Multi Functionality of Sawah systems: Why sawah based rice farming is critical for Africa's green revolution

T. Wakatsuki, Kinki University

SMART IV kickoff workshop from 16-17th August 2010, Africa Rice, Cotonou

No Sawah, No Green Revolution

Water control through Sawah system is prerequisite for Green Revolution in SSA

What is the core technology for African Rice Green Revolution?

(Three Essential Technologies)

1, High Yielding Varieties (HYV)

2, Soil, fertilizer and pest management (Fertilizer)

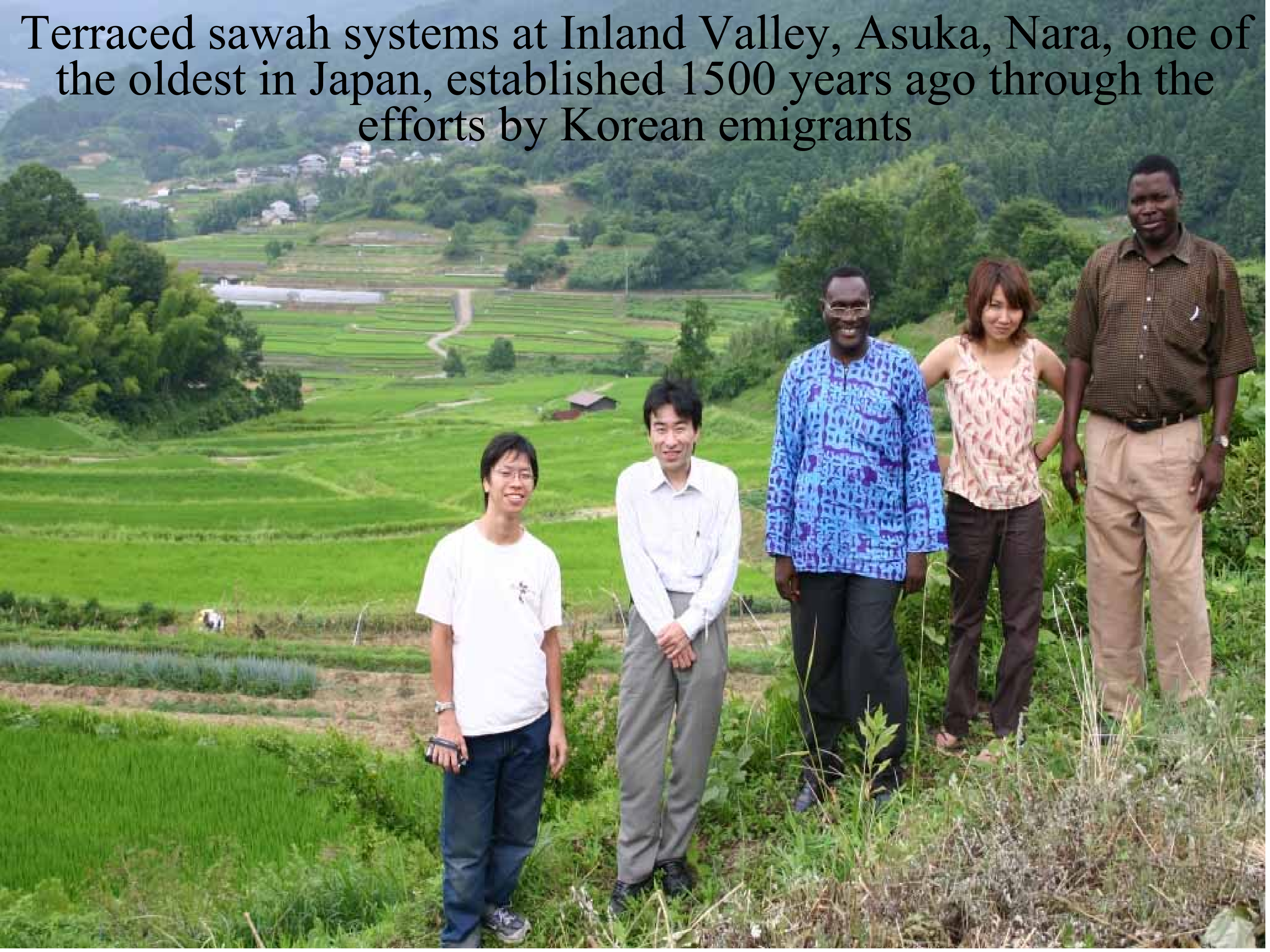
3, Water management (Irrigation)

After the dramatic success by CYMMET and IRRI in 1970s in Latin America and Asia, various HYVs were available in Sub Sahara Africa during last 40 years, 1970-2010.

However, the green revolution is yet realized in Sub Sahara Africa.
Why ? Are there any missing factors?

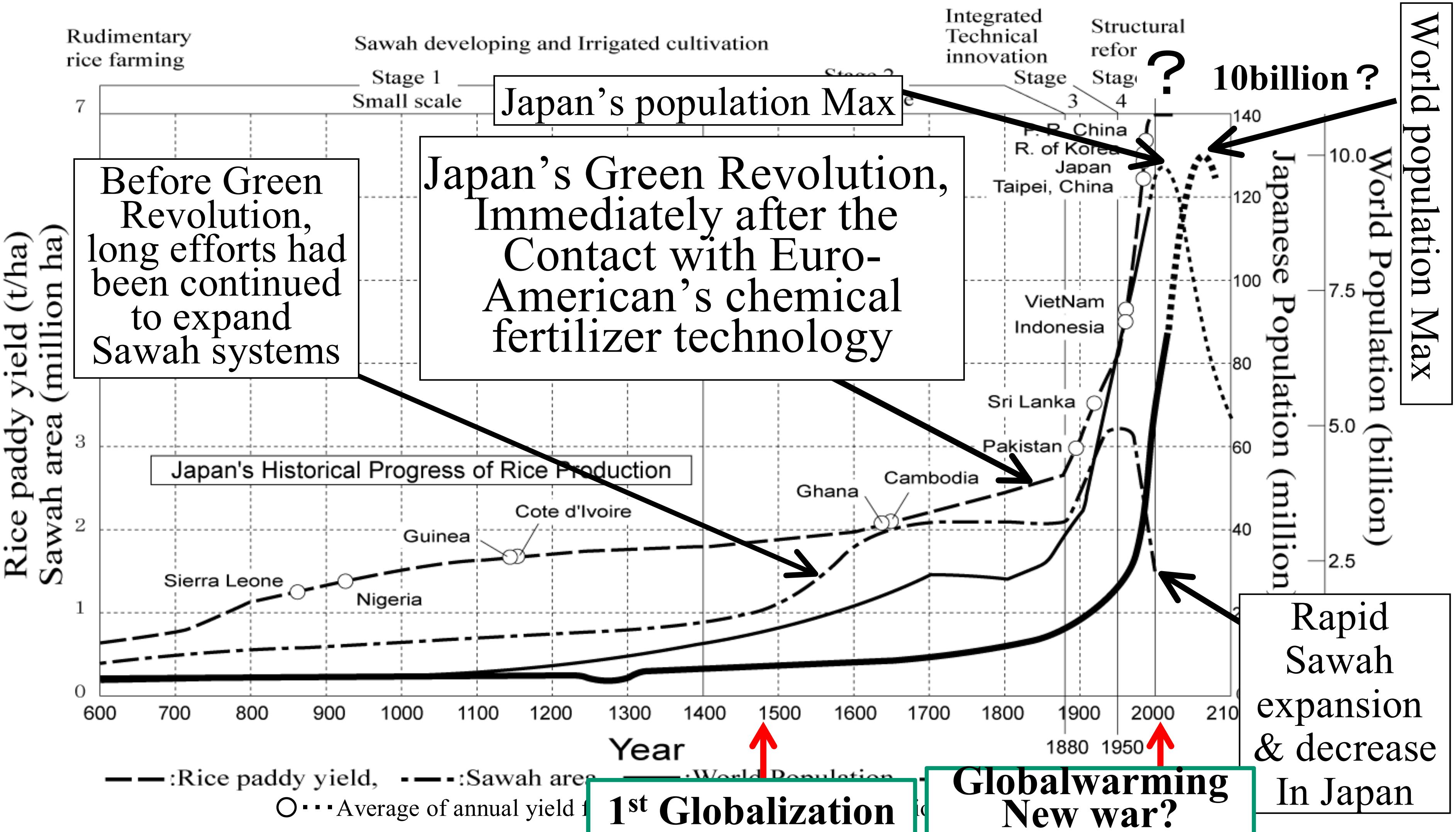
Sawah systems developed & managed by Chinese Farmers (Otsuka 2004)

Forest Destruction by Shifting Upland Paddy Cultivation in Guinea Highland: Upland rice can not be sustainable without sawah or soil conservation measures



Terraced sawah systems at Inland Valley, Asuka, Nara, one of the oldest in Japan, established 1500 years ago through the efforts by Korean emigrants

Farmers' sawah fields are the most important infrastructure :Farmers' Fields come the first : *Japanese Experiences*



Population, Rice yields & Sawah area of historical path in Japan in comparison with Asia & Africa Takase & Kano,1969, modified

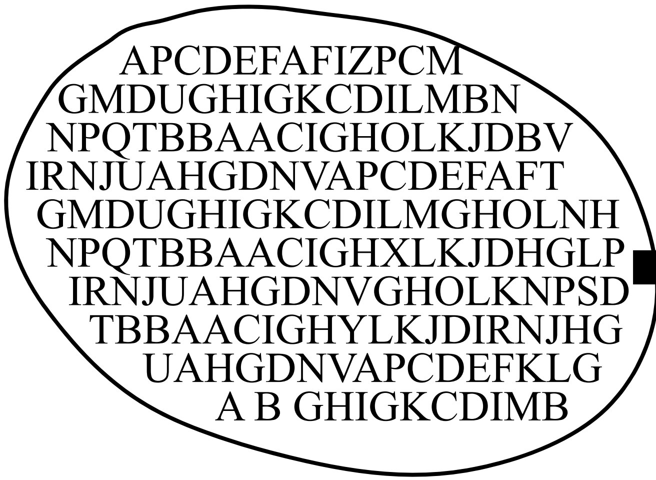
Lowland paddy field at Sokawe, Kumasi, Ghana
Three Green Revolution technologies can't apply

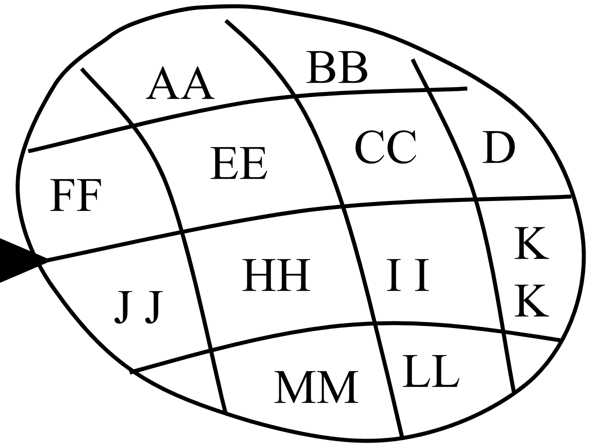
Once Sawah system was developed, yield can reach at least 4t/ha. If improved rice agronomy can practice, such as System Rice Intensification, yield reach to 10t/ha (CRI sawah team, Ghana)

SRI practice needs good leveling and water control based on Sawah, Sumatra, Aug,10

Farmers' Paddy Fields:
Diverse and mixed up environment.No clear field demarcations

Sawah demarcates land based on topography, hydrology and soils, which make possible water control. Then green revolution technology of fertilizer, irrigation and HYV are useful.





