

**Ministry of Agriculture
The Republic of Sierra Leone**

**Sustainable Rice Production Project
in the Republic of Sierra Leone**

Project Completion Report

**Annex 1:
Re-revised Edition of
the Technical Package on Rice Production**

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Technical Package on Rice Production (Re-revised Edition)

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Summary

- a. The re-revised edition of the Technical Package on Rice Production (TP-R) added to the previous edition new recommended rice cultivation techniques found effective or verified through the trials and field practices, especially sowing density in the nursery and water management concerning weed and pest controls. The Economic Evaluation part, i.e., Chapter 8, was also revised based on the current situation. Other parts remain the same in principle, containing techniques in land preparation, variety selection, seedling raising, uprooting and transplanting, harvest and post-harvest handling, fertilizer management, and water management. All the practices aim to create a better environment for the rice plant to thrive and to utilize applied fertilizer effectively and efficiently.
- b. To obtain a high rice grain yield, securing a better growing environment for rice plants is essential, particularly at the vegetative growth stage, as the grain yield is much influenced by the number of panicles per unit area, which is determined during the said stage.
- c. Two measures must be taken to enhance rice grain yield: (a) to improve the farming practices; and (b) to apply fertilizer. While both measures are necessary to obtain the target yield of 3 t/ha, the former is the prime measure. The effect of the latter will be little without taking the former.
- d. The TP-R includes land preparation, variety selection, seedling raising, uprooting and transplanting, weed and pest management, harvest and post-harvest, fertilizer management, and water management (see next page). All the techniques create a better environment for rice plants to thrive and utilize applied fertilizer effectively and efficiently.
- e. Fertilizer application could accelerate rice plants' growth, thereby enhancing the yield significantly. However, it is only applicable when improved farming practices are adopted. Pre-condition for practical fertilizer application is to ensure proper water-controlled condition. Quality development of IVS, including irrigation and drainage canals, bund construction, and land levelling works, is required for rice farmers to enjoy a bumper harvest.
- f. Improved farming practices, as well as fertilizer applications, should be made at the right time according to the growth of rice. A proper farming plan should be formulated, and a cropping calendar should be prepared to make timely farming possible.
- g. The use of pure seeds helps enhance yield. Rice seeds should be produced by the rice farmers themselves under the current situation in Sierra Leone, where quality seeds of various varieties are hardly available. Seed multiplication plots should be established at the farmer's rice field, and seeds of the target variety should be produced with unique practices.
- h. Rice farming should be a profitable business to sustain rice production. Improved farming practices should be applied first to enhance rice yield, which makes a profit, although the yield level will not reach the target of 3.0 t/ha. Fertilizer application is the next step to increase the yield further up to 3.0 t/ha.
- i. The following research trials should be carried out to clarify the constraints on yield increase and find ways to enhance the yield further in IVS:
 - (a) Periodical planting throughout the year with solar radiation measurement,
 - (b) Field trial on the effect of compost application on the nursery on the performance of rice after transplanting,
 - (c) Field trials on the effect of potassium application and intermittent irrigation on the mitigation of Fe toxicity in the rice plant,
 - (d) Field trial on phosphorus dose to amend P deficiency,
 - (e) Field trial on sulfur treatment, and
 - (f) Fertilizer trials on various combinations of nutrients.

Summary of Technical Package on Rice Production

No.	Farming practice	Important points
A.	Land preparation	<ul style="list-style-type: none"> • Timeliness of start preparation • Sufficient puddling • Proper land levelling and smoothening
B.	Variety selection	<ul style="list-style-type: none"> • Consideration of the variety's characteristics, especially growth duration and disease/pest tolerance.
C.	Seedling raising	<ul style="list-style-type: none"> • Use of quality seeds • Selection of proper nursery site (exposed area) • A proper size of nursery bed as to seed quantity (1 kg/10 m²) • When the fertilizer is applied in the main field, sowing density could be higher up to 2 kg/10 m². • Adequate amount of seed for the main field area (ca. 30 kg/ha) • Uniform sowing on nursery bed.
D.	Uprooting and transplanting	<ul style="list-style-type: none"> • Uprooting of two to three weeks old seedlings for transplanting • Careful and gentle uprooting and removal of soils from roots • Immediate transplanting of uprooted seedlings • Shallow transplanting (2-3 cm in depth) of two to three seedlings per hill • Uniform planting with 20-25 hills/m²
E.	Weed and pest management	<ul style="list-style-type: none"> • Timely weeding (first weeding at 2-3 weeks after transplanting, followed by occasional weeding depending on the degree of weed infestation) • Fencing and traps to prevent rice plants from being damaged by cutting-grass (cane rats) • Maintaining water in the field during the ripening stage, as well as clearing the surrounding area to prevent rat damage • Preparation of nursery in the backyard of the house, or put a cover on nursery bed until full germination to prevent bird attack • Control of host plants such as ratoons and volunteers of cultivated rice and wild rice (<i>Oryza longistaminata</i>) in which the African Rice Gall Midge survives in the dry season • Early planting before the peak rainy season, intermittent irrigation with a small quantity of water, and occasional drainage to control case worm • Well-balanced nutrient supply to control diseases, including brown spot.
F.	Harvest and post-harvest handling	<ul style="list-style-type: none"> • Timely harvest (at full maturity) to minimize loss • Proper drying before and/or after threshing for storage • Cleaning of threshing ground to avoid contamination with impurities, including small stones • Elimination of impurities through winnowing and cleaning
G.	Fertilizer application	<ul style="list-style-type: none"> • Recommended dose: N-P₂O₅-K₂O = 40-40-40 kg/ha • Two split applications: First with N-P₂O₅-K₂O = 27-27-27 kg/ha at puddling (just before transplanting); second with 13-13-13 kg/ha at panicle initiation (about two months before harvest time). • Uniform application throughout the field. • Avoidance of rain and dews when applied.
H.	Water management	<ul style="list-style-type: none"> • Relatively abundant water at puddling. • Low water level at fertilizer application • Low water level for several days after transplanting • Intermittent irrigation during the vegetative growth period • Relatively abundant water during the reproductive period • Water to drain about two weeks before harvest

1. Introduction

1-1. Concept (premise) of the Package

- 1) To increase crop production in a country, it is essential to raise the productivity level of farmers. It is particularly true when the crop is the staple food, and most of the population is engaged in farming. Rice production in Sierra Leone largely depends on subsistence farmers (Table 1-1). The average rice area per household is about 1.6 ha, and family members carry out the rice farming.

Table 1-1. Rice planting acreage and household composition of farmers in Sierra Leone (a).

Rice acreage (ha/HH)		Household (HH) composition	
Upland	0.7	Number of persons/HH	6.5
IVS	0.5	No. of persons in agricultural work/HH	2.8
Others (b)	0.3		
Total	1.6		

a) Interviewed survey on about 4,500 HHs. GoSL/WFP/UNDP/UNICEF/WHO/FAO (2006).

b) Boliland, riverine and mangrove swamp.

- 2) The Technical Package on Rice Production (TP-R) focuses on inland valley swamp (IVS) as target agro-ecology since IVS is distributed throughout the Country and utilized for rice cultivation by many small-scale farmers. Also, there is more room for enhancing the rice productivity in IVS compared to other agro-ecologies, including upland, mangrove swamp, boliland, and riverine. Rice production in upland is hardly enhanced with cultural improvement, and water control is barely possible without a considerable investment in mangrove swamps, boliland, and riverine grassland. In IVS, water can be controlled with human power to a certain extent: field improvement is likely to be sustained by the farmers' effort. The rice farmers in Asia have implemented such lowland development for at least several hundred years.
- 3) Most information herein is obtained in the Kambia district, where a JICA-supported technical cooperation project, "Sustainable Rice Development Project (SRDP)," was implemented for four (4) years between 2010 and 2014. Yet, the content is applicable all over the Country because the Project found no difference in the farming system or soil fertility between the Kambia district and other districts in various agro-ecologies, including IVS.
- 4) Under the current farming system in lowlands, including IVS, the rice culture is dominantly practiced under un-controlled water conditions, where no active farming work is performed except rough land plowing and transplanting until harvesting. The primary objective of the TP-R is to increase rice grain yield from about 1 t/ha to 3 t/ha with profit.
- 5) Because of the poor soil fertility owing to a geographical background, anthropogenic fertilizer application is essential to improve the rice grain yield. Although organic or chemical (inorganic or mineral) fertilizers are acceptable, the latter would be more practicable. With 40 kg/ha each of N, P₂O₅, and K₂O, a grain yield level of 3 t/ha can be attained. Pre-condition to realize the target yield is well-controlled water management practice, however. It should also be kept in mind that fertilizer is not a universal remedy and that its full benefits are gained only with good cultivation practices.
- 6) Fertilizer application promotes productivity as far as water is controlled. It is, however, not consistently profitable because yield response to fertilizer application is often not large enough to recover the fertilizer cost under the current socio-economic situation. Continuous efforts to improve the rice cultural practices are required to make rice farming a business.

