydrological conditions which are the most important for site selection

> The successful example of *Sawah* system development:
> (1) Oasis type pump irrigation in floodplain (Sudan savanna zone, Kebbi state)
> (2) Spring based irrigation system (all climatic zones)
> (3) Overflow dykes on small rivers (Guinea savanna zone, forest transition zone, forest zone)

(2) Efficient and Low cost Sawah Development: Skill & Technology

(a) Skills for development
Skill for power -tiller operations
Plowing and Puddling
Soil Moving
Surface leveling & smoothing
Powertiller management

(b) Cost
Power -tiller for development (10ha /power tiller)
Power -tiller spare parts
Fuel for development
Bush clearing, destumping
Bunding and surface treatment
Canal construction
Additional hired labors
Tools and materials
Scientist & engineers cost
Extension officer cost
Farmers' training cost

> **Action research & on -the -job training on site - specific *sawah* development & management**

> ***Sawah* development: at least 10ha per one Power -tiller**

> **Target cost: $1000 - 3000/ha**
>
> **Target speed of development: >3ha/year /powertiller**

(3) Rice farmers enpowerment
Group organization
Selection of leader
Support to the group and leader
Training powertillers ' assisted sawah development
Training powertillers assisted sawah based rice farming
Post harvest technology
Marketing and profit equity
Loan condition to acquire powertillers
Support for rental and acquire land for sawah development

(4) Sawah based rice farming
Management of water control facilities: water sources, intakes, and distributions
Water equity and canal management
Sawah water control
Leveling, smoothing
Bunding
Puddling skills
Nursery and trans - planting
Weed, pests, and birds management
Carbon sequestration and organic matter management
Fertilization and nutrient management
Variety election
Yield target
Cost effective *sawah* based farming
Mono, two, double,& other cropping
Advanced *sawah* - based farming

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

> (1) To train qualified sawah farmers and or groups who could develop sawah >5ha and get annual paddy production >20ton using one powertiller within three years after the initiation of sawah development.
> (2) To train the leading *Sawah* farmers is the key for sustainable and endogenous sawah development. The leading farmers can train farmers and farmers groups to achieve the target as qualified *Sawah farmers*.
> (3) If site selection is suitable for sawah development, sawah is developed more easier in Africa than that in Asia.

> **Minimization of outside funds is key for sustainable and endogenous development : farmers to farmers technology transfer sites > > sites of extension officers > researchers' demonstration sites**

A general time schedule for establishing a *sawah* eco-technology system model of 2-3 ha

I. Site selection: Spend 2-3days per potential area and specifically observe and examine the various land attributes.

(1) Priority areas are the ongoing Fadama and lowland rice cultivation sites: Potential area should be larger than 5-10ha for the sustainable application of sawah eco-technology. The best season for site selection will be from September/October (just before harvesting) to January/February (just after harvest). Intensive interaction with rice farmers on the local hydrological conditions for the past 10-15 years is important.

(2) Secured continuous water flow: > 5months, base water discharge: > 20 l/sec, (i.e., >1500 - 2000 m^3/day), potential irrigated *sawah* area: >10-20 ha,

(3) No strong flood attack: Flood depth should be < 50cm and continuation of the flood should not exceed 3-4days, Flood water discharge should be < 10 ton/sec

(4) Flat and very gentle slope are preferable (< 2%). If slope is < 1%, leveling operation would be easy.

(5) Strong will of rice farmers to master *sawah* technology skills and *sawah* development by farmers' self support efforts

(6) Good access road is necessary for demonstrations

II. New Sawah Development for demonstration: 2-3 months

Three to four extension officers from state Agricultural Development Project (ADP) or Fadama III offices and 3-10 active farmers which should be trained through intensive OJT by one or two sawah specialists (Sawah specialists of SRI and CRI as well as MOFA extension officers in Ghana, IITA's Hirose Project, NCAM *sawah* team, UNN and Abeokuta *sawah* teams in Nigeria).

(1) Bush clearing, de-stumping, and delineation of possible sawah area: : 10-20 working days/ha

(2) Site survey and mapping: 1-3 working days/ha
Put in 1-3 of about 100 m X and Y axis lines using survey tools, such as laser assisted Total Station (Cannon Co. Ltd.) if possible. If not available, use 90°crossed line using simple measuring tools. Draw upland and lowland borders and river/canal line, land owner/tenure lines.