Fertilizer, Irrigation, and HYV are not effective No Green Revolution possible

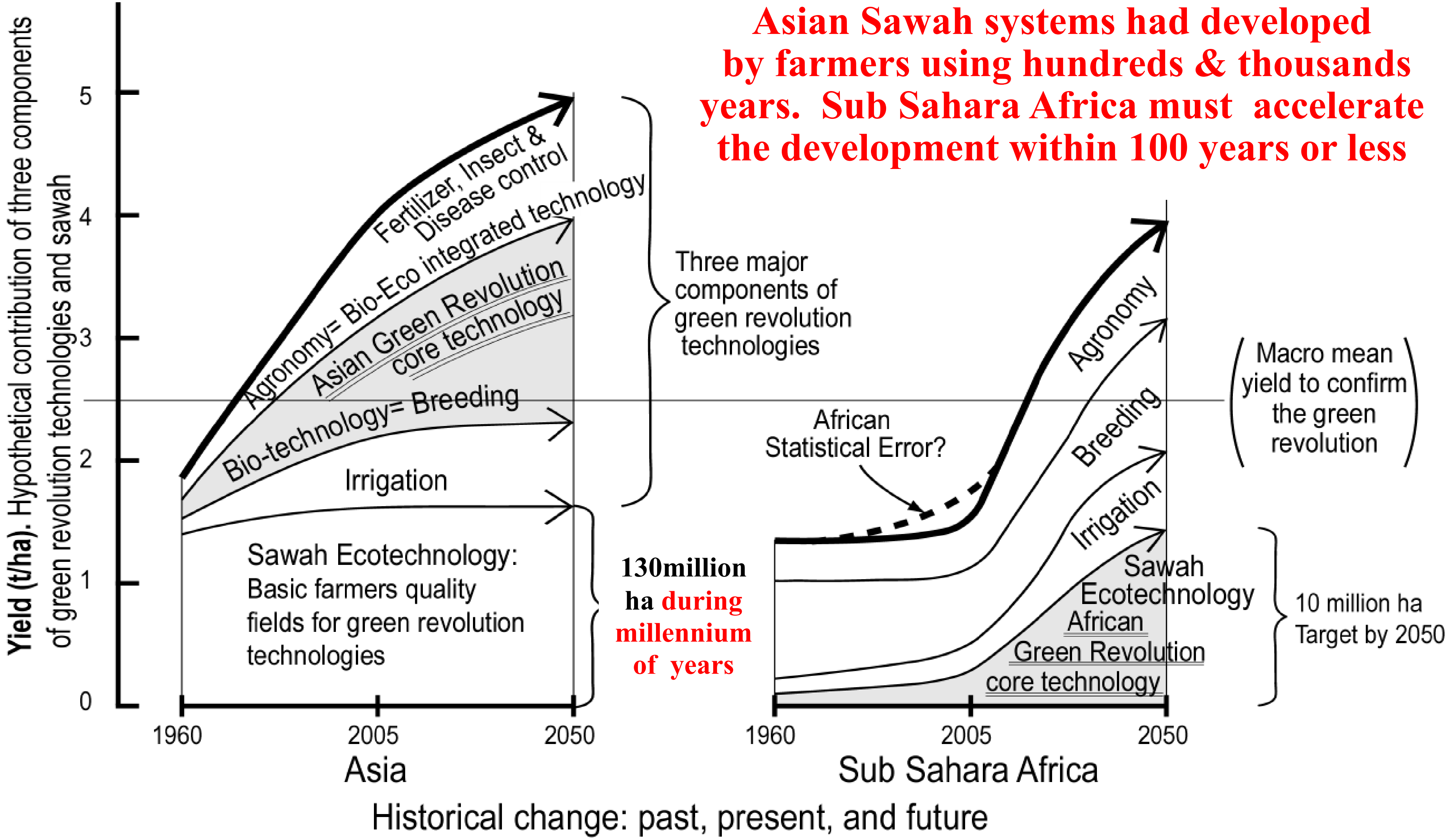
Sawah based Farming system

Fig. Sawah hypothesis (I): Farmers Sawah should comes the first to realize green revolution. Scientific technologies needs classified demarcated land eco-technologically

No proper English/French &local language in West Africa to describe eco-technological concept and term to improve farmers'rice fields, Sawah or SUIDEN (in Japanese)

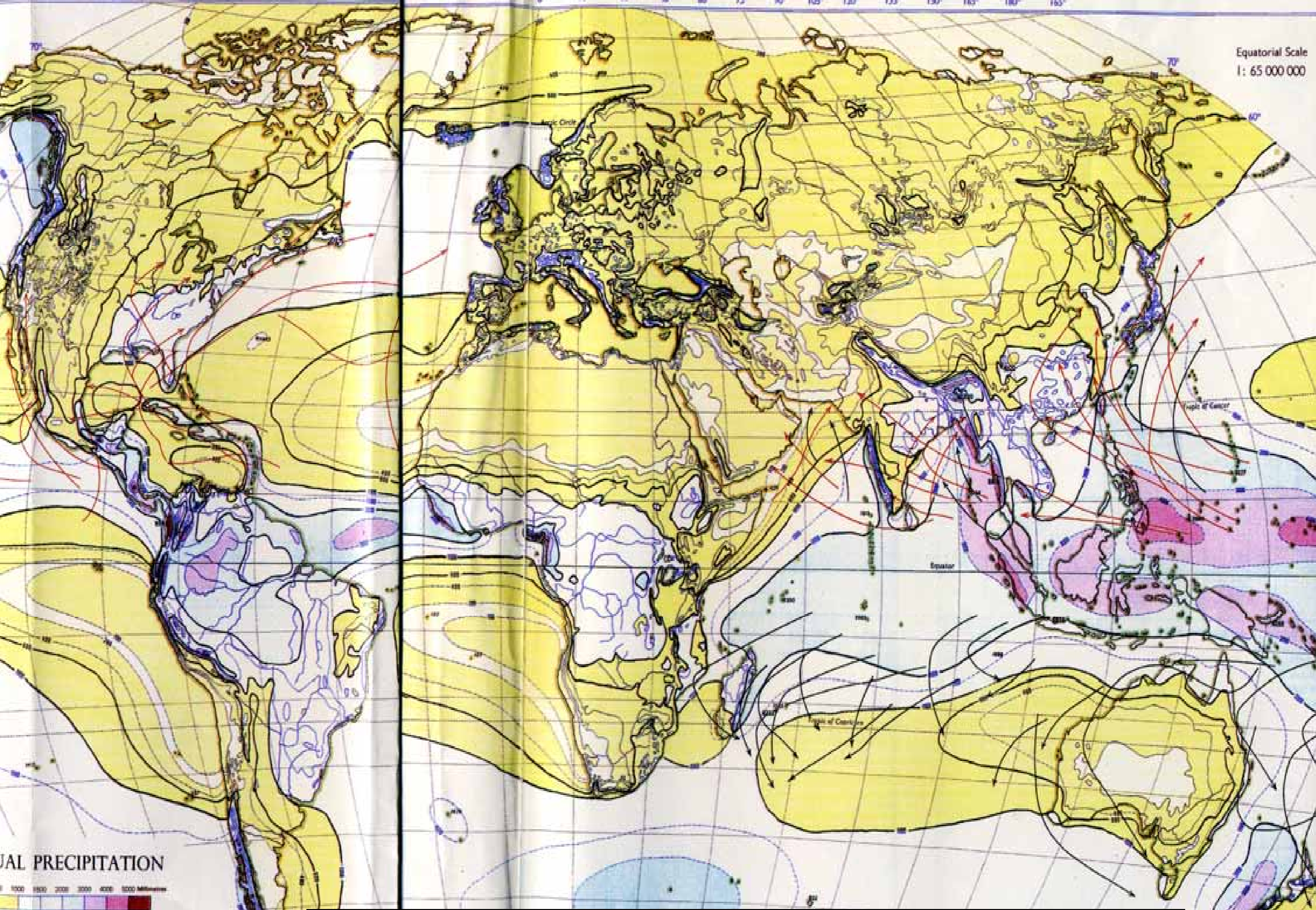
Suiden(Japanese) =SAWAH(Malay-Indonesian)

	English	Indonesian	Chinese(漢字)
Plant Biotechnology	Rice	Nasi	米, 飯, 稲
	Paddy	Padi	稲, 籾
Environment Ecotechnlogy	(Paddy)?	Sawah	水田



Sawah hypothesis (I) for Africa Green Revolution:

hypothetical contribution of three green revolution technologies & sawah system development during 1960-2050. Bold lines during 1960-2005 are mean rice yield by FAOSTAT 2006. Bold lines during 2005-2050 are the estimation by the authors.



Distribution of World Precipitation

Can watersheds of SSA sustain Sawah system? High rate of soil erosion and lowland sawah soil formation can be compensated by high rate of soil formation in Asia. However soil formation, soil erosion and hence lowland soil formation are very low (only 10-20%) in comparison with Asian watersheds