- 7) The impact of the fertilizers on the environment will be minimal because the fertilizer rate at 40 kg/ha each of N, P₂O₅, and K₂O recommended in the TP-R is relatively small.
- 8) The principle of rice cultural practices in the TP-R is applicable to large-scale farming and small-scale farming on fringes (a few percentages each of the areas) of mangrove swamp, boliland, and riverine grassland. In fact, for the latter, farmers currently grow rice in a similar manner as in IVS. Yet, the large-scale farming itself is out of scope to the TP-R because the investments in mechanization and business-oriented farm management, etc., are not comparable to subsistence farming.

1-2. Simulation of grain yield evolution

Current rice grain yield in Sierra Leone is estimated at around 1 t/ha (See 9. Appendices, A1.6-1). The TP-R recommends improved cultural management, especially for short and medium growth duration cultivars (Table 1-2). Grain yield at 2 t/ha is feasible by applying improved cultural management (Fig. 1-1).

Table 1-2. Some key points of farming activities in improved (recommended) culture methods (a)

Item	Conventional	Improved	(unit)	Contribution to yield
Seedling age	4-10	2 - 3	weeks	Large
Planting depth	5-15	2 - 3	cm	Large
Hill density	15-50	25	hills/m ²	Fairly
Weeding	none	2 - 3	weeks after T/P	Large
No. plants	5-10	2 - 3	per hill	Marginal (b)
Water management	none	properly		Large

T/P: transplanting

- a) Most effective to cultivars with growth duration of 100-120 days.
- b) Greatly contribute to the seed saving.

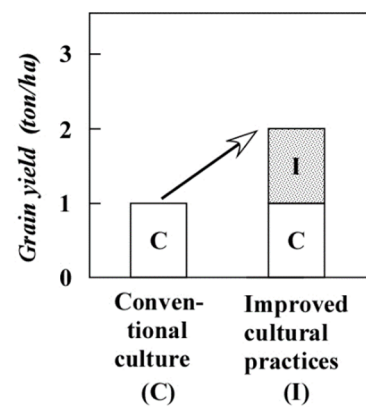


Fig. 1-1. Schematic illustration of rice grain yield increase by cultural practice improvement

Fertilizers per se barely enhance productivity when applied in the conventional farming system (Fig. 1-2, left). Old-age seedlings do not develop a sufficient number of tillers (panicles at full maturity, the dominant yield component), and fertilizers are flown away when applied shortly before heavy rain without well-protected bunds (dikes) for instance.

Reasonable water control is a must for fertilizer application because rainfall reaches nearly 2,000 mm during the main rice cropping season in Sierra Leone. Yield increment by fertilizer application at 40 kg/ha each of N, P₂O₅, and K₂O will be 1 t/ha, whereas grain yield can reach about 3 t/ha with complete crop management conditions (Fig. 1-2, right).

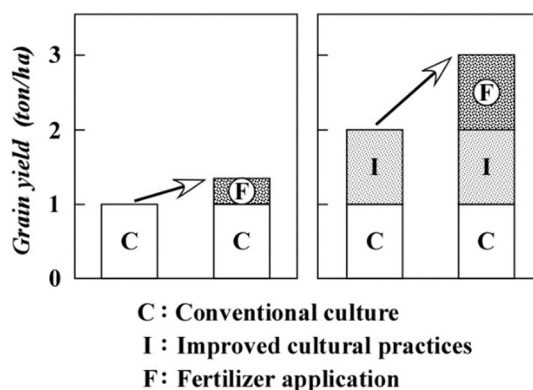


Fig. 1-2. Schematic illustration of fertilizer effect on grain yield

2. Growth Development and Yield Components

2-1. Growth stages of rice plants

Rice plants sown or transplanted in the field develop a new leaf successively about every four days under tropical lowland conditions. They produce tillers, grow taller, and increase their body weight (Fig. 2-1). A turning point in this development occurs with panicle initiation (about 30 days before heading or flowering) (Fig. 2-2), after which the plants develop their panicles or reproductive organs to be consumed by humans for food. Hence, the growth of rice plants consists of vegetative growth, reproductive growth, and ripening (grain filling) stages. It should be noted that the growing period of the latter two is about one month each irrespective of cultivars with different growth duration.

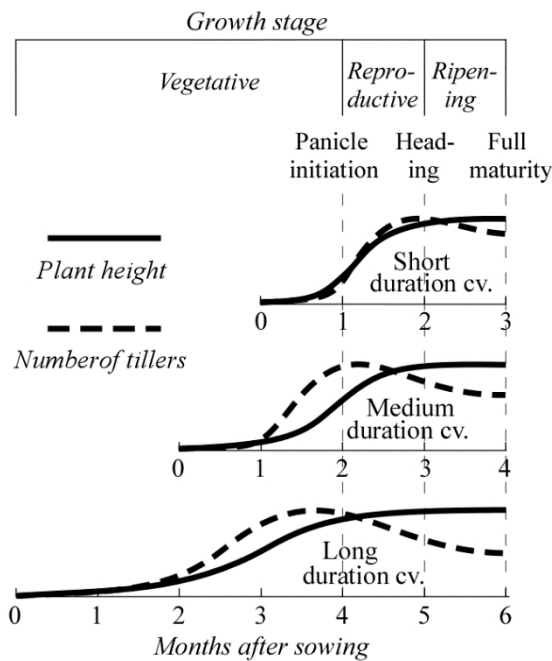


Fig. 2-1. Growth stages of various cultivars with different growth duration.

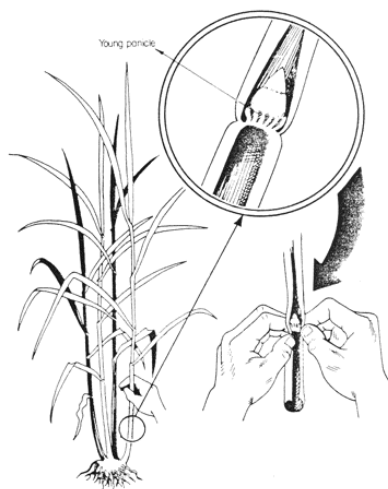


Fig. 2-2. Rice primordium shortly after panicle initiation (Vergara, 1992). Flowering occurs about 30 days after the start of panicle formation in the tropical lowland condition.

Crop management refers to what human beings can provide the crops with favorable conditions to grow healthily and strongly, resulting in a high yield. Farmers should carefully observe any changes in the plants throughout their growth stages and take necessary action timely so that the goal can be attained.

2-2. Yield components

In this text, “grain” refers to rough rice (brown rice with the husk). The final product obtained from the rice plants is simply a mass of grains. Still, it biologically consists of several components: e.g., the number of panicles per hill and the number of grains per panicle.

The developmental process of the yield components has been extensively studied and documented, including the relationships among components and the effects of environmental factors on the components. External factors like solar radiation, water, and nutrient affect the development of respective yield components at a specific growth stage (Fig. 2-3).

Favorable condition positively promotes the numbers of tillers and spikelets per panicle. In contrast, grain size (often expressed as 1000-grain weight) and ripened percentage (grain-filling ratio) are negatively affected under unfavorable conditions such as low solar radiation and poor nutrient status. The former is limited because it is bounded with a glume size formed before heading, and the latter is 100% at maximum. Above all, it is understood how great the number of tillers contributes to the grain yield.

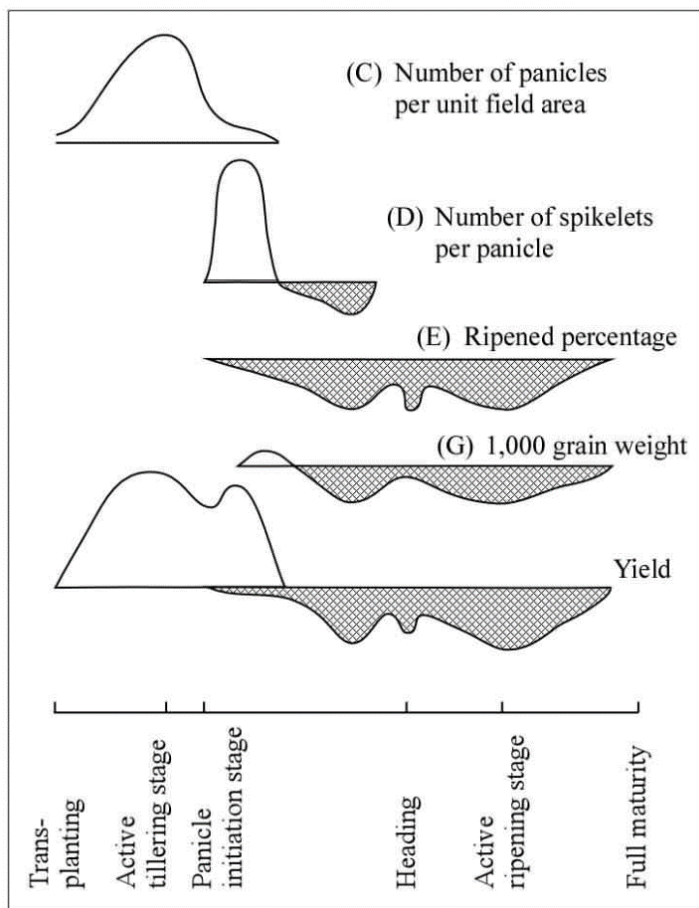


Fig. 2-3. Schematic diagram of the processes of the yield and yield component development in rice plants (Based on Matsushima, 1959). The positive (blank areas) and negative (hatched areas) represent the effects of the environment.