Note: Since farmers cannot use such tools, sawah eco-technology uses water as a guidance of topography. Therefore sawah system development must be done using water. Water shows height difference. Skilled sawah staffs can make good canal line slope, not too steep to avoid canal cutting, using water. Sawah plot levelling can be also done using water and soil as a marker within ± 5cm height difference without using such sophisticated laser apparatus.

(3) *Sawah* delineation based on contour line with 30 cm height difference: 5 working days
 (a) Should be started from the lowest valley bottom at each land boundary/tenure lines,
 (b) Should be a straight line and as large as possible for efficient use of power tiller,
 (c) use pegs and rope to delineate bunding location, field borders and canal lines

(4) Bunding: 15-25 working days/ha
The standard size of bund is 50 cm width x 50 cm height (± 20 cm)
 (a) Big bunds for flood prone areas and field boundaries
 (b) Standard bunds for major *sawah* delineation
 (c) Small bunds for sub-*sawah* delineation

(5) Canal and drainage lines: 10-60 working days/ha
Appropriate slope of canal should be less than 1% (preferably 0.1-0.5%).
If canal is too steep, bottom soils will be eroded and would cave in.

(6) Dyke: 30-50 working days/ha. About 500 sand bags (30kg each) reinforced with wooden piles and plank can manage to lift the central river water height by 1-1.5m with 10-15m width of about 5,000-10,000 ha size of watershed under 1500 mm annual rainfall. If watershed size is 2500-5000, about 300 sand bags should be enough. Labour requirements will be 30 mandays.

(7) Nursery preparation: 3 working days/ha in three phases at three week intervals, one day for each phase. Nursery should be prepared 15 to 25 days before transplanting

(8) *Sawah* ploughing, puddling, leveling and smoothening: 50-80 working days/ha

III. Sawah based rice farming in the first year of new sawah development

(1) *Sawah* water control: 10-40 working days/ha

(2) *Sawah* systems maintenance: 10-30 working days/ha

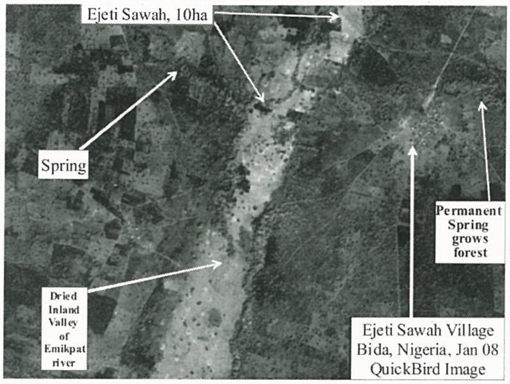
(3) Transplanting: 10-20 working days/ha
(4) Fertilization: 2-3 working days/ha
(5) Weeding:6-7 working days/ha
(6) Bird-scaring:10-30 working days/ha
(7) Harvest: 7-15 working days/ha
(8) Threshing:10 working days/ha

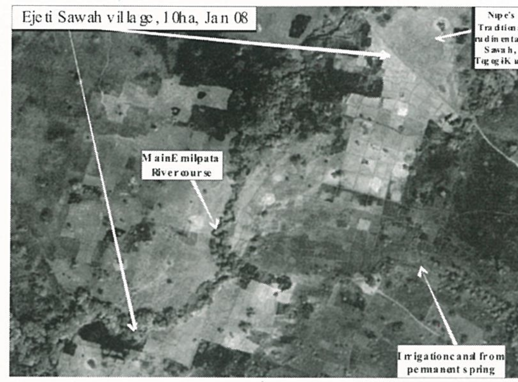
IV. Overall Target for sustainable sawah development and sawah eco-technology dissemination

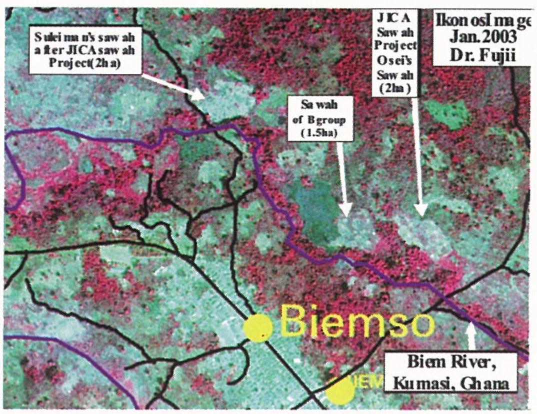
The final goal is to realize 20-50 tons of paddy production at a total revenue of US $10,000-25,000 per year using one power tiller (cost is $3,000-$5,000) within three years after the initiation of new sawah development. If paddy yield is 4t ha^{-1} and only mono cropping is possible, at least 5ha of sawah can be developed using one power tiller.