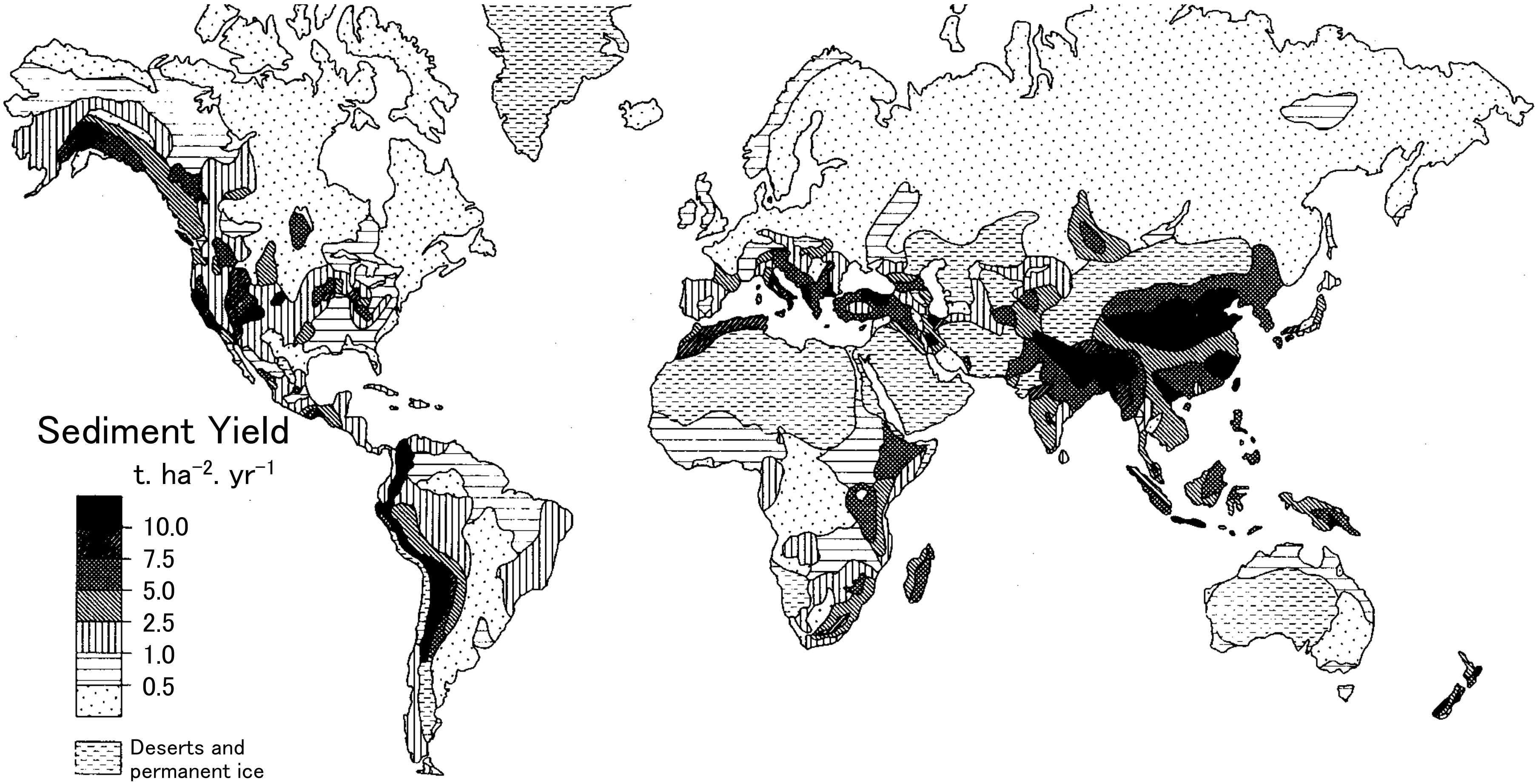


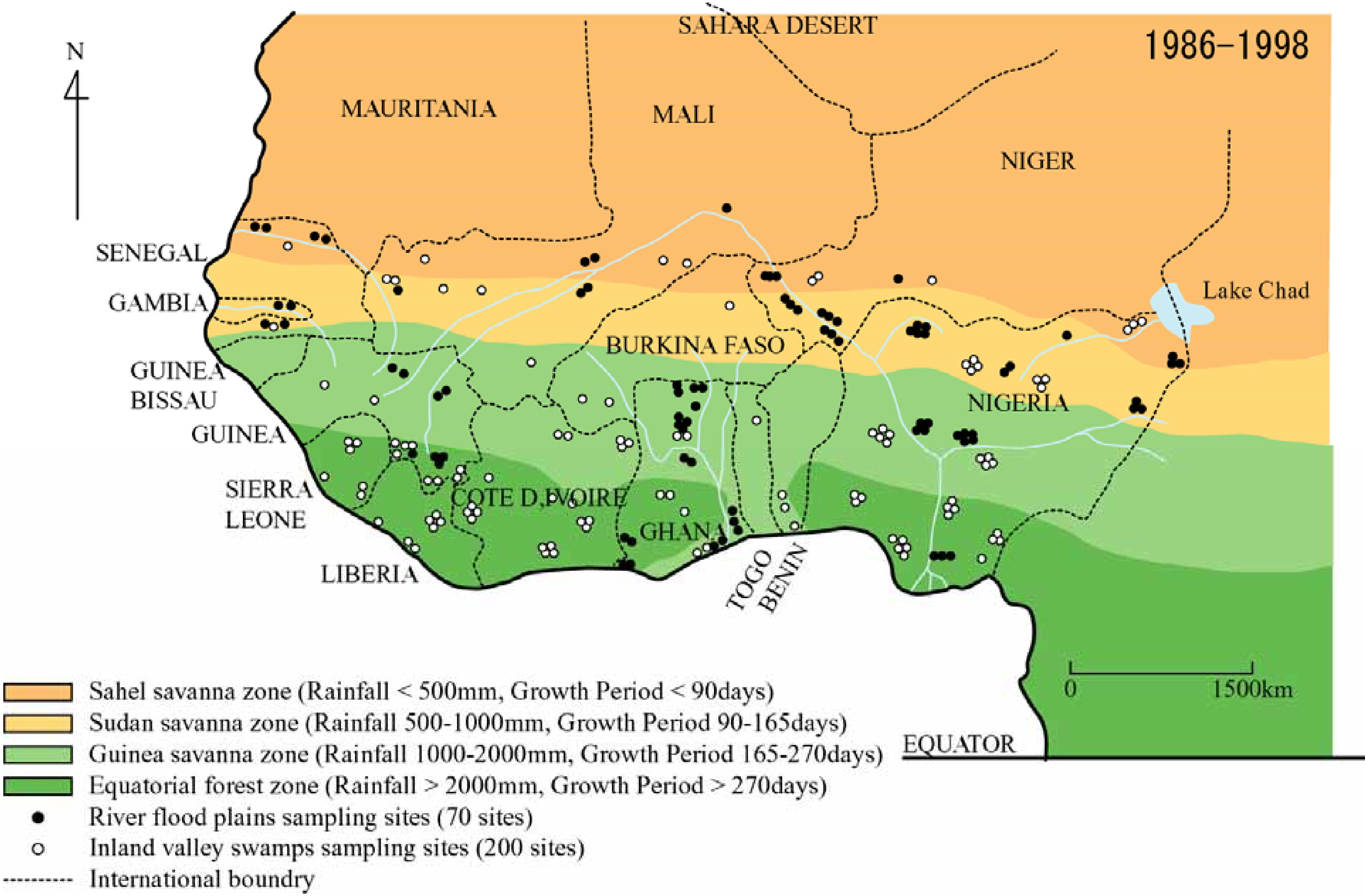
Fig.8. Rate of soils erosion in the world (Walling1983)

Table 1 Distribution of lowlands and potential irrigated sawah in SSA (Hekstra, Andriesse, Windmeijer 1983 & 1993, Potential Sawah area estimate by Wakatsuki 2002)

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

Priority target is the inland valley because of easier water control

Max 20million ha (Estimated sawah area came from the relative amount of water cycle in Monsoon Asia, which has 130 million ha of sawah)



West Africa map showing selected sampling sites of lowland soils. (Buri and Issaka et al)

Mean values of fertility properties of inland valleys (IVS) and flood plains (FLP) of West Africa in comparison with lowland top-soils of tropical Asia and Japan

Location	Total C (%)	Total N (%)	Available P (ppm)**	Exchangeable Cation (cmol/kg)				Sand (%)	Clay (%)	CEC /Clay
				Ca	K	Mg	eCEC			
IVS	1.3	0.11	9	1.9	0.3	0.9	4.2	60	17	25
FLP	1.1	0.10	7	5.6	0.5	2.7	10.3	48	29	36
T. Asia*	1.4	0.13	18	10.4	0.4	5.5	17.8	34	38	47
Japan	3.3	0.29	57	9.3	0.4	2.8	12.9	49	21	61

*Kawaguchi and Kyuma (529 sites), 1977,** Bray II.

Source: Hirose and Wakatsuki (268 sites), 1997.

How can we overcome low level nutrients & scarce water in Sub Sahara Africa

Basic infrastructure for rice farmers fields to make useful scientific technologies , such as lowland sawah systems is the answer

- The integrated management of lowland & upland, for example, SATOYAMA type watershed agro-forestry, is also key eco-technology
- The core region of West Africa has similar climate, soil, hydrology, and crops to northeastern Thailand: Asian African collaboration in future

(1) Ethiopia, Kenya, Tanzania, Uganda, Rwanda, and Burudi have fertile soils because of orogenic activities

(2) Madagascar and Zanzibar have their own traditional sawah systems because of the long relation with Indonesian and Asian

Sawah hypothesis(II): Sustainable Productivity of lowland Sawah is more than 10 times than Upland Field

1ha sawah is equivalent to 10-15ha of upland

	Upland		Lowland(Sawah)
Area (%)	95 %		5 %
Productivity (t/ha)	1-3 1 ≦ **		3-6 2**
Required area for sustainable1 ha cropping*	5 ha	:	1 ha

* Assuming 2 years cultivation and 8 years fallow in sustainable upland cultivation, while no fallow in sawah

**In Case of No fertilization

Multi Functionality of Sawah Systems

I. Intensive and diverse nature of productivity

(1) Weed control

(2) Nitrogen fixation ecosystems: 20 to 200kgN/ha/year

(3) To increase Phosphate availability: concerted effect on N fixation

(4) pH neutralizng ecosystems: to increase micro nutrient availability

(5) Geological & irrigation fertilization: water, nutrients and topsoil from upland

(6) Various sawah based farming systems.

(7) Fish and rice, Goose and sawah, Birds and sawah, Forest and Sawah

II. To combat Global warming and other environmental problems

(1) Carbon sequestration through control of oxygen supply. Methane emission under submerged condition. Nitrous oxide emission under aerobic rice

(2) Watershed agroforestry, SATOYAMA, to generate forest at upland

(3) Sawah systems as to control flooding & soil erosion and to generate electricty

(4) Denitrification of nitrate polluted water

III. To create cultural landscape and social collaboration

(1) Terraced sawah as beautiful cultural landscape

(2) Fare water distribution systems for collaboration and fare society

Comparison between Biotechnology and Sawah Ecotechnology Options for Rice Production

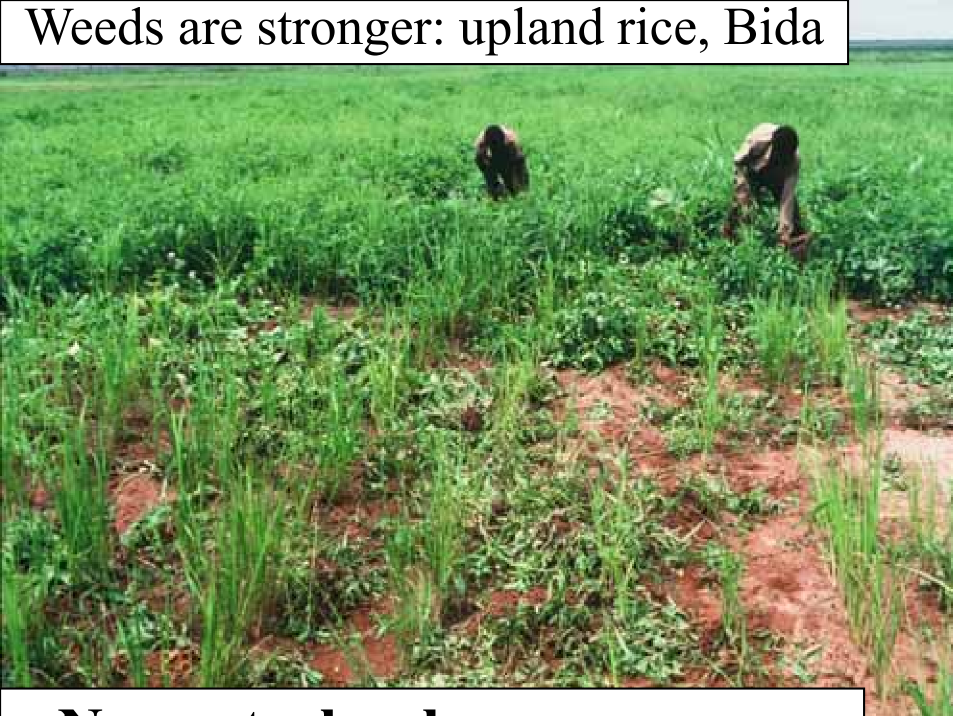
(1) **Water shortage**: **Genes for deep rooting、C4-nature、and Osmotic regulation.** Eco-technology of Sawah based soil and water management, bunding, leveling, puddling, and surface smoothing with various irrigations, Aerobic rice, System rice intensification

(2) **Poor nutrition, acidity and alkalinity**: **Gene of Phosphate and micronutrient transporter.** Eco-technology of Sawah based N fixation, increase P availability and micro- as well as macronutrient. Geological fertilization and watershed agroforestry(SATOYAMA systems), organic matter and fertilization. Bird feculent are rich in P.

(3) **Weed control**: **Gene of weed competition, rapid growth**. Eco-technology of Sawah based weed management through water control. and tans-planting. Leveling quality and surface smoothing of sawah are important. Duck and rice farming.

(4) **Pest and disease control**: **Various Resistance genes**. Eco-technology of Sawah based silica and other nutrients supply to enhance immune mechanisms of rice. Mixed cropping.

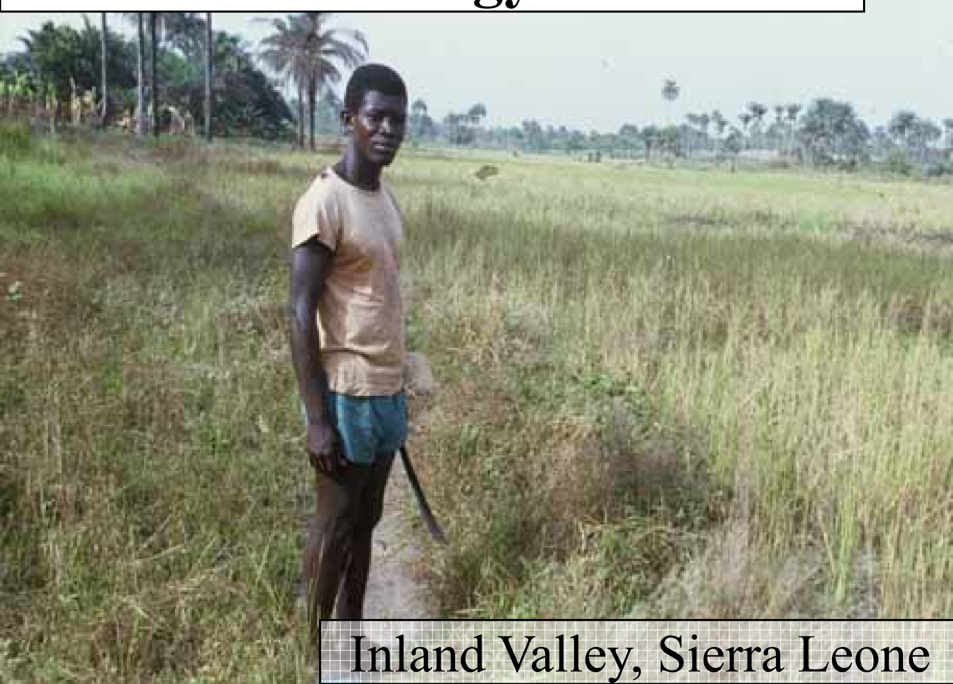
(5) **Food quality**: **Vitamine rice gene**. Sawah based nutrition control. Fish, duck and rice in sawah systems



Weeds are stronger: upland rice, Bida

Nupe's indigenous partial water control system

No ecotechnology measures



Inland Valley, Sierra Leone

Once Sawah systems are developed by farmers' self-support efforts and water is controlled, majority of HYV can produce higher than 5 t/ha

Table Mean gain yield of 23 rice cultivars in low land ecologies at low (LIL) and high input levels (HIL), Ashanti, Ghana (Ofori & Wakatsuki, 2005)

		← ECOTECHNOLOGICAL YIELD IMPROVEMENT					
	Entry No. Cultivar	Irrigated Sawah		Rainfed sawah		Upland like fields	
		HIL	LIL	HIL	LIL	HIL	LIL
		(t/ha)		(t/ha)		(t/ha)	
BIOTECHNOLOGICAL IMPROVEMENT	1 WAB	4.6	2.9	2.8	1.6	2.1	0.6
	2 EMOK	4.0	2.8	2.9	1.3	1.4	0.5
	3 PSBRC34	7.7	3.5	3.0	2.1	2.0	0.4
	4 PSBRC54	8.0	3.7	3.8	2.1	1.7	0.4
	5 PSBRC66	5.7	3.3	3.8	2.0	1.8	0.4
	6 BOAK189	7.0	3.8	3.7	2.0	1.4	0.3
	7 WITA 8	7.8	4.2	4.4	2.1	1.8	0.5
	8 Tox3108	7.1	4.1	4.0	2.3	2.3	0.6
	9 IR5558	7.9	4.0	3.8	2.0	1.8	0.5
	10 IR58088	7.7	4.0	3.7	1.8	1.4	0.3
	11 IR54742	7.7	4.3	4.0	2.2	1.9	0.4
	12 C123CU	6.9	4.1	4.2	1.9	2.0	0.4
	13 CT9737	6.5	4.0	4.0	1.7	1.9	0.6
	14 CT8003	7.3	3.8	3.8	1.7	2.0	0.5
	15 CT9737-P	8.2	4.0	4.3	1.8	1.2	0.5
	16 WITA1	7.6	3.6	3.3	1.8	0.9	0.3
	17 WITA3	7.6	3.5	4.1	2.0	1.3	0.5
	18 WITA4	8.0	4.1	3.7	2.1	1.5	0.3
	19 WITA6	8.0	3.5	4.0	2.3	1.4	0.3
	20 WITA7	7.3	3.7	3.8	2.2	2.0	0.4
	21 WITA9	7.6	4.4	4.5	2.8	2.0	0.6
	22 WITA12	7.6	4.0	3.8	1.9	1.8	0.4
	23 GK88	7.5	3.8	3.5	2.0	1.8	0.5
	Mean (n=23)	7.2	3.8	3.8	2.0	1.7	0.4
	Range	(4.0-8.2)	(2.8-4.4)	(2.8-4.5)	(1.3-2.8)	(0.9-2.3)	(0.3-0.6)
	SD	1.51	0.81	0.81	0.45	0.44	0.12