In yield analysis, various components and combinations of these components are used. Some examples are presented below.

1) Relationship between the grain yield and the yield components is:

$$\begin{aligned}\text{Grain yield} &= A \times B \times D \times E \times G \\ &= A \times B \times F \times G \\ &= C \times F \times G\end{aligned}$$

where,

Grain yield: Grain weight per unit field area

Yield components (with an example value)

A: Number of hills per unit field area: e.g., 20 hills/m² = 200,000 hills/ha

B: Number of panicles per hill: e.g., 6 panicles/hill

C: Number of panicles per unit field area = A x B = 120 panicles/m²

D: Number of spikelets per panicle: e.g., 100 spikelets/panicle

E: Proportion of filled grains: e.g., 0.85 (85% of the spikelets matured into filled grains)

F: Number of filled grains per panicle = D x E = 85 grains (filled)/panicle

G: 1,000-grain weight: e.g., 25g/1,000 grains = 0.025 g/grain = 25 mg/grain

2) In actuality, the grain yield = A x B x F x G = 20 x 6 x 85 x 0.025

$$= 255 \text{ g/m}^2 = 2.55 \text{ t/ha} \cong 41 \text{ bu/acre}$$

Note that the unit of the bushel (bu) for grains (rough rice) is converted at the official rate of 25 kg/bu (See Section A3. Conversion table).

3. Rice Culture Management

3-1. Land preparation

Land preparation works include slashing, clearing, plowing (digging), puddling, and leveling.

3-1-1. Site selection

In the IVS ecology, farmers grow rice in the same fields every year and thus understand relative soil fertility in the area and the potential problems (e.g., weed infestation, pests, and flooding). In case rice is grown in a new area, flat low land should be given priority, and necessary water control facilities such as drainage canal, bunds, peripheral canals, a head bund, should be constructed.

3-1-2. Canal maintenance

During the dry season (or before the rainy season starts, in Feb. - May), maintenance and/or rehabilitation of drainage and peripheral canals should be done to properly control water in the lowland. Drainage canal should be dug to remove sediments deposited during the last rainy season and secure the drainage capacity. Peripheral canals should also be dug to restore the discharge capacity and heighten the bund not to allow run-off water to overflow the bund.

Destroyed and/or weakened parts of bunds are rehabilitated and strengthened. When new soils are piled, they should be moistened with water and compacted well to strengthen them.

3-1-3. Slashing the vegetation and weed handling

The traditional method of land preparation practiced by farmers is acceptable. The vegetation in the field is slashed (brushed out), dried and then burned. If there are early rains or the slashing is delayed, the slashed weeds are removed to an area outside the main field or heaped at designated spots.

Note on weed handling

Weed control plays a key role in rice cultivation regardless of whether it is in the uplands or lowlands. Burying organic matter (e.g., weeds), nutrients are released through decomposition. However, this could only be applied under well-aerated conditions, as in upland cultivation.

Under oxygen-deficient conditions as in the case of submergence, the decomposition of organic matter leads to an increase in iron in the soil, which the rice plant can absorb (as ferrous is converted into ferric iron), especially when there is a deficiency of minerals in the soil.

A healthy rice plant can tolerate a certain level of iron since it actively expels ferric iron. When the ferric concentration in the soil exceeds the threshold or when the nutritional conditions of the plant are unfavorable, however, the plant will suffer from iron toxicity since this is prevalent in many lowlands, especially in IVS areas.

Drainage helps to wash out and oxidize ferric iron, but it is difficult to drain water from fields in the lower areas of lowlands and this requires lengthy and laborious work. The farmers should try to remove as many of the weeds from the main field as possible to keep them from being mixed into the soil and prevent iron toxicity where it is expected.

3-1-4. Plowing (digging)

The plowing practices currently adopted by the farmers are acceptable, in which soils are plowed using a long-handled large hoe designed for the heavy clay soils in the area. Deep plowing (about 20 cm deep) is

recommended, although it is often difficult to plow beyond 10 cm deep with manual plowing. Because plowing is the hardest work and is time-consuming, the main field should be plowed before sowing in the nursery.

Use of cattle for plowing should be promoted. Work oxen are common in a part of Samu and Mambolo chiefdoms, Kambia district. Mechanization for plowing by tractor and power tiller is costly, especially in maintenance. Government has supported it with heavily subsidized scheme (Spencer, 1981).

Plowing in mangrove swamp

In the mangrove swamp areas, the rice fields should be plowed well before nursery preparation starts to allow sufficient time for any accumulated salts to be washed out of the soil by fresh water; either rain or river.

3-1-5. Puddling and field flattening (smoothing)

Sufficient puddling is essential for shallow planting (Fig. 3-1) that allows first the new roots and then the tillers to develop rapidly and vigorously. For efficient transplanting, large clods should be broken into small pieces until they become like mud. However, proper puddling is rarely observed in farmers' fields.

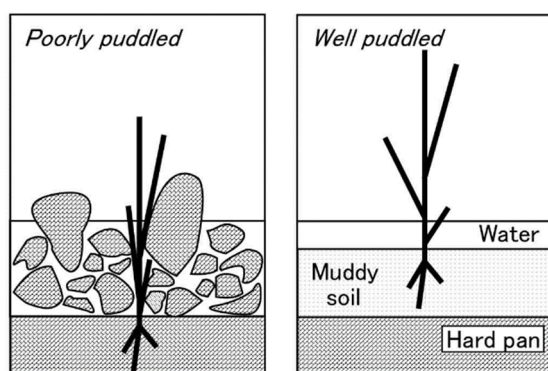


Fig. 3-1. Poorly and well puddled lowland rice fields. Note: Shallow transplanting is possible only when the main field is well puddled and flattened.

Farmers generally stop puddling after breaking the large clods (20 to 40 cm) into smaller clods (5 to 20 cm): They call this activity 'turn-over'. Some farmers do better by stamping the clods to further break them down into mud over the spot (a few square meters).

Land flattening (smoothing or leveling) is done with flat rake made of wood. The leveling work together with good puddling creates uniform environment in terms of water depth and nutrient supply so that the planted seedlings grow uniformly in the field.

3-2. Cultivar selection

- 1) One should bear in mind that there is no perfect cultivar (variety) in the world. The main reason is that rice plants are grown in diverse condition. High-yielding cultivars are often susceptible to diseases and deep flooding, for instance. Rice scientists actively work on releasing an almighty cultivar, but have not yet succeeded and may be never in future. Release of a tolerant cultivar and pathogen degeneration form a vicious cycle.
- 2) To secure stable and better production, the primary category of cultivar selection would be growth duration, disease tolerance follows, and third might be palatability.

As for growth duration, photoperiod-sensitive, long growth duration cultivars are selected when one expects flooding for a certain period: ROK 10 is one of such cultivars, for instance. These cultivars well tolerate deep water owing to a tall-stature and possess an advantage in harvesting after the end of rainy season.

Because the majority of rice fields are not equipped with water control facility and thus water is a primary limiting factor in the dry season cropping, cultivar selection is made in accordance with water available period. In many cases, the only choice will be a short duration cultivar, especially in IVS with semi- or none perennial stream.

- 3) Cultural management differs according to cultivars, especially with their growing period. Strong photoperiod-sensitive cultivars possess long duration of the vegetative growth and generally grow tall, so that some moderate, stable yield will be obtained without full care of cultural management. Such cultivars will sustain against deep planting of old seedlings and even competitive to weeds. They will tolerate to prolong flooding too.

In contrast, when one selects modern improved cultivars, he or she will fail to obtain high yield without full care of crop management practices like shallow planting with young seedlings and with proper water control. The main reason is that most of such cultivars are characterized with a limited period of the vegetative growth and with short stature. Nursery period becomes critical when short duration cultivars like 90-100 days are used, because the vegetative growth duration lasts only 30-40 days. When seedlings stay in a nursery for one month or longer as commonly practiced with indigenous (local or traditional) cultivars, plants initiated panicle formation soon after transplanting. Under such a condition, the number of spikelets becomes as small as 4-10 in each panicle (Photo 3-1).