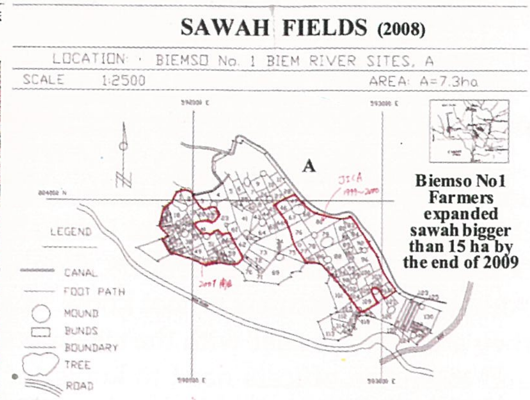
The most important factor in site selection, appropriate *sawah* system design, development and management is collaboration between researchers and farmers. Scientists and extension officers should have the skills for *sawah* development. Although local farmers do not know *sawah* technologies (before the project starts), they are very familiar with the site-specific hydrological conditions that scientists and extension officers need to know for *sawah* development. Thus, collaborative action-research between farmers and scientists is essential. The priority for site selection is the inland valleys and to some extent the flood plains depending on location and existing conditions. The water conditions of inland valley streams are critical. Water has to flow for more than 5 months continuously, with a discharge of more than 10 l s^{-1}. Otherwise, farmers have to develop additional ponds/wells/dug-out to secure water for sustainable *sawah*-based rice cultivation. If floods reach deeper than 50 cm and continue for over 1 week with a discharge of more than 10 m^3 s^{-1}, major flood control measures have to be put in place. This is difficult for farmers' groups at the first stage of *sawah* development. Therefore, inland valleys that will require such extra inputs should be avoided in the demonstration and training stages.

Some examples of following photographs on next pages show autonomous expansion of Sawah system in inland valley ecosystems at Bida and Zaria, UN-vilalge, Nigeria and Adugyama, Biemso No1, Baniekrom, and Sokwae in Ashanti, Ghana









Cost effectiveness of *sawah* approach

Cost-effective *sawah* development is critical (Table 4). Although the cost of applying the *sawah* approach is less than 10% that of the cost of ODA-based irrigation schemes (Table 1), the initial *sawah* development relies heavily on use of a power-tiller, which makes up 50% of the development cost. Therefore, apart from the importance of training power-tiller operators (Ademiluyi, 2010), high-quality, durable, and low-cost power-tillers are necessary (Kolawole et al. 2011). Once *sawah* is developed, power- tiller cost for rice farming will not be a major problem. If farmers are well trained during the first year (normally difficult period of *sawah* development), *sawah*-based rice farming would be more sustainable than old-style ODA- based irrigation projects. Since the *sawah* approach gives sustainable low-cost personal irrigated *sawah* system development, which costs about 10% of ODA-based irrigated *sawah* development, there may be the need for special subsidization to encourage *sawah* development by farmers in the first year.

Asian farmers can buy similar power-tillers for just $1500-4500, while commercial prices of power-tillers in Ghana and Nigeria are $3000-9000. So it may be necessary to apply a special subsidy to encourage farmers to develop *sawah* in the first year. If sawah developments are accelerated and power tiller markets are expanded in the near future, power tiller cost would be in the same price ranges as in Asia ($2000-$5000 including shipping cost). Fortunately, African lowlands especially inland valleys have quite adaptable topography and wide areas of virgin land to develop *sawah* systems rapidly. Once African farmers able to acquire the necessary skills and *sawah* systems developed, *sawah*-based rice farming will be more sustainable than the old-style ODA-based irrigation projects.