Because of cost of green revolution technology, yield must be higher than 4t/ha

Sawah based rice production: Ecotechnology for Food, Environment, Landscape, and Culture(Multi-functionality)
(World Heritage, Ifugao people, Philippine,Koudansha Co. Ltd, 1998)

Nasi Padang, Indonesian Sawah restaurant, 1 Aug. 2010

Sawah is ecotechnology based Multi-Functional constructed Wetland: Production, Environment, and Cultural landscape (JICA sawah project)

Inland valley, Ashanti, Ghana, 2001

Biemso No.1, Zongo site in 2002
Pudling, soil moving & leveling

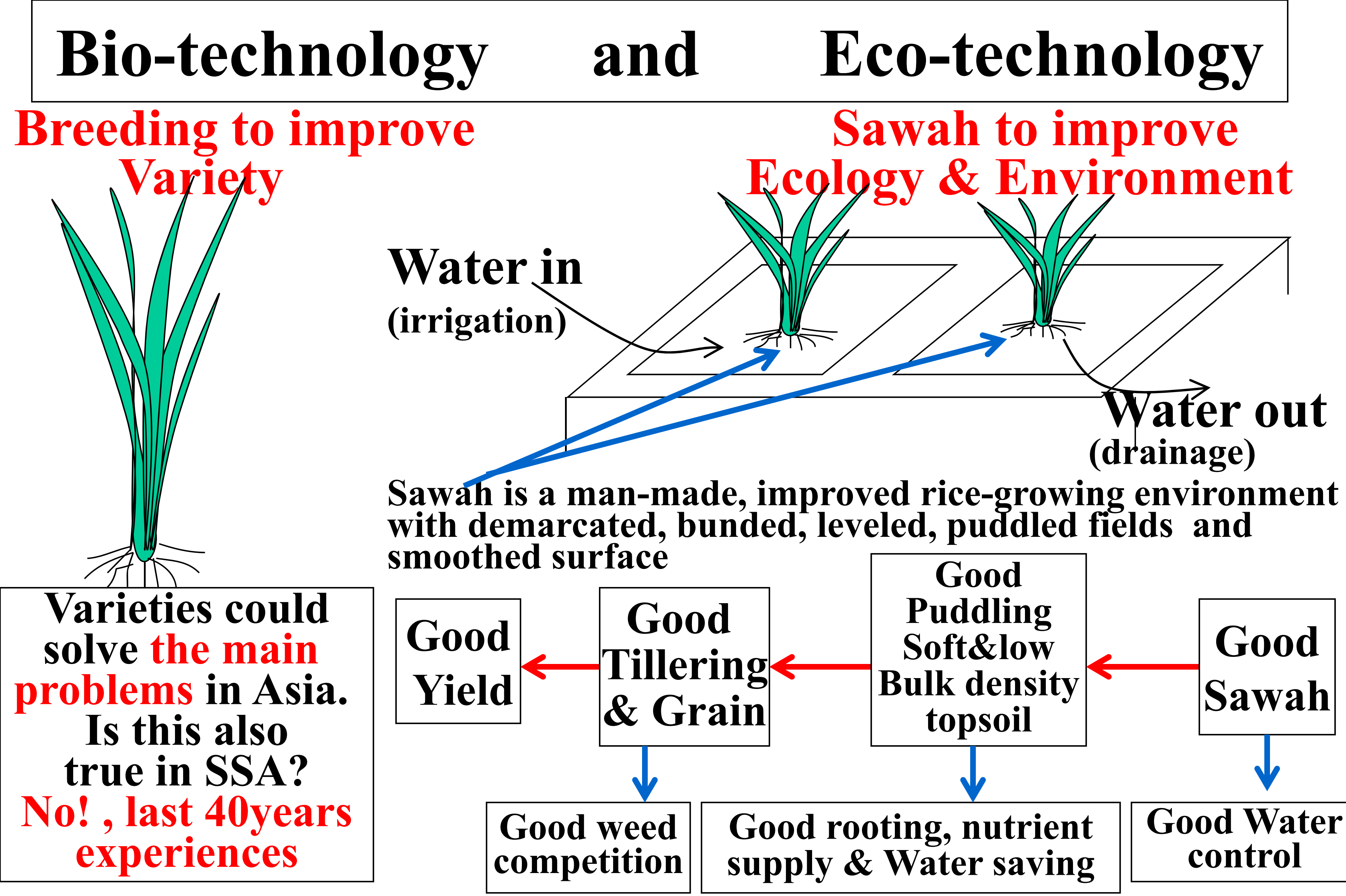


Fig. Rice (variety) and environment (Sawah) improvement. Both Bio & Eco-technologies must be developed in appropriate balance

<u>Mr. Tawiah</u> and his rice, growing on sawah about 4ha developed by himself, with CRI/SRI, and JIRCAS scientists, August 2009. This original site of JICA/CRI sawah project in 1997-1999

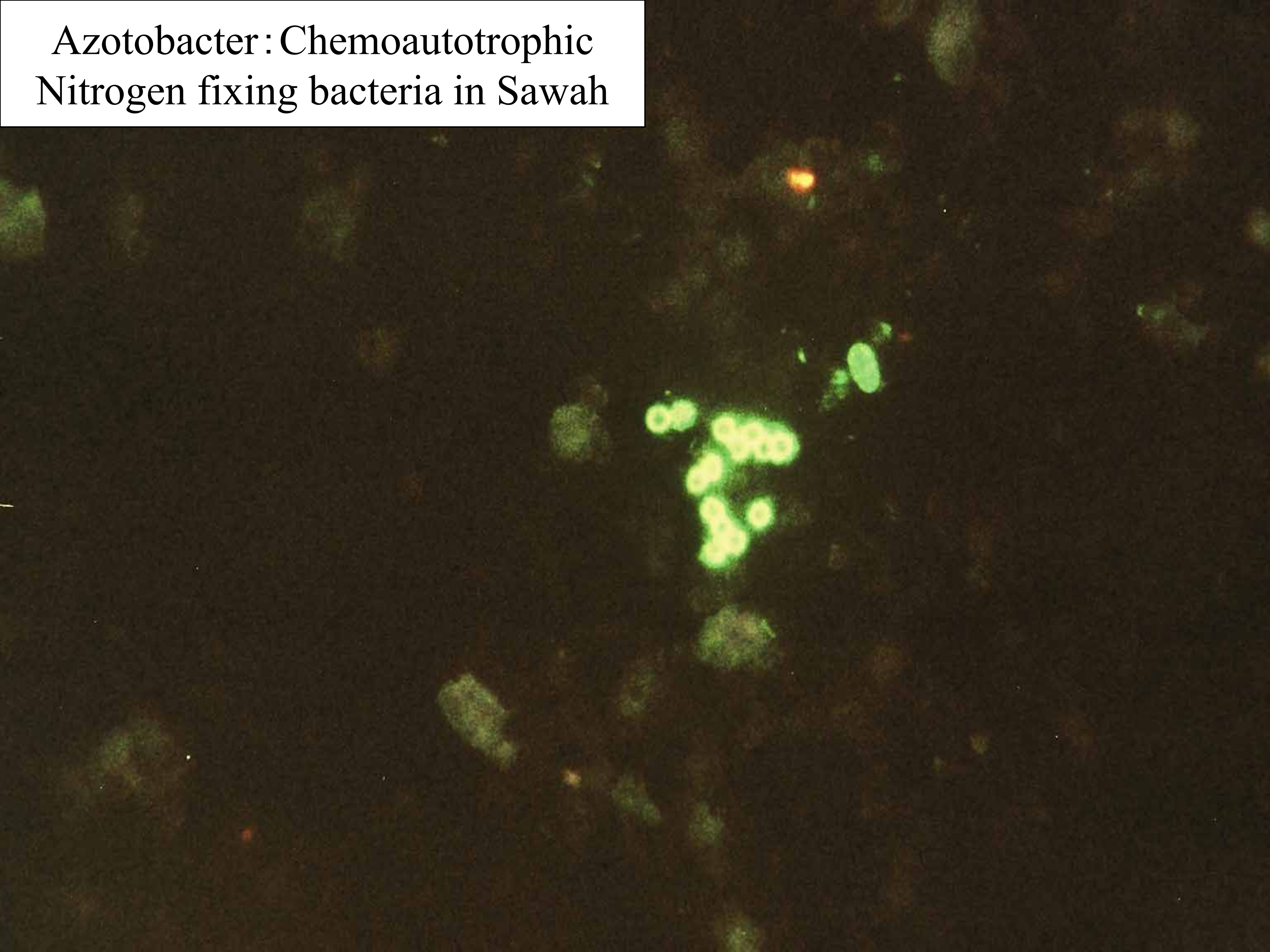
New Sawah, Pampaida, UN millennium village, Zaria

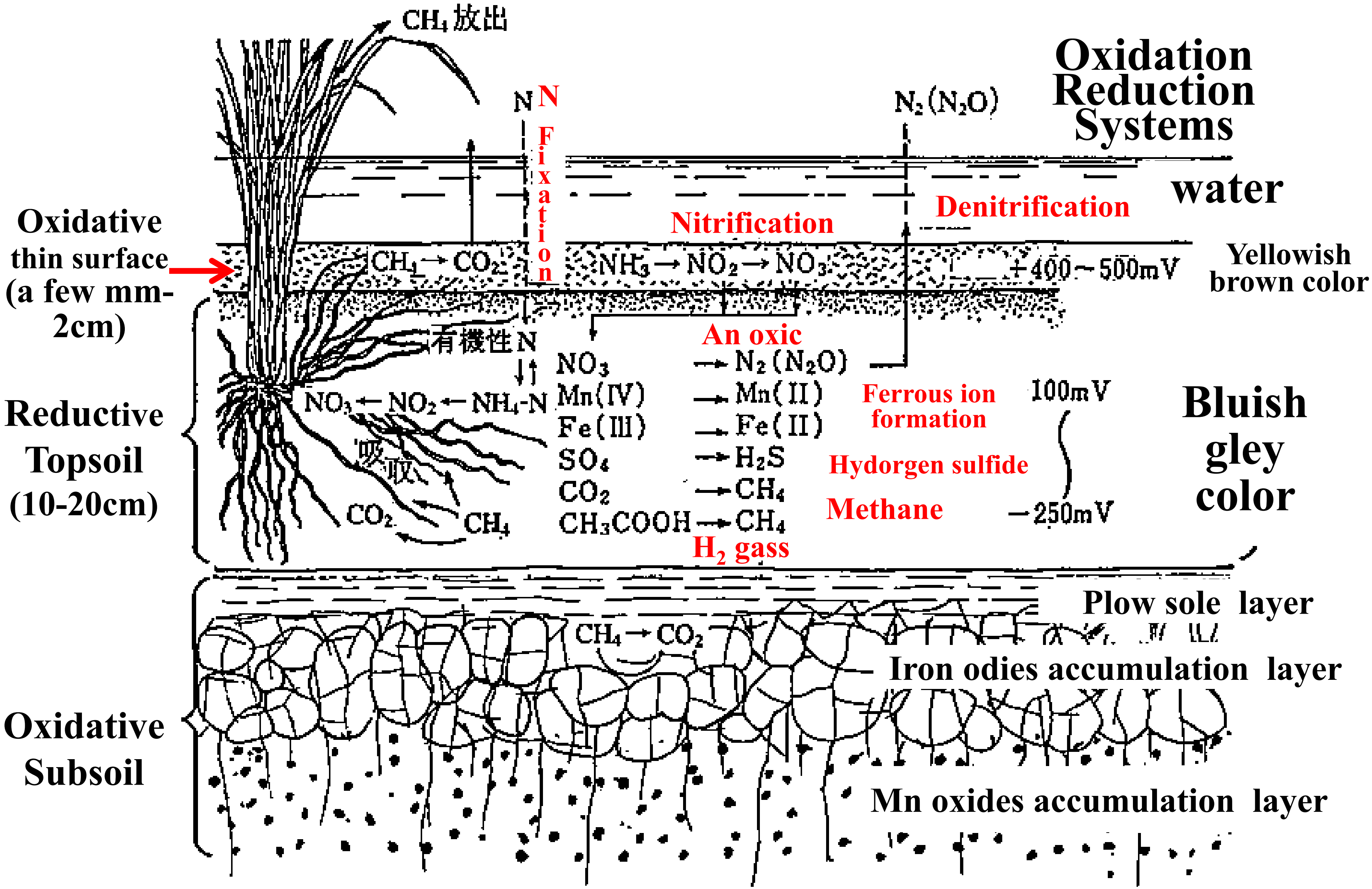

Sawah and traditional non sawah rice ,
Pampaida, UN millennium village, Zaria
Poor tillering and aggressive
weed in non sawah field