Photo 3-1. Unexpected flowering of short duration cultivar (Eitori: 3 months) at two weeks after transplanting. One-month-old seedlings were transplanted. (Mapilla/Port Loko)

- 4) Some selected cultivars growing in the country are summarized in Table 3-1. Unfortunately, their coverage of planted area, genetic background and such important traits as details of plant type, lodging resistance, disease tolerance, grain type, degree of shattering, seed dormancy, etc., are not available. Yet, we understand that farmers well observe the plant characteristics of various cultivars and select rational cultivars according to the topographical and climatic condition (Table 3-2).
- 5) The number of tillers is generally 3-5 per hill regardless of cultivars in the conventional farming system. Yet, majority of cultivars growing in Sierra Leone possess a high capacity of tiller development in general. ROK 5 and ROK 10, for example, easily produce 50-60 tillers/plant under favorable condition (Fig. 3-2). Because the number of panicles is a dominant factor to obtain high yield among various yield components, it is the most crucial step to develop a large number of tillers at the early growth stages. Light and nutrient are cardinal points how vigorously rice plants are able to develop tillers.

Table 3-1. Selected rice cultivars grown in various regions of Sierra Leone (a).

Cultivar	Region (b)	Agro-ecology (c)	Planting years	Growth duration (month) (d)	Plant height (cm)
<i>Indegeneous (local) cultivars</i>					
Bako	N	Upland	100+	5	-
Benbe	S	Upland	100+	5	-
Beyaya	N	IVS	100+	5	-
Bongbo	S	Upland	100+	4	-
DC (Pa DC)	N	Upland	100+	6	-
Fei	S	Upland	100+	4	-
Gawai	S	Rv	100+	6	-
Kambame	S	Rv	100+	6	120
Kayankalia	N	IVS	100+	6-7	-
Kogbatei	S	Rv	100+	6	-
Kpenei	S	Rv	100+	6	-
Kulma	N	Boli	100+	6-7	-
Layana	N	IVS	100+	7-8	-
Pakailahun	N	IVS	100+	6	120
Parmoi	S	Upland	100+	4	-
Patei	E, S	IVS	-	5-6	90
Quatikandor	N	IVS	100+	5-5.5	150
Sinkariyana	N	IVS	100+	5	-
Soronkadi	N	IVS	100+	4-5	85-100
Wusie	E, S	IVS	100+	4-6	90-150
Yagbassay	N, E, S	IVS, Upland, MS	100+	4-5	60-100
Yainkendeo	E	Upland	100+	5-6	100-130
Yaraduca	N	IVS	100+	7-8	120-150
Yornjorwa	E	IVS, Upland	100+	6-7	110-120
<i>Improved/Semi-improved cultivars</i>					
					Rv
Butter cup (e)	N	IVS	10	3.5	110-130
CP4	S	IVS, Boli	30	6-9	-
Indochina	N	Rv, Boli	30	6	150-200
Kori-Korie	N	Upland, IVS, Boli	2	4	60
LAC 23	E, S	Upland	40-50	4-5	120-150
Nerica L19	N, E, S, W	IVS	3-5	4	80-120
Pakiamp (f)	N, E, S, W	Upland, IVS, Boli, MS, Rv	10	4-5	110-150
CCA (g)	N	IVS	-	3.5	80
ROK 3	N, E, S	Upland, IVS, Boli, MS	30	4.5-5	100-120
ROK 5	N, S	IVS, MS, Upland	30	4-5	130-150
ROK 10 (h)	N, E, S	MS, IVS, Boli, Rv	30	5-6	130-150
ROK 14 (i)	W	IVS	30	4	120
Sinoa	N	IVS	50 ?	3.5	-
Yeffin	N	IVS	2	3.5	120-140

a) Most information collected during the training on TP-R for MAFFS staff by SRDP/JICA (2014). b) N: Northern, E: Eastern, S: Southern, and W: Western. c) IVS: inland valley swamp, Boli: boliland, Rv: riverine grassland, and MS: mangrove swamp. d) Growth duration of photoperiod-sensitive cultivars vary with planting season. e) Synonym: Patele. f) Locally called as Rizis in the east. g) 'Chen-chu-ai'. Synonym: Patheden. h) Synonym: Tonsor Kayrain and Gbasnin in the north. i) Formerly called as Mange 2.

Table 3-2. Reasons for cultivar choice (a).

Reason	Reason
<i>Growth trait</i>	<i>Advantage</i>
High tillering ability	High grain yield (i)
Short duration (b)	High GY without fertilizer
Lodging resistance (c)	High yield in marginal, infertile soils
Tolerance to deep flooding	High tillering (large number of panicles)
Stable harvesting time (d)	Tolerance to flooding
<i>Abiotic resistance</i>	Resistant to lodging
Resistant to diseases	Tolerance to salinity
Resistant to insect damage (e)	Tolerance to pests
<i>Grain quality</i>	Resist. to rice blast
High palatability (tasty) (f)	Resistant to diseases
High market price	Resistant to rats
Red rice	high palatability
High filled grain (g)	Good quality overnight in cooked rice
	<i>Disadvantage</i>
a) See Table 3-1 for information source.	Fertilizer need for high yield
b) The item might contradict to (c), but it does not: there are both photo-sensitive and non-sensitive cultivars.	Susceptible to lodging.
c) Some cultivars are susceptible to lodging.	Susceptible to pests
d) Regardless of planting time due to strong photo-sensibility.	Susceptible to rice blast
e) e.g., gall nudge.	Susceptible to case worm
f) Grow for home consumption while growing improved cultivars for selling.	Susceptible to weeds
g) Might be related to low yield due to a small number of spikelets.	Susceptible to rats
	h) Several reasons contradict each other between advantage and disadvantage.
	i) Called as business rice due to poor palatability.

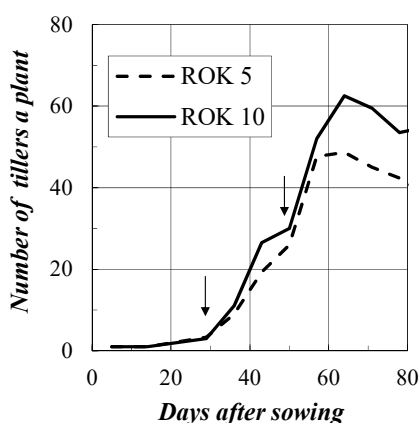


Fig. 3-2. Examples of tiller development capability in selected cultivars (pot culture) (ADPK, 2008).

Arrows show the time of top dressing at 0.3 g/pot each of N, P₂O₅ and K₂O. No basal fertilizer was applied. Note that fertilizer supply was controlled not to develop excess tillers.

6) Several cultivars differed in plant traits are always recommended to grow in a season as some farmers practice. The practice will help mitigate possible risk suffering from climatic (especially rainfall) and hydrological fluctuation, because majority of rice fields currently lies under the poor water control. Combination of short, medium and long duration cultivars is advised. The area to be planted with cultivars differed in growth duration might be split equally or unevenly: their proportion totally depends on the environmental factors and the farmers' strategy. The result will greatly help the yield stability and lessen the hunger period too. If there is any extra production in a lean season, farmers could sell it at higher price.

- 7) Many cultivars possess the ability to develop sufficient number of tillers as far as nutrient status is favored. In this respect, majority of current cultivars hold the potential to produce grain yield at 4-5 t/ha.
- 8) Farmers often introduce exotic cultivars from neighboring villages and even from other regions/countries. Newly introduced cultivars should be planted in a small scale, being not in a large scale, at the first year, even though such cultivars well performed in the original place. Carefully watch the plant growth, especially pest occurrence. Because it is endemic, the cultivar might suffer from unexpected disease break under the different environment. Similar cautious observation is also needed to find the growth difference between the rainy and dry season cropping. Gradual increase of planting area is strongly recommended for newly introduced cultivars.
- 9) A cultivar is often given with different names. ROK 10 is occasionally called as 'Gbas-nin' or 'Tonsor Kayrain', for example.
- 10) Farmers often claim that grain yield is revived by renewing a cultivar when the yield of the going cultivar declines. A casual sequence is hardly understandable. Nevertheless, we should pay a full attention on the issue that breeding of cultivars tolerant to low-nutrient conditions is widespread in the world (SRDP, 2014). The fields would become barren if the farmers keep growing tolerant cultivars. Such cultivars gobble up what little nutrients remain in the soil, and eventually all the nutrients will be exhausted. Therefore, careless introduction of low-nutrient tolerant cultivars should be avoided in coping with soils of low fertility.

3-3. Seedling raising

In the transplanting method, the first step in attaining a high yield is to raise healthy and sturdy seedlings. Such seedlings are ready to extend new roots into the soil of the main field with sufficiently accumulated carbohydrate and mineral nutrients, and autonomous growth will start within a few days after transplanting. Excessive elongation of the shoots (etiolation) should be avoided, because etiolated seedlings are lacking in nutrient accumulation in their body even though they grow tall. Etiolation is stimulated with dense planting, prolonged growth and shade (weak sunshine).