Table 4a. Cost and Income (US $) of Site Specific Personal Irrigated *Sawah* Development and *Sawah*-based rice cultivation (Ghana & Nigeria, 2009)

Activity	Cost/income elements, performance/durability of pump & power tillers	Spring-based (mean slope 1.5%)	Flood plain (mean slope 0.5%)	Stream dyke-based (mean slope 1%)	Pond-based (mean slope 1%)	Pump-based** (mean slope 1%)	Non *sawah* (2%)
A. *Sawah* development activities (first year of new *sawah* development only, per ha)							
Clearing & destumping	10-20 working days‡	70	70	70	70	70	35
Bunding	20-30 working days‡	100	70	85	85	85	NA
Ploughing	20-30 working days‡	100	70	85	85	85	NA
Puddling, soil movement, leveling	30-50 working days‡	200	135	170	170	170	NA
Pumping machine cost	3 ha/year†	NA	50	Na	30	200	NA
Power tiller cost#	2-3ha/yr, 6-15ha/life	700	500	600	600	600	NA
Main canal	$1000 for 100m/ha	NA	Na	100	100	Na	NA
Branch canal	$35 for 100m/ha	70	35	70	70	70	NA
Interceptor canal	$35 for 100m/ha	35	Na	35	35	35	NA
Dyke/weir	$400 for 20m x 5m x 3m per 3ha/3	NA	Na	150	Na	Na	NA
Pump fuel	3-20 days ($20/day)	NA	100	Na	60	400	NA
Flood control	$700 for 150m x 2m x 2m per 3ha/3	NA	270	70	Na	Na	NA
Pond construction	$1400 for 20m x 20m x 2m per 3ha/3	NA	Na	Na	500	Na	NA
Total cost of development		1275	1300	1435	1805	1715	35

‡1 working day cost $3.5. †Pumping machine: 15% depreciation, 10% spare parts. #Power tiller cost: $5000 for 3-5 years life, 15% depreciation, 10-20% spare parts; initial *sawah* development claims heavy load on power tiller, which comprises 50% of cost of development. *Direct sowing and/or dibbling. **Pump based systems have poor economic returns, if yield is same as other systems.

Since rice farmers have to master a wide range of skills, including ecological engineering, intensive on-the-job training continuing for 5-6 months is very important. One of the factors working against realization of green revolution in Africa is the failure to scale up successful results of past agricultural research (Ejeta, 2010). We do not want this to be the lot of this promising technology. The *sawah* approach has therefore arrived at a scaling-up stage to show clear road map for rice green revolution in Africa (Table 5). Thus our *sawah* approach becomes comparable for research, development, and dissemination of good varieties.

Table 4b & c: Cost and Income (US $) of Site Specific Personal Irrigated *Sawah* Development and *Sawah*-based Rice cultivation (Ghana & Nigeria, 2009)

Acticvity	Cost/income elements, performance/durability of pump & power tillers	Spring-based (mean slope 1.5%)	Flood plain (mean slope 0.5%)	Stream dyke-based (mean slope 1%)	Pond-based (mean slope 1%)	Pump-based** (mean slope 1%)	Non sawah (2%)
B. Sawah-based rice farming cost (first year only, per ha)							
Nursery bed	1-2 work- days‡	5	5	5	5	5	15
Seed cost	30-90kg ($10 per 10kg)	30	30	30	30	30	90
Sawah water mag,t	12-35 work- days‡	40	40	40	40	120	NA
Transplanting	15 work-days ($3/day)	45	45	45	45	45	NA
Rope & markers	5 bundles ($2/bundle)	10	10	10	10	10	NA
Weeding labour	6-7 work-days ($3/day)	20	20	20	20	20	50
Herbicide	5Litres ($8/L)	20	20	20	20	20	NA
Fertilizer	200kg/4bags($20/50kg)	80	80	80	80	80	NA
Fertilizing	3-4 work-days ($3/day)	10	10	10	10	10	NA
Bird scaring	10-30 work-days ($1.5/day)	20	20	20	20	20	40
Harvesting	7-15 work-days ($4/day)	60	60	60	60	60	30
Threshing	10 work-days‡	35	35	35	35	35	15
Sawah-based rice farming cost		375	375	375	375	465	240
Total cost in first year		1650	1765	1810	2180	2180	275
Yield	4 - 4.5 t ha^{-1}	4.5	4.0	4.5	4.5	4.0**	1.5
Gross income	$500/t paddy	2250	2000	2250	2250	2000	750
Net income		600	325	440	70	180	475
C. **Sawah-based rice farming cost (subsequent year, per ha)**							
Pump	2-10 days($15/day)	NA	50	NA	30	150	NA
Ploughing	5-7 work-days‡	15	15	15	15	15	NA
Puddling, leveling	6-9 work-days‡	30	20	30	30	30	NA
Power tiller	10 ha/year, life 5-7 yrs	90	80	90	90	90	NA
Maintenance of canal, dyke, pond	15% of new construction	15	70	70	90	15	NA
Nursery bed	1-2 work- days‡	5	5	5	5	5	15
Seed cost	30-90kg ($10 per 10kg)	30	30	30	30	30	90
Water mag't	20 work- days ($2/day)	40	40	40	40	40	NA
Transplanting	15 work-days ($3/day)	45	45	45	45	45	NA
Rope tec	5 bundles ($2/bundle)	10	10	10	10	10	NA