Submerged sawah:
Multi functional ecosystems of various interaction between Rice, Algae,
Fish, Goose, microbes, and others

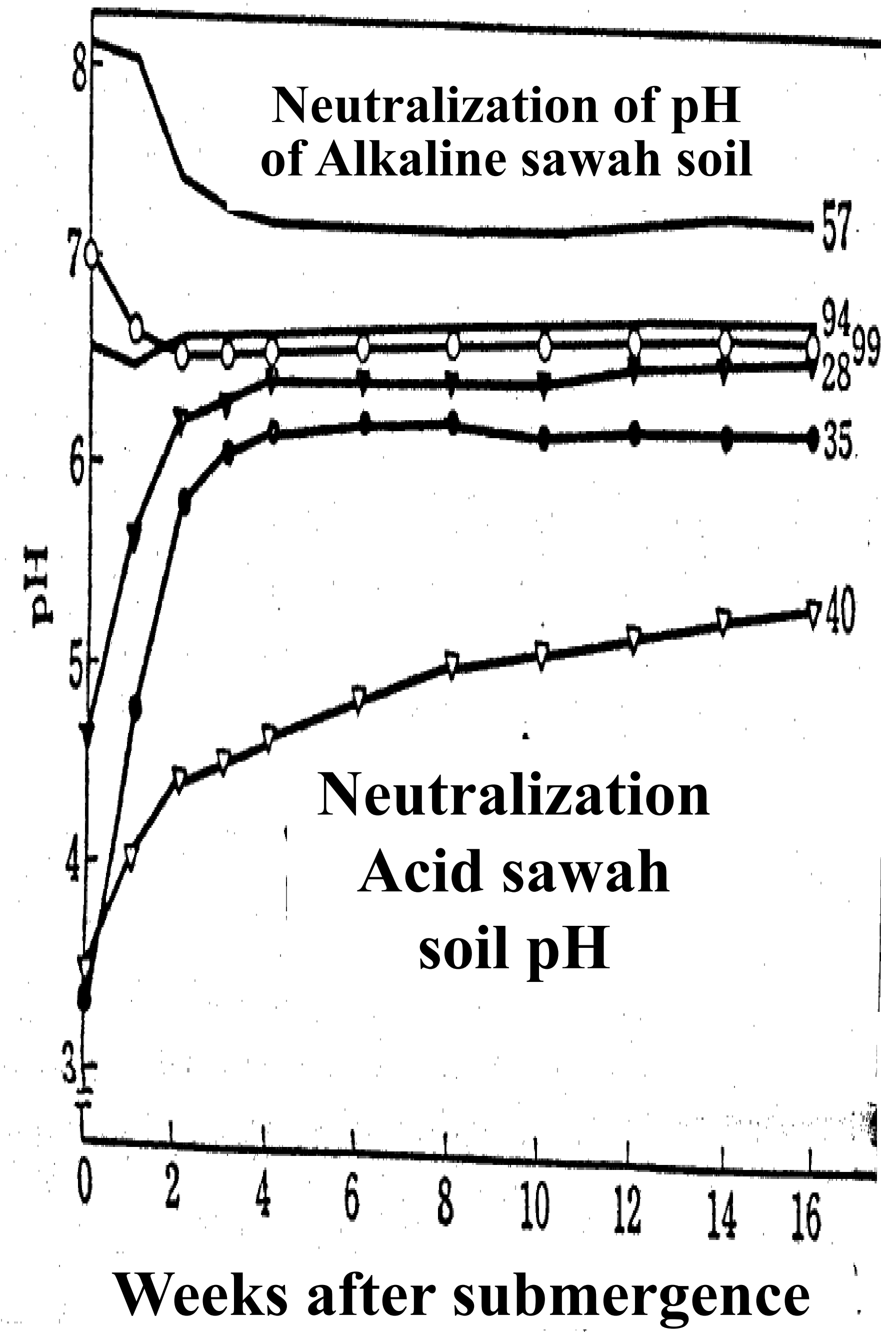
Left :nitrogen fixing Azola

Azotobacter : Chemoautotrophic Nitrogen fixing bacteria in Sawah





Typical Sawah soil profile development under submerged condition

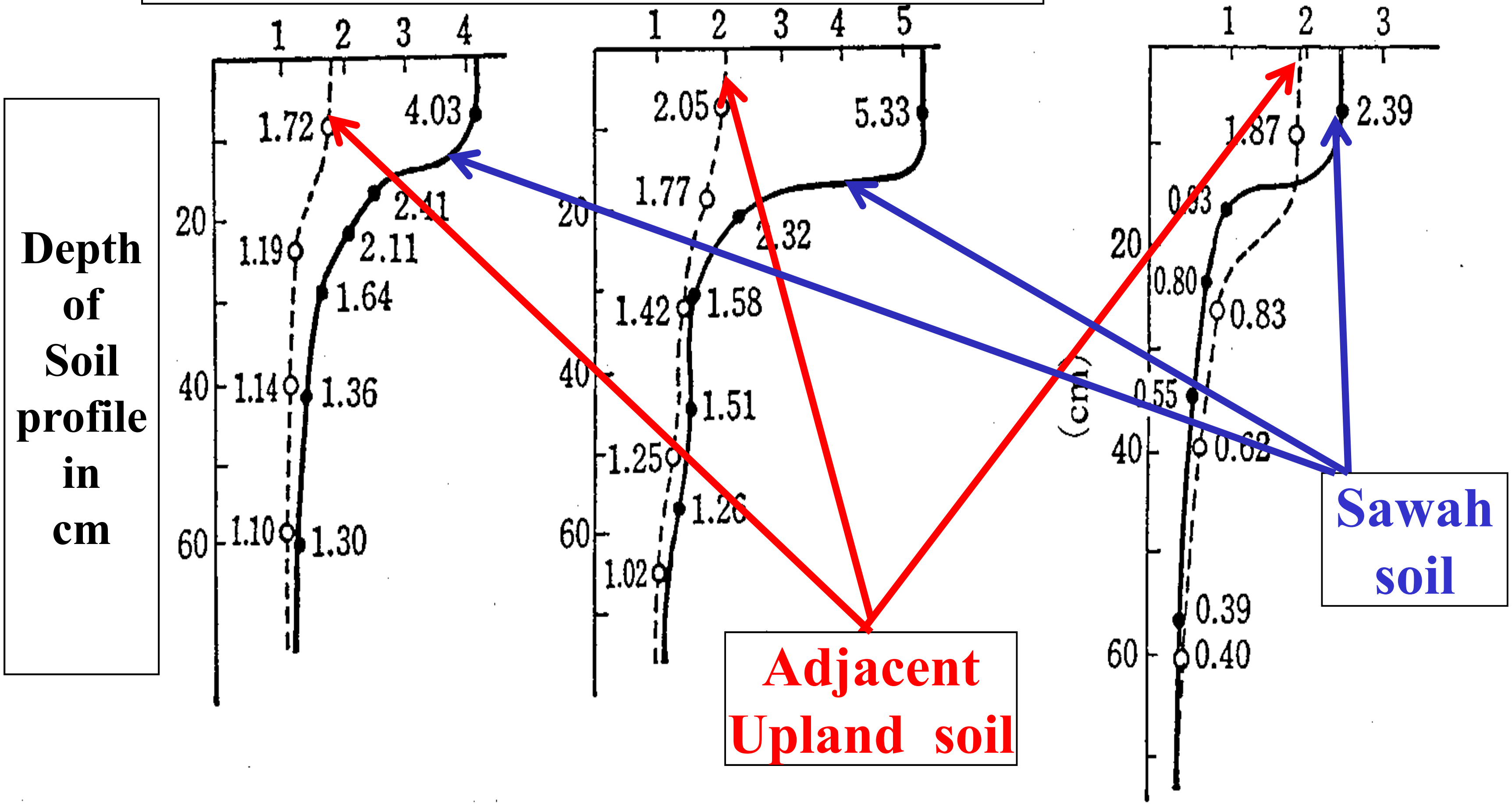


soil No.	Soil texture	pH	Content(%)		
			OM (%)	Fe(%)	Mn(%)
28	埴 土	4.9	2.9	4.70	0.08
35	埴 土	3.4	6.6	2.60	0.01
40	埴 土	3.8	7.2	1.50	0.00
57	埴壌土	8.7	2.2	0.63	0.07
94	埴 土	6.7	2.6	0.96	0.09
99	埴壌土	7.7	4.8	1.55	0.08

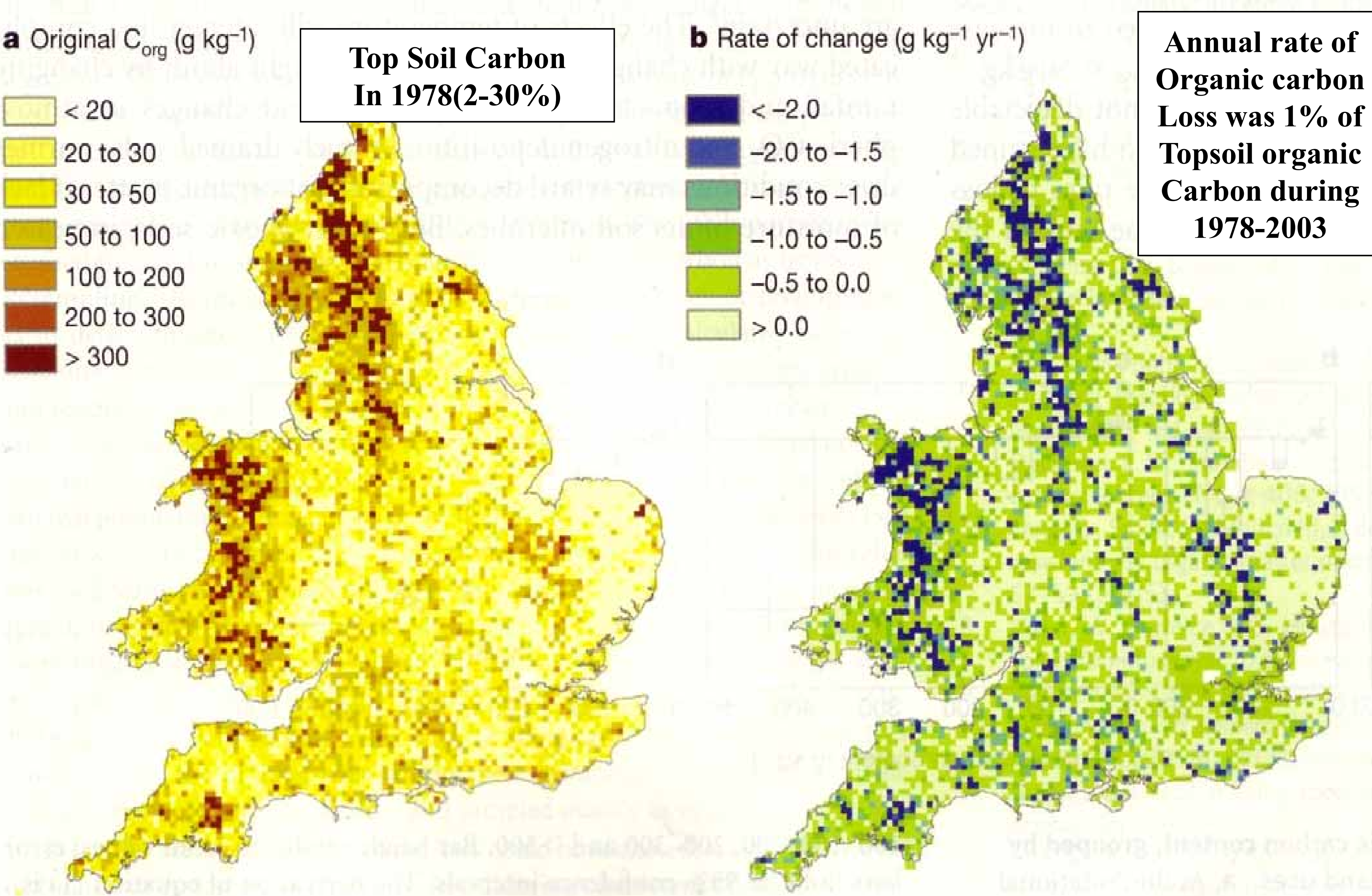
Sawah soil neutralization through submergence(Ponnamperuma 1976)