3-3-1. Seed selection

Seeds with high purity are obtained through sorting out. Seeds of weed and other rice varieties are eliminated. Seeds of the target variety are discriminated from those of mixed cultivars by their color, size, shape, own length, etc. Immature seeds are also eliminated. Yet, this procedure is unable to eliminate seeds with different plant traits like growth duration and height. The best and the first approach to obtain pure seeds is complete roguing in the seed multiplication field, as explained later (6. Seed Production).

Fully filled grains are selected with water. Soaking seeds in large quantity of water in a bowl or bucket, one can easily eliminate floated (sterile or unfilled) grains. Use of salt solution is the most recommended method. Specific gravity of solution at 1.13 g cm⁻³ (2.1 kg of table salt dissolved in 10 L of water) will select fully filled seeds.

3-3-2. Germination test

The germination rate of seeds should always be tested to estimate the quantity of the seeds needed and to evaluate their viability. The rate should preferably be higher than 80%. If it is less than 80%, it is advisable to discard the stock and find better quality seeds. If another seeds are unavailable, no alternative remains: one ought to use those seeds considering low germination percentage. Irregular germination and growth is frequently observed with those seeds.

A germination test is performed as:

- a) Place a sheet of clean absorbent paper or cloth in a shallow container (about 10 cm in diameter or square);
- b) Select 100 seeds randomly from a stock and spread them evenly on the paper or cloth in the container;
- c) Pour a sufficient amount of water for the seeds to become soaked and cover the container with any material that prevents excess evaporation;
- d) Leave the container in a room for 4 to 5 days or 1 week at maximum; and,
- e) Count the number of germinated seeds in the container.

Transplanting and direct sowing

Lowland rice culture in Sierra Leone is practiced both with transplanting and direct sowing methods. Small-scale farmers mostly adopt the former in all agro-ecologies, including mangrove swamp, and do the latter in very limited cases. The greatest advantage of transplanting method is relative easiness in weed control, and wide adaptability to irregularity level in field surface and seed saving follow.

In contrast, large-scale, mechanized farming in boliland and riverain is mostly practiced with direct sowing. Well levelling of fields and full water control are essential to attain high yield under the direct sowing method. Because such fields are unavailable in the country, rice plants are often grown with deep water condition in the major growth stages: floating rice is not rare. Seeds in direct-sowing system are sown in dry land, being not in wet land. The present Package focuses on transplanting system, which is practiced by most farmers.

3-3-3. Nursery preparation

- 1) Dry and wet nurseries: a dry nursery is recommended for the rainy season cropping. Based on the observations of farmers' nurseries, various disadvantages of a wet nursery during the rainy season are noted, such as the frequent occurrence of submergence, diseases and seedling etiolation. A few farmers sow the seeds under water, but many farmers do so on the lower ground near lowlands. Such nurseries soon becomes saturated or submerged by rain or water seepage. They can be broadly categorized as a wet nursery. For the dry season cropping, a wet nursery is the only choice.
- 2) Nursery preparation: Since nursery preparation does not require much labourer, it should be started after plowing is completed. It will help avoid the risk of prolonged nursery period that may happen when land preparation is delayed.
- 3) Location: A site well exposed to the sun should be selected for the nursery. If the nursery is shaded, the seedlings will become etiolated.
- 4) Seed requirements and the nursery area: Assuming that the germination rate is 80%, the plant density is 25 hills/m², the number of seedlings is three per hill, the emerging (sprouting) rate in situ is 80%, and the 1,000-grain weight is 25 g, the quantity of seeds needed in order to cover one hectare (≅ 2.5 acre) of land is:

$$25 \times 3 \times 25 / (1,000 \times 0.8 \times 0.8) = 2.9 \text{ g/m}^2 = 29 \text{ kg/ha} \cong 30 \text{ kg/ha}$$

$$\cong 12 \text{ kg/acre} \cong 0.5 \text{ bu/acre}$$

Seed requirement is largely affected with the number of seedlings planted per hill (Table 3-3). The larger the number of seedlings per hill, the larger the seed requirement.

Table 3-3. Seed quantity required for transplanting seedlings in main field with various combination of 1,000-grain weight of seeds and the number of seedlings per hill (a).

Number of seedlings /hill	Seed requirement (kg/ha)			Nursery area (m ²) (b)
	1,000-grain weight (g)			
	20	25	30	
1	8	10	12	100
2	16	20	23	200
3	23	29	35	290
5	39	49	59	490
10	78	98	117	980

a) Calculated on the basis of 25 hill/m², 80% germination by incubation, and 80% emergence (sprout) in nursery.

b) Nursery area is applicable only to 2-3 week-old seedlings with $\pm 20\%$ allowance.

Note that seeding rate of one bu/acre (= 63 kg/ha) is widely adopted for lowland rice transplanting, which is the same as that for upland areas. However, this rate is too high since it is based on the number of seedlings for transplanting at a rate of 6 to 10 per hill. Transplanting 2 to 3 seedlings/hill is sufficient to produce the necessary number of panicles for a reasonably high yield. It should be kept in mind that one advantage of transplanting is to save seed requirement.

- 5) When the planned field area is large and transplanting cannot be completed within a few days, it is prudent to sow the seeds in the nurseries on different days according to the transplanting schedule. The first priority is to keep the seedling in the nurseries for just the right period, 2-3 weeks.
- 6) Nursery size: The information on the nursery size in Table 3-3 is for reference only, since the sprouting rate of seeds in nurseries is unstable. The sprouting rate is highly site-specific and is prone to be affected by the properties of the soil and climatic conditions. In general, a sparse density (wider nursery area for a given quantity of seeds) is favorable for the healthy growth of the seedlings since there is less competition for light and nutrients.
- 7) Seed beds preparation and sowing: For uniform sowing, the seeds are divided into two at a 1:2 ratio, of which 2/3 is sown first, and the remaining 1/3 is used to even out any uneven distribution of the seeds on the seed bed. The field is shallow-tilled or covered with light soils after the sowing.
- 8) Mulching: Mulching with rice straw, palm fronds, etc., for a few days after sowing is recommended to protect the seedlings from heavy rains, as has been practiced by many farmers. This practice also helps prevent bird damage and keep favorable humidity even though there is a dry spell.
- 9) Bird scaring: Birds should be scared away for a week or so, starting immediately after sowing.
- 10) Weeding: Timely weeding is advised as necessary. If the seeding rate is appropriate, regular weeding will not be necessary.

Fertilizer application to nursery

In general, fertilizer application to nurseries is not recommended although some dose of fertilizer may be applied to seedbeds. The use of fertilizer in the nursery should be carefully considered. Fertilizer application is acceptable when it is sunny but it should be avoided when cloudy days continue or the seedlings are growing in wet or shaded conditions. Under such conditions, the seedlings become etiolated and prone to diseases. The sole use of nitrogenous fertilizer is not recommended. Instead, NPK compound fertilizers (e.g., 15-15-15) should be used, if applied.

3-4. Transplanting

3-4-1. Seedling age

The recommended seedling age for transplanting is at 4th leaf stage on the main culm, when a plant starts to develop tillers (Photo 3-2). It corresponds to 2 to 3 weeks after sowing depending on temperature. The higher the temperature is, the faster the growth is. The seedling quality deteriorates if the nursery period is too long. If transplanted properly, healthy (sturdy) seedlings start to develop new roots within a few days at the latest and successively develop tillers from every leaf node. Thus, when healthy and active seedlings are transplanted, a sufficient number of tillers (eventually panicles) foretells a high yield at an early stage of growth.

Use of young seedlings is especially critical in short duration cultivars (i.e., 3 months). When old seedlings are used, plants emerge panicle primordia soon after transplanting. Such a practice induces plants to produce only a few number of spikelets (Photo 3-1) because plants are not able to produce a large number of spikelets due to limited time.



Photo 3-2. Rice plant at the 4th leaf stage. Note that the first tiller emerges at the 1st leaf node. The number indicates the order of the growth of the leaves on the main stem.

Note that a disadvantage of old seedlings is not applicable to traditional, photoperiod- sensitive cultivars (Fig. 3-3). Their vegetative growth duration is long enough to sustain active growth when they are planted in the early rainy season. This is the one of the reasons why farmers prefer to grow long duration cultivars under the conventional culture condition.

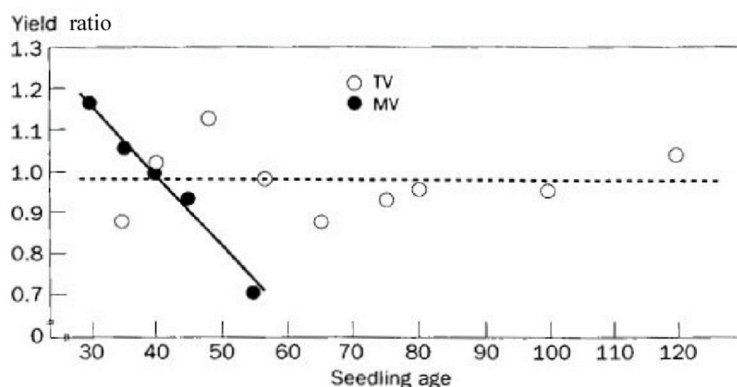


Fig. 3-3. Grain yield of traditional (TV) and modern (MV) cultivars, expressed as ratio of yield to yield of 40-d-old seedlings (Gines et al., 1985).