Acticvity	Cost/income elements, performance/durability of pump & power tillers	Spring-based (mean slope 1.5%)	Flood plain (mean slope 0.5%)	Stream dyke-based (mean slope 1%)	Pond-based (mean slope 1%)	Pump-based** (mean slope 1%)	Non sawah (2%)
Weeding labour	7 work-days ($3/day)	20	20	20	20	20	50
Herbicide	5Litres ($8/L)	20	20	20	20	20	NA
Fertilizer	200kg/4 bags ($20/50kg)	80	80	80	80	80	NA
Fertilizing	3work-days ($3/day)	10	10	10	10	10	NA
Bird scaring	15-30 work-days ($1.5/day)	20	20	20	20	20	40
Harvesting	15 work-days ($4/day)	60	60	60	60	60	30
Threshing	10 work-days‡	35	35	35	35	35	15
Sawah-based rice farming cost Total cost in first year		525	610	580	630	675	240
Yield	4-4.5t ha^{-1}	4.5	4.0	4.5	4.5	4.0**	1.5
Gross income	$500/t paddy	2250	2000	2250	2250	2000	750
Net income		1725	1390	1670	1620	1325	510

Table 5. Roadmap to African Rice Green Revolution by Sawah Eco-technology

Period	Activity
1986-2002	10 sites. 6ha of *Sawah*, 17years of trial and error. JICA/CSIR and MEXT assisted sawah project. West African wide survey on traditional rice farming and basic research on site specific sawah development by farmers' self support efforts at Bida, Nigeria and Kumasi, Ghana
2003-2007	20 sites, 30ha, Benchmark watershed. MEXT assisted basic research sites. Basic action research to develop site specific personal irr igated *Sawah* by farmers at Bida in Nigeria and Kumasi area in Ghana
2007-2011	>100 sites, >200ha, *Sawah* eco-technology. MEXT specially assisted promoted research. Kinki Univ./NCAM/Fadama III/SRI/CRI, JIRCAS, SMART -IV. *Sawah* eco-technology establishment and to prepare large scale action research on *Sawah* eco-technology dissemination in Nigeria, Ghana, Togo and Benin
2012-2016	>500 sites, >2500ha of *Sawah* in each country. African adaptive *Sawah* eco-technology dissemination, evolution and endogeneous development. Kinki Univ./NCAM/Fadama III/SRI/CRI, JIRCAS, SMART -IV and JICA-CARD. To start large scale action research on *Sawah* eco-technology in the whole of Ghana, Nigeria as well as Togo, Benin and others in West Africa and Sub-Saharan Africa.
2017-2022	> 2500 sites, > 25000ha of *Sawah* in each country. African wide adaptation and dessimination and endogeneous *Sawah* eco-technology development
2022-2026	> 20,000sites, > 200,000h a of *Sawah*. African wide spontaneous and rapid sawah expansion and the realization of the African Rice Green Revolution and African Rice Potential.

Conclusion

For a faster realization of the rice green revolution in sub-saharan Africa, there must be a starting point (reference country) to lead the rest of the region. The process should start from Ghana and Nigeria, with the rest of the countries following as illustrated in the proposed road map. The sawah eco-technology has the potential of not onlymaking sub-sharan Africa self-sufficient in rice production and ensuring food security but more importantly it ensures environmental stability.

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