Organic matter % in Lowland Sawah soils in comparison with soils in upland management condition

Upland terraced sawah and upland Non-sawah

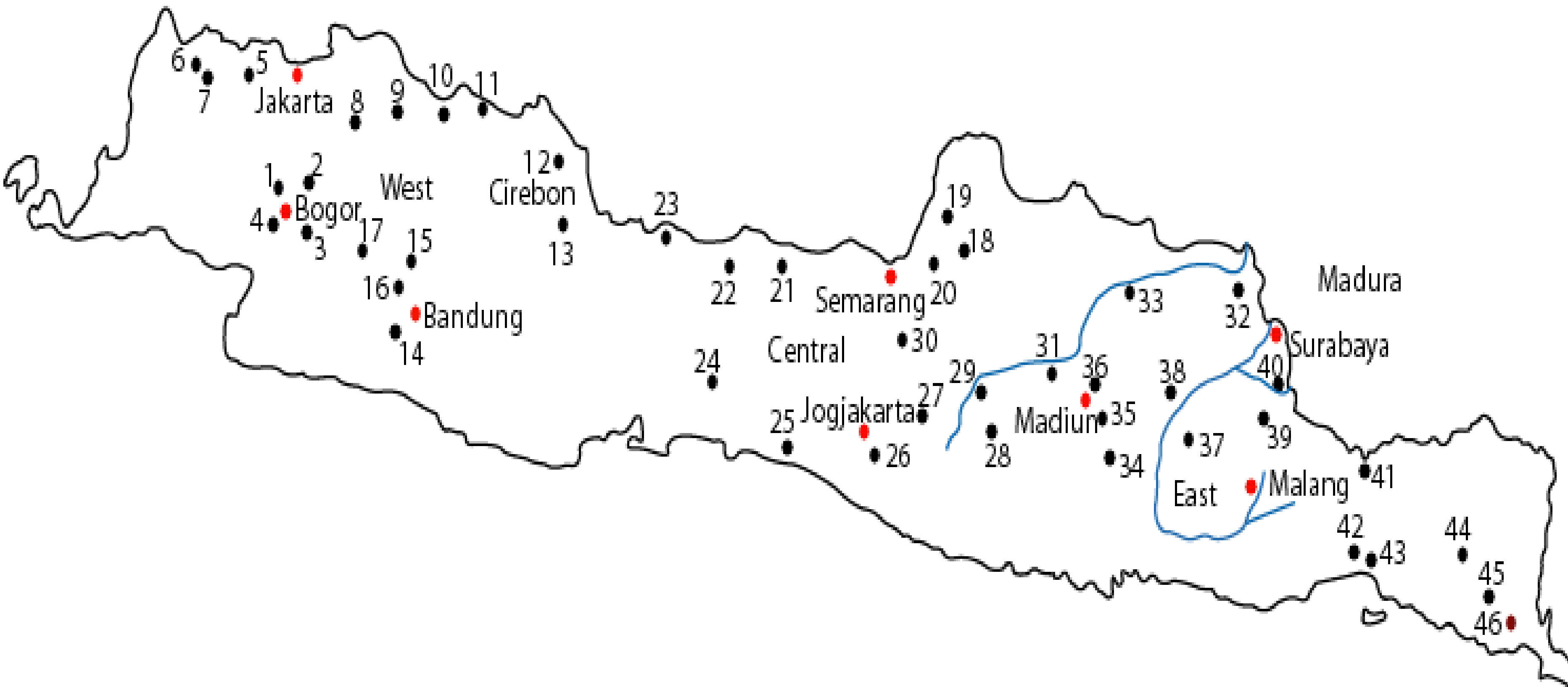


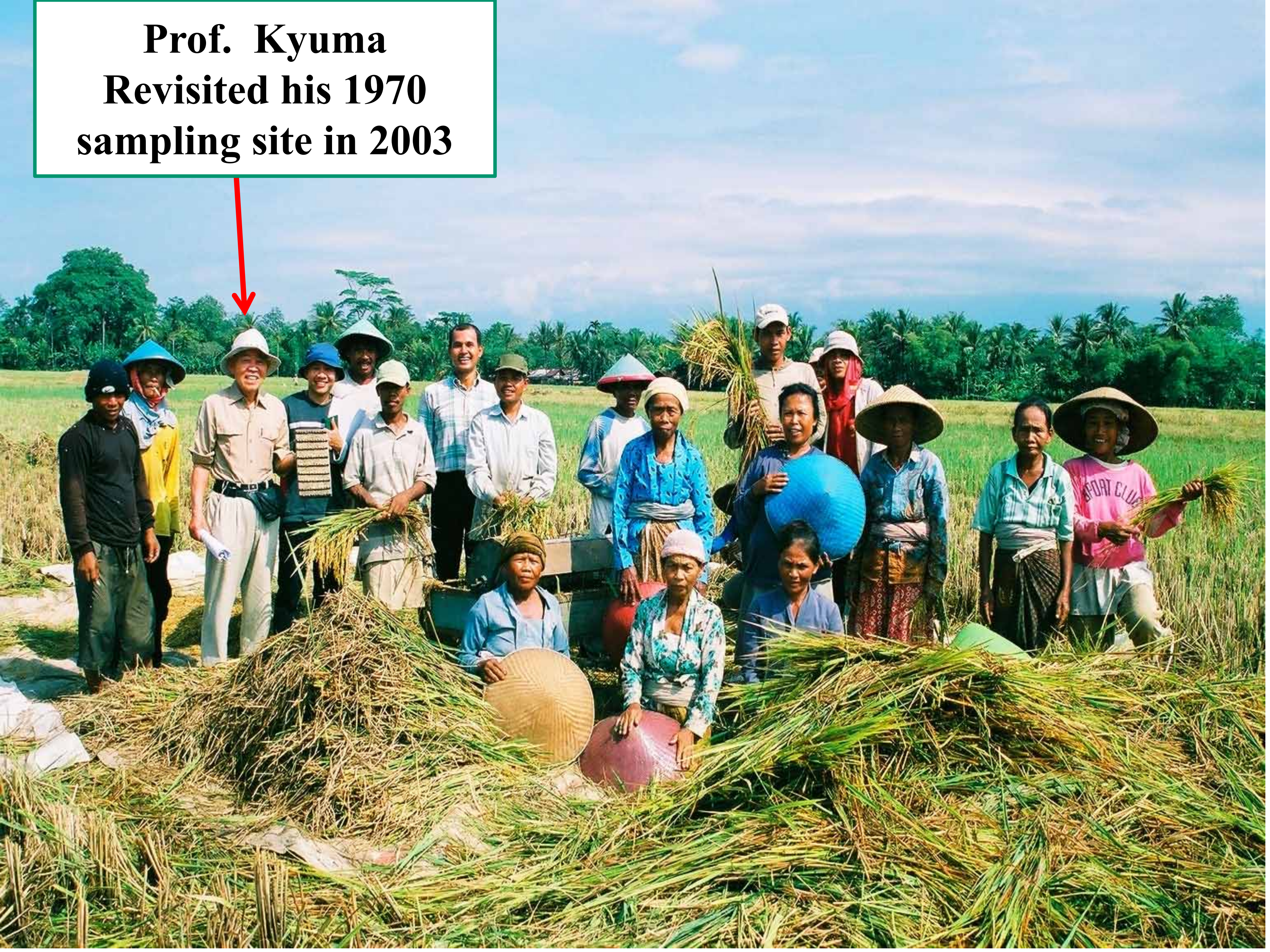
Organic matter % in Sawah soils in comparison with soils in upland management (Mitsuchi 1970, 1974)



Soil Carbon Change: Carbon losses from all soils across England and Wales 1978-2003 (Nature Vol.437/ 8, September, 2005 p.245)

Sawah soil carbon change of Java, Indonesia, during 1970-2003, the Green revolution period (Darmawan et al 2006)




Prof. Kyuma
Revisited his 1970
sampling site in 2003


In 2003, Dr. Darmawan collected sawah soils from the same sites where Prof Kyuma surveyed in 1970

Table 3 Changes in total carbon and total nitrogen (Mg ha[-1]) content in the 0–20 cm and 0–100 cm soil layers in seedfarms and non-seedfarms from 1970 to 2003 in Java, Indonesia

	Seedfarm				Non-Seedfarm			
	0–20 cm		0–100 cm		0–20 cm		0–100 cm	
	1970	2003	1970	2003	1970	2003	1970	2003
Total carbon (Mg ha^{-1})								
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
Standard deviation	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})								
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
Standard deviation	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. *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$

Both C & N increased 30% per30 years during Green Revolution

Macro-scale watershed eco-technological mechanisms to support Sawah hypothesis II: Geological Fertilization of eroded top-soils and accumulation of nutrient rich water in lowland Sawah

Sustainable green revolution by sawah and SATOYAMA systems for combating Global warming: (1) efficient use of water cycling and conservation of soil fertility, (2) Ecological safe carbon sequestration by CDM, Bio-char and humus accumulation in sawah Soil layers, which will eventually transfer to sea floor, and (3) increase soil productivity by bio-char and humus accumulation

Micro-scale eco-technological mechanisms to support Sawah hypothesis II: Enhancement of the availability of N, P, K, Si, Ca, Mg, and micronutrients and quality carbon accumulation