Seedling age for mangrove swamp

For mangrove swamp, the seedlings age for transplanting can be as old as 4 weeks, because young seedlings are known to be susceptible to salt injury. Salts still remain at the time of transplanting. The nursery area for 4-week-old seedlings should be 1.5 of that shown in Table 3-3.

3-4-2. Uprooting

The seedlings should be uprooted from the nursery beds on the same day they are to be transplanted. The roots of the seedlings developed in the nursery become inactive because new roots develop from the stem base and extend into the soil to take a firm hold in the main field. The stem base should therefore not to be damaged, and attention should be paid to avoid knocking the seedlings hard with the hands or feet when the mud is being removed from them.

It is prudent to pick only a few seedlings at a time so that the mud can be removed by gently shaking or brushing them, as some farmers do. It is an easy and fast way to remove the mud, and it is almost as fast as pulling out a handful of seedlings at a time. Trimming the roots little affects the quality of the seedlings. Cutting-off the roots at a few cm depth by a shovel is alternative for uprooting. Washing the roots in water is also an appropriate way to remove the soil if water is abundantly available.

If old and tall seedlings must be used for any reasons, their elongated leaves should be trimmed since trimming lessens the water loss from transpiration and mitigates damage after transplanting. Trimming will help shallow planting too.

3-4-3. Hill (planting) density

The recommended planting density is about 25 hills/m² (e.g., hill spacing: 20 cm x 20 cm) for medium to long growth duration cultivars. Because the tillering ability of many cultivars currently used in the area is high (Fig. 3-2), they adapt themselves to a given plant spacing. The number of panicles per unit field area does not increase in proportion to an increase of the planting density: it is controlled by the availability of nutrients and solar radiation, in addition to the varietal traits. Eventually, the final yield is little affected with a wide variation of the density (Fig. 3-4). Spacing the seedlings too close should be avoided.

Besides, close spacing promotes vertical growth in the plant, rendering it susceptible to lodging. However, slightly closer spacing can be recommended for short duration (90-100 days) cultivars (e.g., Buttercup, Kissy fundy, etc.), especially in dry season cropping.

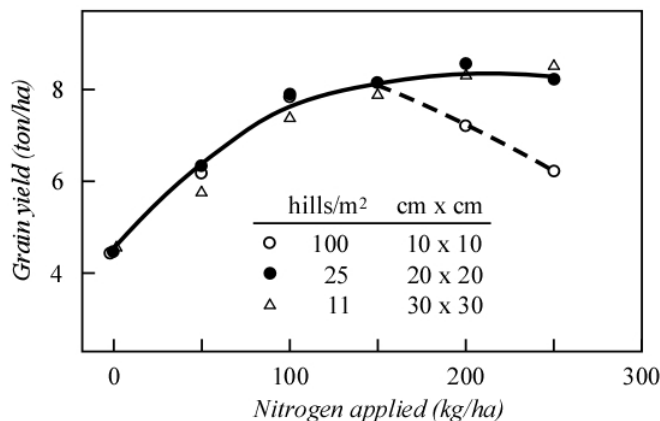


Fig. 3-4. Effect of nitrogen application on grain yield in relation to planting density (Kurashima, 1970). (Variety: IR 8. Dry season at IRRI)

3-4-4. Planting depth

The recommended transplanting depth is 2 to 3 cm. This shallow planting promotes the rapid development of new roots and tillers and eventually a greater number of panicles (Fig. 3-5), which is a dominant component of grain yield. Farmers should be careful not to transplant too deeply or fold the seedling stem, especially when using a planting fork (Fig. 3-6).

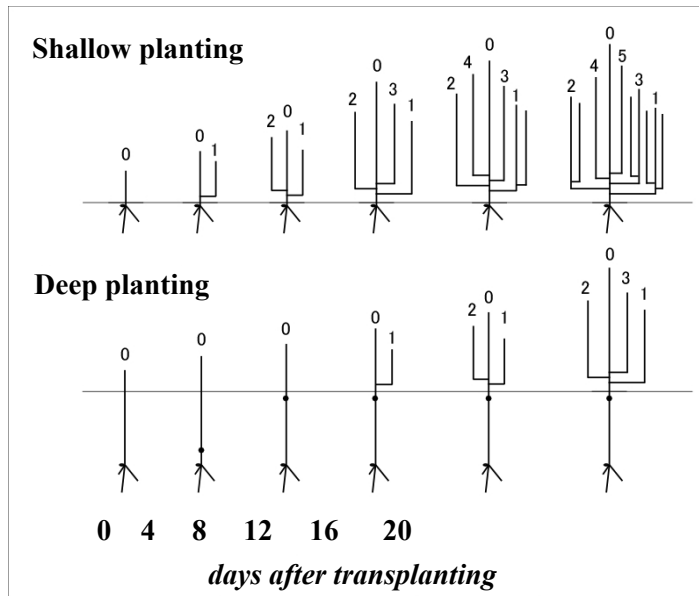


Fig. 3-5. Tiller development affected with planting depth.

Note that proper planting depth will be affected with soil physical properties. When the soils are soft and fragile with loamy and peaty characters under ill-drainage condition, the soil surface should be settled down by puddling the fields a few days before transplanting. If necessary, make the planting depth deeper than the recommended one.

When plants are deeply planted, they elongate mesocotyl until the stem base reaches closer to the ground surface, and then they start tiller development (Photo 3-3). Time wasted for unnecessary elongation results in reduced number of tillers (Fig. 3-5).

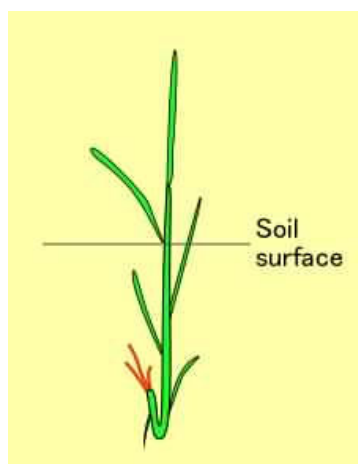


Fig. 3-6. Folded stem of a seedling due to the improper use of a planting fork



Photo 3-3. Elongated mesocotyls due to deep transplanting. Deep transplanting causes a delay in tiller development.

3-4-5. Number of seedlings per hill

The recommended number of seedlings per hill is 2 to 3 regardless of the agro-ecological regime (including mangrove swamp areas). The number of panicles per unit field area (a dominant yield component) is little affected with the number of seedlings per hill. The reason is the same as that for the planting density mentioned above. Using fewer seedlings is to economize on seeds. By planting fewer seedlings per hill, the farmers can easily cut their seed costs up to 1/4 or 1/5 of the present cost of planting 10 seedlings/hill or even more (Table 3-3). One seedling/hill is also allowed, because such a practice does not affect productivity.

3-4-6. Filling the missing hills

The missing hills must be filled starting on the day following transplanting for about a week. At the same time, any disturbance to the main field should be carefully monitored, such as the inflow of heaped weeds from the surrounding fields after a heavy rain.

3-4-7. Planting pattern

Random planting, being currently practiced by farmers, is acceptable. Rice plants are capable of producing many tillers so that they easily adjust an irregular gap (Fig. 3-7). Line transplanting makes weeding easy. However, it is optional because it is time consuming and labour intensive than random transplanting. Line planting take considerable advantages on the use of a rotary weeder.

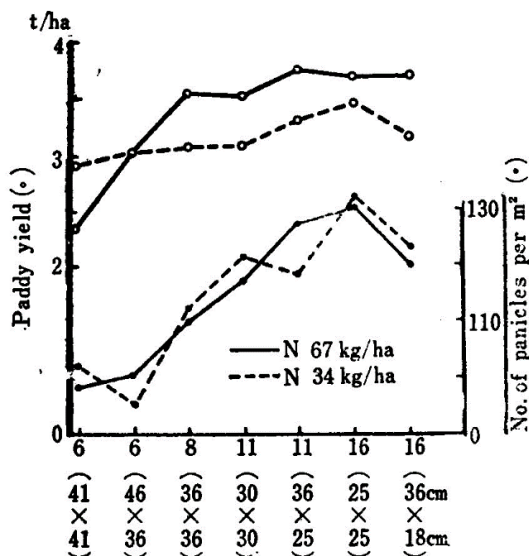


Fig. 3-7. Grain yield and the number of panicles affected with nitrogen application rate and planting pattern (Sugimoto, 1975).