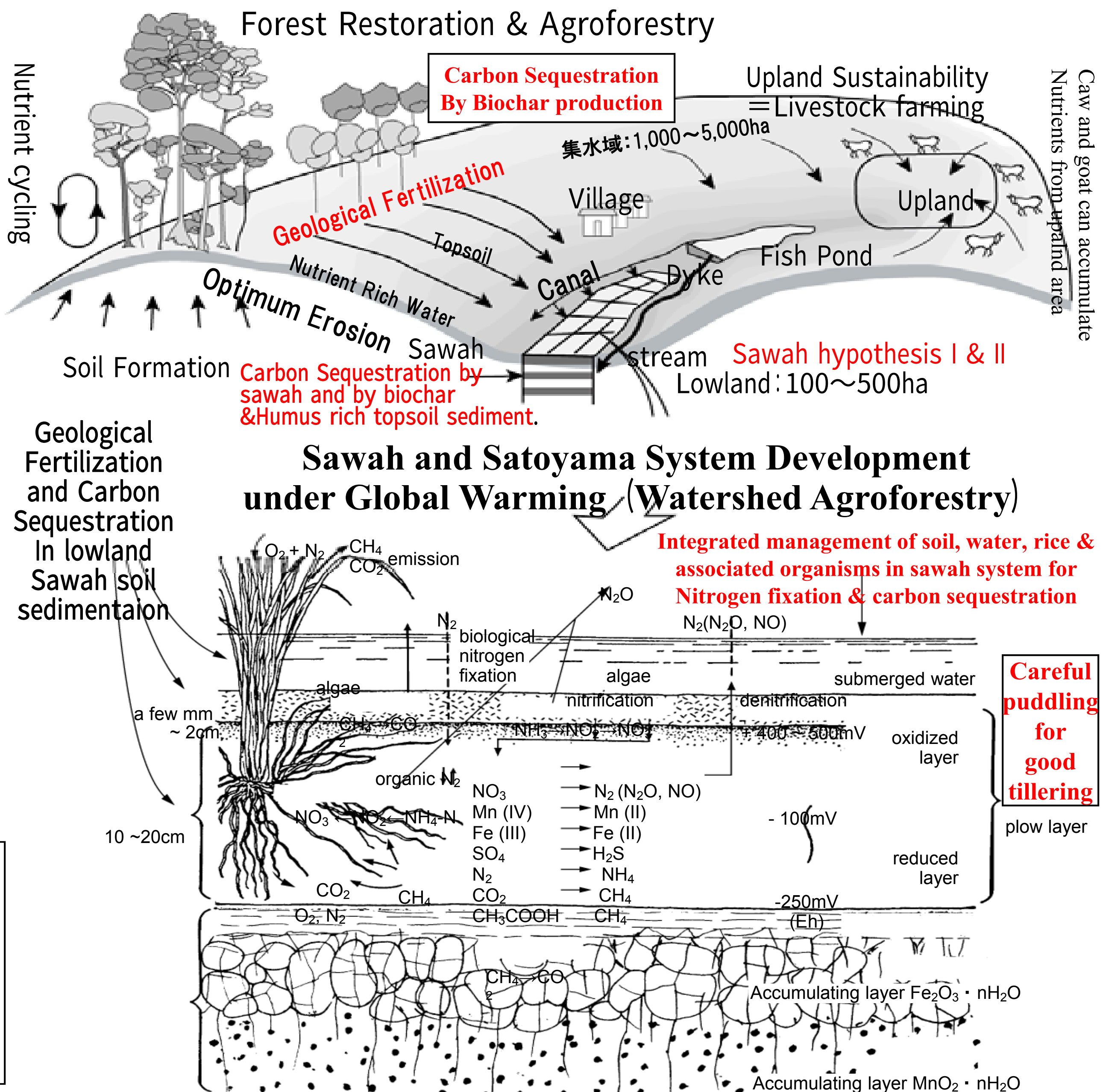
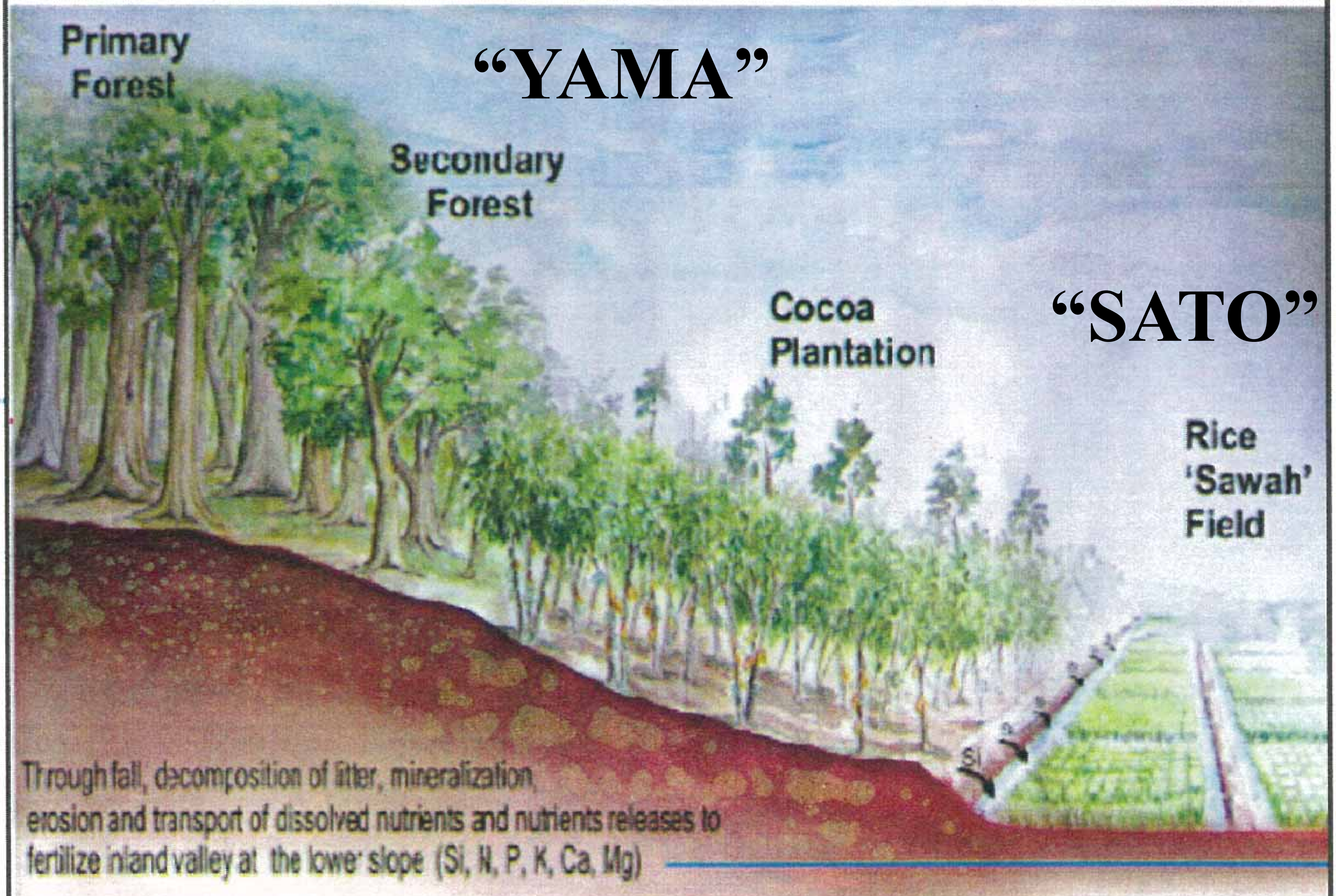
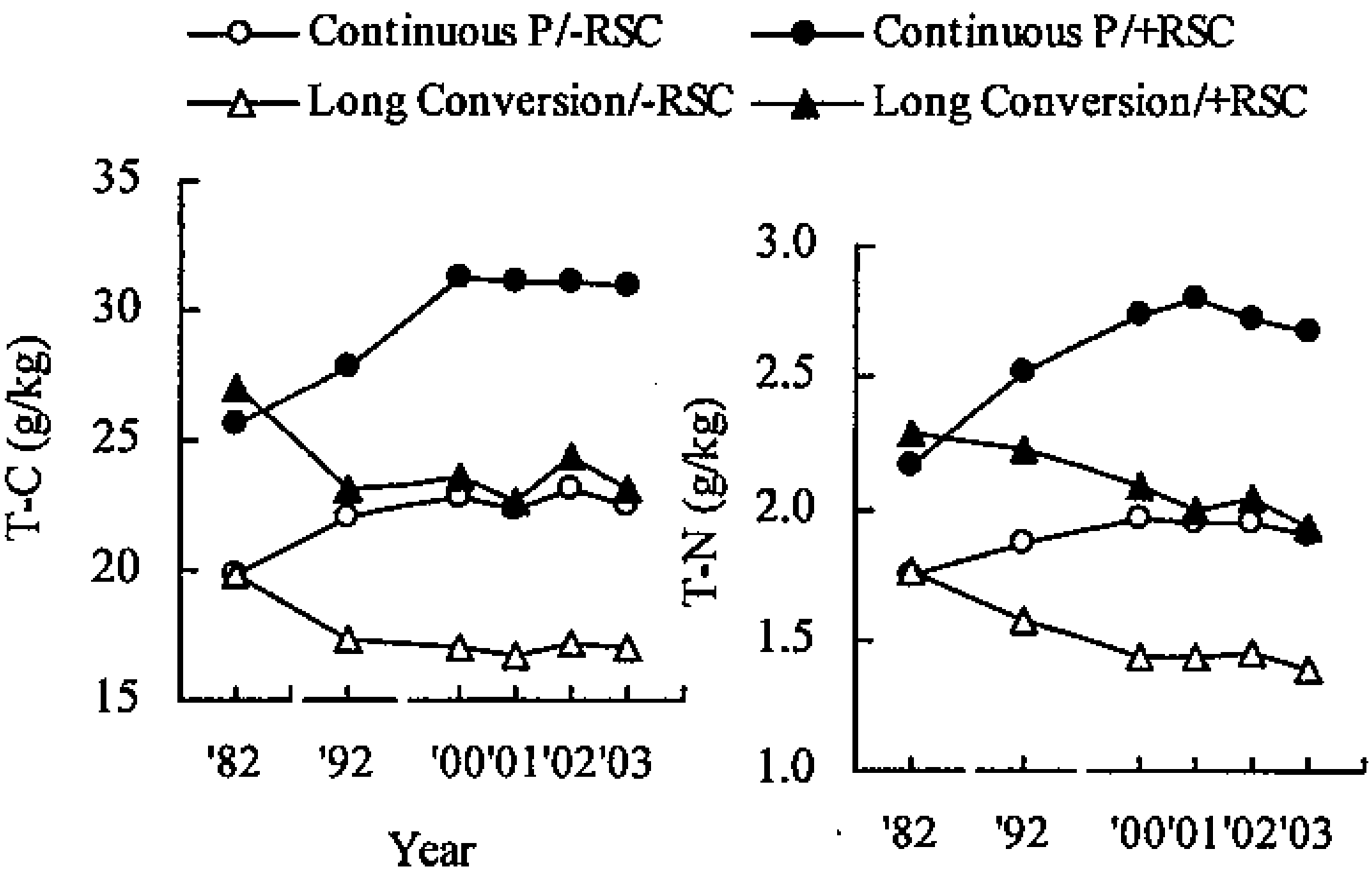


Fig. Sawah hypthesis (II) and creation of African SATOYAMA watershed systems to combat food crisis and global warming



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

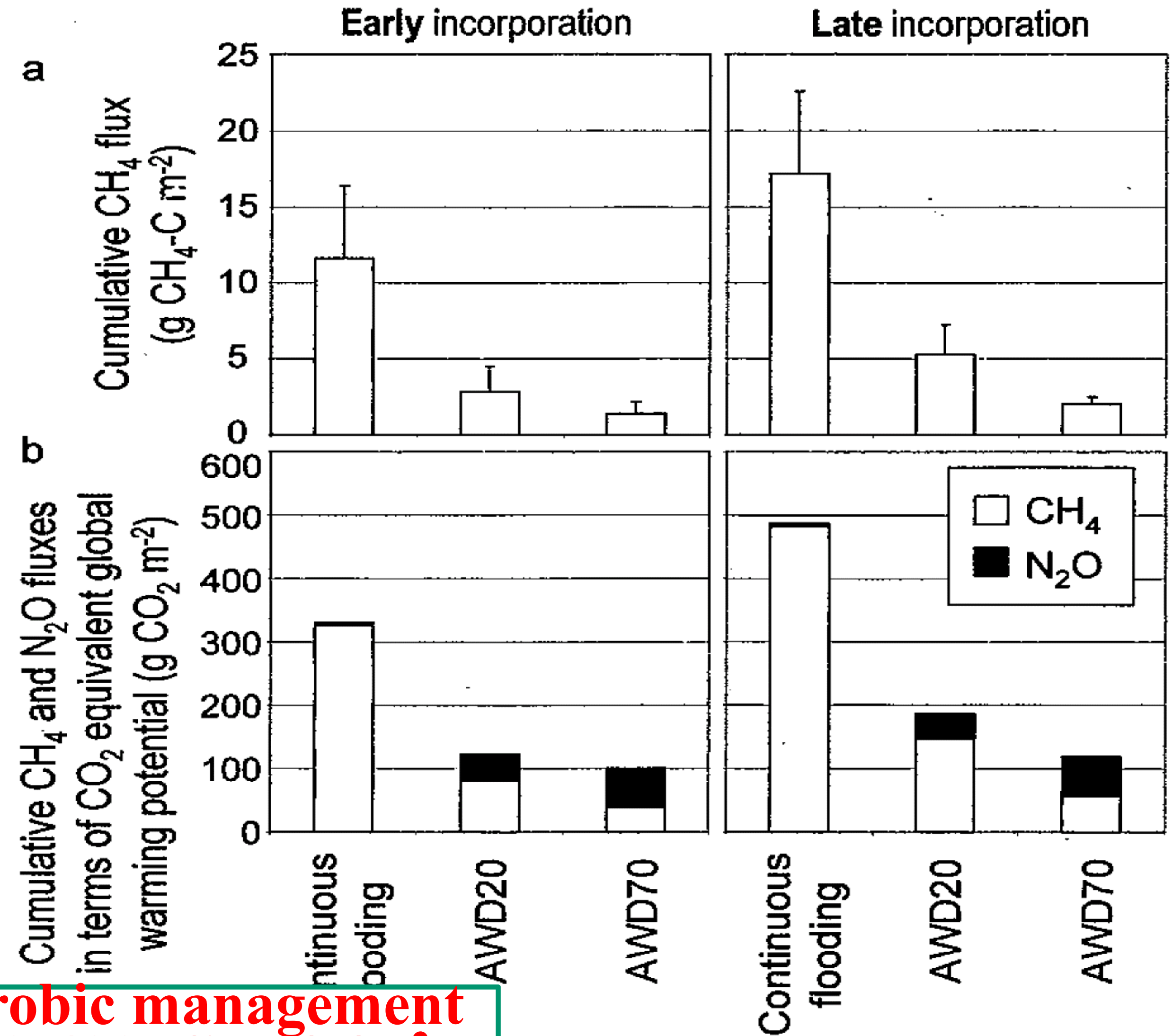

Nigeria Nupe's rudimentary Sawah system
THANK YOU FOR LISTENING



Upland/aerobic management reduce 50-100gC or 200-400gCO_2 /y/m^2

Fig. 5 Changes in total C and N contents of the soil in long-term upland conversion system. P, paddy; RSC, rice straw compost.