Variety: Radini China 4. Malaysia.

3-5. Weed and pest control

The growth of rice plants is affected with various weeds, rodents, birds, insects, and diseases. The use of agrochemicals for pest control is not included in the Package: consult Reissig, et al. (1986) and FAO (2005) for details when necessary.

The surrounding area of nurseries and main fields should be kept clean at all times. Cleaning helps prevent rodent attacks, the occurrence of diseases, insect damage.

3-5-1. Weed control

Growth of rice plants competes with that of weeds for nutrient and light condition. The prevalent weeds are grasses, sedges, broad-leaved weeds, etc. They are site-specific, and proliferate in different period

according to the soils and water regime. Hence, the timing and frequency of weeding depend on the location. SRDP recommends one thorough weeding at 2 to 3 weeks after transplanting when weeds are still small.

Pulling weeds by hand is the traditional and most direct way of controlling weeds in rice fields. As the rice plants grow normally, they form a canopy that suppresses weed growth by blocking the sunlight. However, when the growth of the rice plants is retarded (due to improper transplanting, malnutrition, etc.), repeated weeding will be required until the plants reach the level of normal growth. Several experiments show the better result with double weeding (Table 3-4).

Table 3-4. Effect of frequency and time of hand weeding on rice grain yield (ton/ha) of ROK 14 in IVS (RARC, 1995) (a)

Number of hand weeding	Time of weeding (WAT)	Grain yield (ton/ha)	(b)
0	-	1.7	f
1	4	2.8	cde
1	6	3.0	abcd
2	4 & 10	3.3	abcd
2	6 & 10	3.1	abcd
3	2, 6 & 10	3.6	abcd

WAT = weeks after transplanting

a) Average over three seasons at Rokupr and Bo.

b) Means having the same letters are not different by DMRT.

Weed control relevant to nutrient replenishment

Farmers in Sierra Leone adopt several methods to control weed for preparing lowland rice fields.

- a) Slush, dry for a few weeks, and burned, when weed growth is exuberant and there is enough time to dry them,
- b) Slush and removed, when the site is wet or rain comes earlier than expected,
- c) Incorporate weeds into soils with plowing, when weeds are not thick,
- d) Ridge or mound building with incorporating weeds, leave for about several weeks to decompose them, and then level down.

Choice of the practice is subject to the vegetation and water regime in respective environment.

Nutrient enrichment would be large by (d) and small by (b). Mounds and ridges in lowland during dry season are prepared for upland crops like vegetables, sweet potato, groundnuts, etc. in a similar manner to (d). The quantity of nutrients released and contributed to rice growth is needed to estimate through chemical analyses and field trials.

Farmers are used to apply compost to vegetables and to mulch the mound with rice straw during dry season after rainy season rice is harvested. The straw is surely decomposed during the vegetable growth so that nutrients released contribute to subsequent rice growth, because those mounds are levelled down for rice culture.

Weeding in mangrove swamp

In the mangrove swamp areas, weeding is not necessary because the growth of the dominant weed, crawling grass ('kireh-kireh') is suppressed by the rice plants growing over it.

3-5-2. Rodents

Cutting-grass (cane rats) sometimes cause serious damage to the rice plants because they move in groups and feed on the plants and rice. Any site where an attack is expected should be protected using fencing and traps. Hunting nets may be used to catch them, and slashing the bush around the rice fields is also effective. In the northern part of Kambia District, several villages cooperate with each other and open their big farms together (in a scale of several hundred hectares) to dilute the damage. Yet, rice fields adjacent to the bush suffer more and sometimes a rodent family nestles in a large farm.

Maintaining water during ripening stages is an appropriate measure, in addition to weeding in the surrounding area, to prevent rat damage.

3-5-3. Birds

Bird scaring is essential at the time of sowing seeds on nursery and ripening stages. If the area intended for the nursery is not large, it is prudent to prepare the nursery in the backyard of the house, as is practiced by many farmers. For a relatively large nursery, mulching is an adequate measure to prevent seedlings from bird attack. In the main field, bird scaring (mainly for weaverbirds) should start immediately after flowering regardless of the agro-ecologies.

3-5-4. Insects

Generally, the occurrence of insect damage in Sierra Leone is low, possibly due to the heavy rains during the main rice cropping season (rainy season). Nevertheless, several species of insects like African Rice Gall Midge, case worm, stem borer, stalked-eye fly, etc. are observed.

1) African Rice Gall Midge

The larvae attack the growing points of rice tillers and cause the leaf sheath tissues to form a tube-like structure called a 'silver shoot gall' that resembles an onion leaf (Nwilene, et al., 2006). As long as the extent of the infection is confined to 10% of the total number of hills and 1 to 2 tillers per hill at the maximum, its effects on the final yield will be minimal since other hills or new tillers compensate for the loss.

Nevertheless, the damage can be serious, as farmers in the western parts of Kambia district reportedly abandoned the affected rice fields because of gall midge damage. Host plants of African Rice Gall Midge such as wild rice (*Oryza longistaminata*), ratoons and volunteers of cultivated rice plants should be controlled during the dry season to reduce the number of population (Nwilene, et al., 2006). Cultivars resistant to the insect such as Cisadane are available; however, there are many biotypes of the gall midge and the selected cultivar may be vulnerable to the type of gall midge in the area (Reissig, et al., 1986).

2) Caseworm

The larvae of the caseworm cut parts of the leaves of young rice plants and roll them into tubes called cases (Reissig, et al., 1986). The pattern of caseworm damage in the fields is not uniform since the larvae living in their cases are often carried from one side of the rice field to another by the wind or water currents. The damage can be controlled by early planting before the peak rainy season and by drainage. Inflow of run off water into the field should be prevented by constructing dikes along peripheral canals as it exacerbates the damage. If irrigation water is supplied, it should not be much in quantity in one time.

Infection by the aforementioned two insect species occurs only up to the active tillering stage of the rice plant. Other pest insects of rice include the leafhopper and rice bug. Stem-borer and stalked-eye fly can be observed, but their serious damage has not been reported.

3-5-5. Diseases

Brown spot and several other fungal diseases are common and found across all the rice agro-ecologies (Photo 3-5 to 3-7). These fungal diseases are closely related with a physiological condition, caused by a nutrient imbalance in the rice plant, so that they are called as physiological diseases.



Photo 3-4. Several diseases observed in Kambia district

Brown spot is rare in rice plants grown in fertile soils (IRRI, 1986). The leaves of a rice plant affected with brown spot often show potassium deficiency symptoms, and is low in potassium concentration in the plant. Potassium fertilizer or NPK compound fertilizer is effective in remedying the disease.

Leaf-scald (Photo 3-6) is a fungal as well. To prevent this disease, the sole use of nitrogenous fertilizer should be avoided. Rice blast is often found in old seedlings in nurseries but is not common in upland rice possibly because of the favorable rainfall in the uplands. Viral diseases such as rice yellow mottle virus are rare in the country.

3-6. Harvesting and post-harvest management

The rice field should be frequently visited as the end of the maturity period of rice approaches, and the harvest time is determined from the plant conditions in the field. The work schedule for rice handling on the harvest day should be planned in advance. Accordingly, a suitable site for drying and threshing should be located, and labourers for the handling tasks should be mobilized beforehand.

3-6-1. Harvesting

1) Timely cutting

Proper cutting at the right time is essential in attaining the maximum yield with the minimum grain losses and quality deterioration. The day of harvest must be carefully determined and the work on the day should be planned in advance. If the optimal time were missed, grains would shatter.

The maturity of the grains can be inferred from some indicators:

- a) when the majority (about 85%) of the grains turns brown or golden in color,
- b) dryness and hardness judging from biting them,
- c) the degree of grain shattering, and
- d) when the color at the panicle base and uppermost internode turns to yellow (or a dried state).

When the color of the husk (hull) turns brown, violet or black, any one of the latter three indicators above ((b), (c) or (d)) or a combination of these indicators may be used.

Matured grains should be harvested early in the morning if they are fully ripe. Harvesting in the middle of afternoon especially during the harmattan period should be avoided due to grain shattering or panicle breakage. It is strongly advised to sharpen knives frequently during harvesting as is practiced by many farmers.

2) Cutting straw or panicle picking

Straw cutting by a sickle is commonly practiced in the northern region, and panicle harvesting (Photo 3-5) in the eastern region. The latter possesses an advantage of picking fully matured panicles only under the condition of mixed cultivars with different growth duration, but a disadvantage on time consuming. Sickle harvesting is described in the following text.



Photo 3-5. Panicle harvesting

A typical manual cutting method is to grasp straws at about two third of the straw length above the ground and cut them with a small straight (kitchen) knife. To minimize the risk of shattering grains, knives should be sharpened before cutting and during cutting as necessary. The cut straw is held in one hand and as more panicles are cut, and they are added to the bundle (or bunch) in the hand. When the handful bundle is large enough, it is put on the nearby convenient place. Several handful bundles piled up are tied them with a wisp of straw or palm leaves.