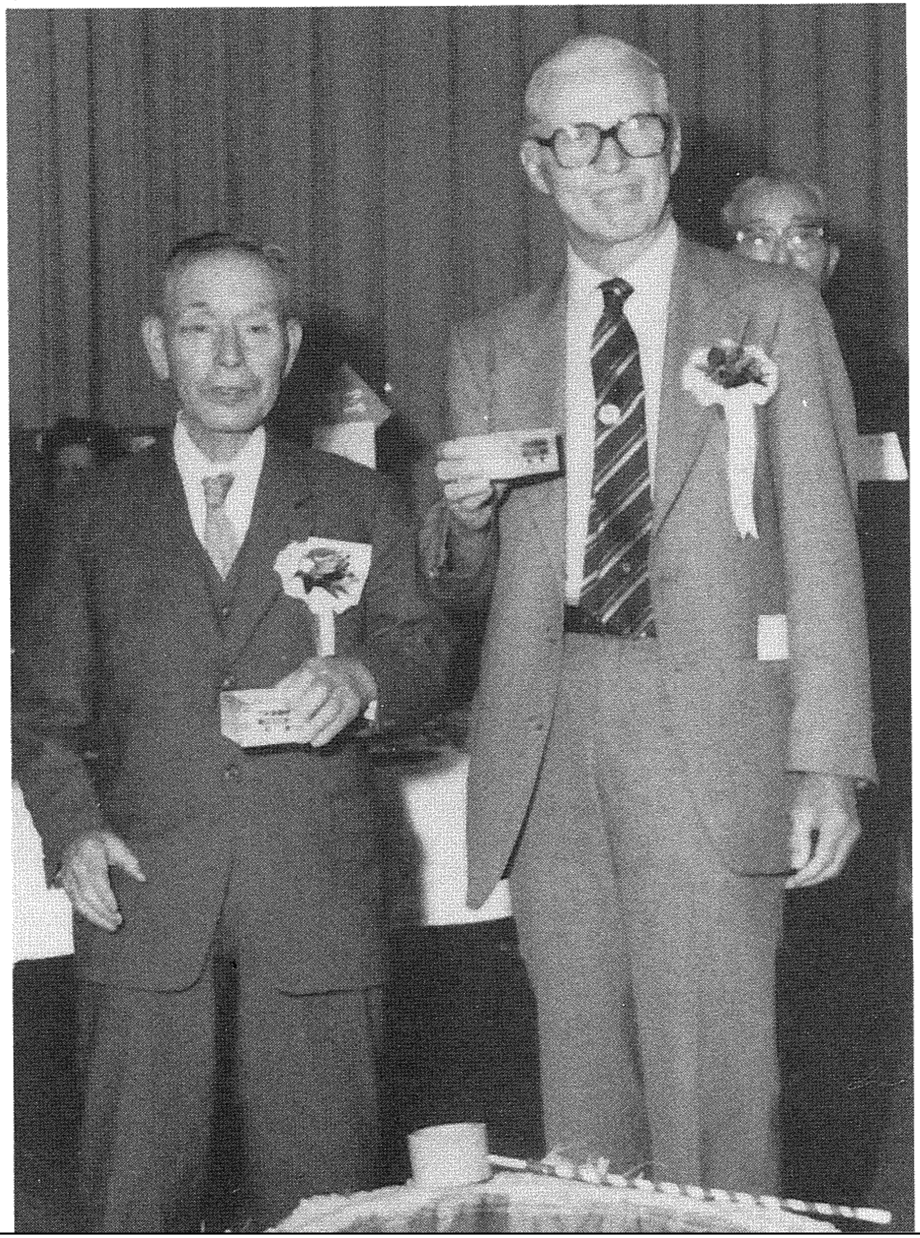
100gCO_2/m_2 is equivalent to 0.27ton C/ha 200g of CO_2 is equivalent to 0.54 g of C



Upland/aerobic management reduce 200-400gCO_2 /y/m^2

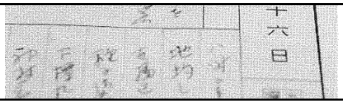
Figure 1. Cumulative CH_4 flux (a) and cumulative CH_4 and N_2O fluxes in terms of CO_2 equivalent global warming potential (b) during rice cropping period (January 29, 2007 (transplanting) – May 8, 2007 (harvest around this date); the conventional cropping period in dry season in the region). Bars indicate S. E. (only for **a**) (n = 3).

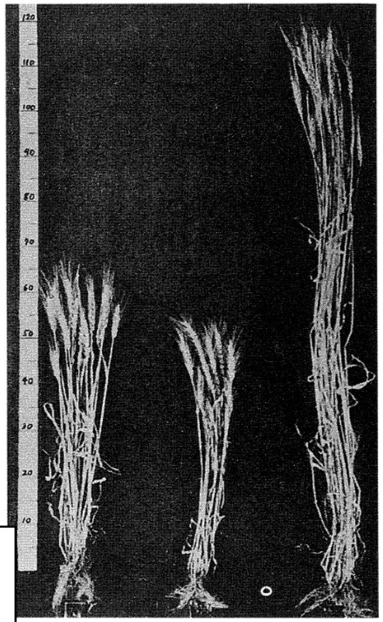
AWD20: irrigation under water potential-20kP(=2-3 days after water saturation）
AWD70:intermittent irrigation under water potential at-70kP(close to upland)



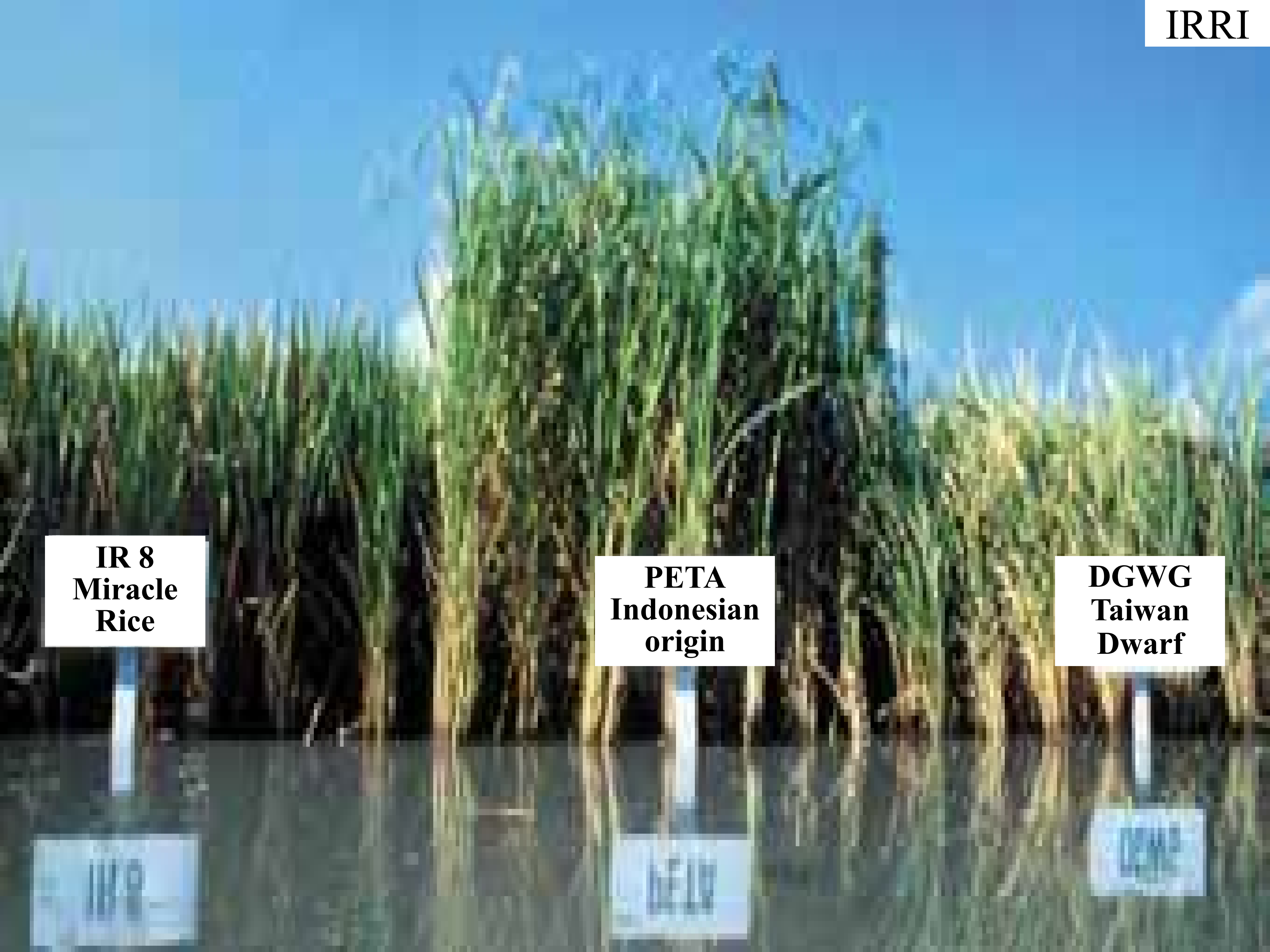
上／新品種を生み出すため、岩手県立農事試
験場では地道な小麦の栽培が続けられた

Right:Turkey Red
Center:
Fruit DARUMA
Left: NORIN 10
in 1935



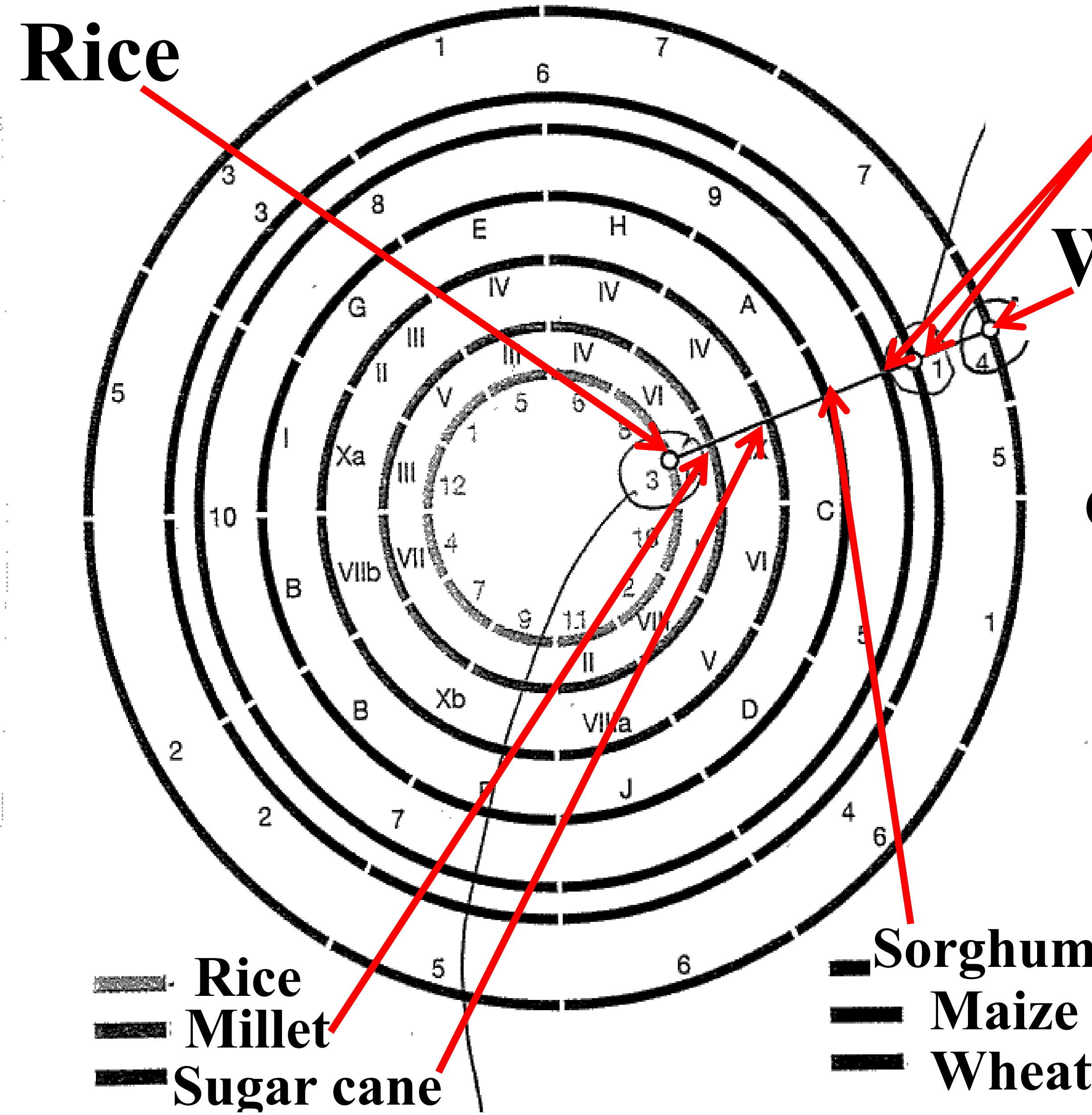


Dr.G. INAZUKA bred Norin 10 of wheat in 1935. The Norin 10 was collected by US occupied force in 1951. Dr. N. Borlaug bred, released 14 HYVs using Norin 10 in 1957. The start of CG center


IRRI
IR 8
Miracle
Rice
PETA
Indonesian
origin
DGWG
Taiwan
Dwarf

Left: traditional old variety

Right: Semi-dwarf high yielding variety (Sd1)



High Yielding Varieties for Green Revolution in Asia and Latin America have the same Gene, Sd 1. The Norin 10 was the first variety that expressed the Sd 1 character.

(Matsuoka 2004) **Sd1=Semi-dwarf 1**