Rice straws are preferably cut a little longer than the length that farmers commonly do, so that the panicles with short straw are not rolled in the bundle. By doing this, ventilation to the panicles is improved so that they can be dried faster. With longer straws, the panicles can be easily threshed by beating or stamping. It is recommended that binding be done in a container such as large pan or basket: without it, grains are fallen from the bundled panicles during the work. The use of the container is to reduce shattering loss while binding.

3) Transporting

The bound bundles of rice are carried to the place where they are dried and/or threshed. If the drying place is far away from the field, and if the crop needs to be transported a long distance, there is a risk of handling loss. To transport the bundles, a big pan, basket or cloth is recommended to prevent shattering rice.

4) Field drying

The drying place should be clean and as flat and leveled as possible. Use of bamboo or palm leaf mats for underlay is recommended not only to collect shattered grains but also to prevent the grains from mixing with gravels. Any sheets (tarpaulin, plastics sheet, or thick fabric) may also be used as underlay. If there are not enough tarpaulin for both drying and threshing, they should be used for threshing that has priority.

Bundles are collected and stacked at the drying place but they must not be laid directly on the ground, especially in the rainy season. The inside of the stack becomes hot and that would degrade the rice quality because (1) molds grow quickly and infest the grains, (2) discoloration of the grains may result within the first day of field drying, and (3) dry grains may absorb moisture again from wet straw, causing the grains to crack, thereby leading to less head rice after milling.

3-6-2. Threshing and winnowing

1) Threshing

When the bundled rice panicles are adequately dried, they are threshed (to separate grains from straw). The ground preparation for threshing is the same as for drying with bamboo or palm leaf mats over the level ground.

Several threshing methods are practiced by farmers.

- a) Foot threshing or stamping: By trampling on the bundle of panicles spread on the ground with bare feet,
- b) Beating against a threshing rack: By striking the bundle of panicles against a mortar or any hard object (e.g., steel oil drum) set on the ground, and
- c) Beating with stick: By striking the bundle of panicles spread on the ground with a stick.

Any of these methods is fine as long as the ground is clean and levelled. Use of tarpaulin would help prevent contamination with impurities (e.g., sand and small stones).

2) Winnowing

Cleaning works include a) hand sorting and sifting of the bits of straws, chaff and other large and dense materials from the grain piles; b) drying of grains for a few hours; c) winnowing by dropping grains from a basket or bucket through a crosswind or by winnowers if available. Tarpaulin, bamboo mats or palm leaf mats are recommended as underlay to reduce handling losses. Tarpaulin on the ground makes it easy to collect rice grains and helps prevent contamination with impurities.

3-6-3. Hulling (dehusking)

Hulling is the process of removing or separating husks (hulls) and bran from rough rice to produce the edible portion for human consumption. In long-grain varieties, the husk accounts for 18-28% of the grain weight and the brown rice for 72-82%. The brown rice consists of 5-8% bran, 2-3% embryo and 89-94% edible portion. After industrial milling, 100 kg of rough rice yields about 60 kg of milled (polished or white) rice, 10 kg of broken grains, 10 kg of bran and flour, and 20 kg of husks (AGSI-FAO, 1999). In other words, the weight of rice decreases by 40% after hulling.

There are two types of hulling methods, manual hulling by wooden pestle and mortar and mechanized hulling by rice huller (Table 3-5). In manual hulling, grains are dehulled and whitened gradually as they are pounded in the mortar. Excessive impact and pressure result in grain breakage in the milled rice. To reduce breakage, rough rice should be dehulled in a small amount at a time. Careful farmers separate dehulled rice from other several times during pounding.

On the other hand, in mechanized hulling, husks are removed or separated from grains together with bran by force of friction in the milling chamber. The huller must be properly operated to minimize milling loss.

1) Reduction of loss during hulling

The loss of the edible portion of rice by breakage during hulling is attributed to various factors. However, breakage can be reduced if grains are properly dried prior to hulling. To prevent excessive drying, grains

should be mixed and tuned over at some intervals while they are dried.

Table 3-5. General characteristics of two hulling methods (AGSI-FAO, 1999).

Hulling means	Description	Process	Additional information	Comment
Mortar and pestle	Consists of wooden mortar and long heavy wooden pestle, with which to pound the paddy repeatedly against the inner wall of mortar.	Dehulling and polishing to produce milled rice	Mortar is not sunk in the ground. Several people may work together in synchronous action.	Byproducts (bran and broken) are lost with husk. (a)
Rice huller (Engelberg type)	Consists of fluted cylinder on shaft enclosed in hollow cylinder with cast iron top and perforated metal bottom, an adjustable blade, hopper, a pulley, and metal frame.	Dehulling by two operations; 1) Helical ribs at inlet (auger) push paddy to discharge side. 2) Straight ribs on cylinder rotate grains inside while the blade stops rotation of grains causing intense pressure and friction, separating husks, bran, germs and broken that fall on screen perforation. Milled rice is discharged from outlet.	Ground husks, bran, broken, germs, and powdery debris are discharged mixed.	Small capacity millings done in one pass. Generally poor milling performance due to improper operation. Can be used as polisher or whitener to remove bran.

a) Bran and broken rice are fully fed by chicken (SRDP).

2) Mechanized hulling

Husks and bran are separated from grains in two operations (two-pass). After one pass, its byproduct (a mixture of husks and bran) is used to improve the milling recovery for the second pass. The operator can select one operation (one-pass) by controlling the retention time of grains in the hulling chamber with the adjustment of “feed valve” and “discharge valve”. However, more fuel is required for one-pass than two-pass since one-pass operation is more taxing to the engine for keeping high pressure in the chamber.

3-6-4. Storage

The following measures should be taken to reduce losses during storage.

1) Proper drying before storage

Biting the grain is a popular method to test its dryness practiced by the farmers. The grain moisture, however, can be checked by the following method.

- a) Place a handful of grains in a small glass jar (with a screw top if possible);
- b) Sprinkle a spoonful of ordinary salt over the grains at the bottom and seal the top of the jar;
- c) Store for 24 hours; and
- d) Examine the contents of the jar. If the salt clumps together, the grains are too moist to mill or store. If the salt remains dispersed, the grains have moisture content of 15% or less and can safely be milled or stored in bags.

2) Use of pallet

Bags filled with grains should be placed on a pallet avoiding their direct contact with the floor. Pallets are indispensable for keeping the bags away from moisture seeping through the storage floor. If a pallet is not available, timbers or wooden sticks are collected and assembled side by side on the floor as substitute.

3) Rodents control

To keep rodents off, the storage should be properly managed as follows.

- a) Keep the storage place free of fallen grains, garbage, cloths, etc. so that there is nothing for the rodents to feed on, hide or nest in.
- b) Store bags on pallets, ensuring that grains in the bags remain dry.

4) Insects control

Low humidity generally slows down or even stops reproduction of pest insects. If insects are found in storage bags, the grains should be taken out of the bags and dried under the sun.

5) Microorganisms control

Microorganisms also thrive in humid environment. They can be controlled by:

- a) Drying the grains properly before storage.
- b) Checking the grain in the storage regularly.
- c) Drying the grains immediately if they are wet.

Parboiling

Parboiling is common in the northern area, but not in the eastern or southern area in Sierra Leone. Although the parboiling process is labour intensive, some people prefer parboiled rice to white rice (milled rice without parboiling). The reasons are:

- a) Milling recovery is larger in parboiled rice than unprocessed rice due to less breakage during milling;
- b) Parboiled rice increases the volume more than white rice does when it is cooked. Note that net weight is unchanged; and,
- c) It has a high market demand, especially for exporting to Guinea.

The parboiling is conducted with the following three important steps:

- a) Soaking paddy in water to increase its moisture content (to about 30%);
- b) Steaming to complete gelatinization; and,
- c) Drying paddy to a moisture level safe for milling.

Proper drying after gelatinization of starch makes the grains hard and resistant to breakage during milling. Overheating rice by excess boiling or steaming spoils gelatinization. Overheated parboiled rice is thus more prone to breakage after milling than properly parboiled. Steaming or boiling of grains must be stopped before their husks start to split.

The following steps are indispensable to stop gelatinizing after boiling and steaming:

- a) After boiling, remove all the grains and put them in another container;
- b) Add fresh cold water until the grains are completely submerged to cool down;
- c) Remove all the grains from the container and put them in another container;
- d) Add some water and heat it until the steam is visible over the grains in the container; and,
- e) Remove all the grains from the container and allow them to cool down on a mat, tarpaulin or drying floor.

4. Fertilizer Manipulation

4-1. Fertilizer application and rice yield

Soils in Sierra Leone broadly belong to Oxisols or Ferralsols (See 9. Appendices, A1.3-1 and A1.3-2), which are highly weathered. Because of poor soil fertility, rice grain yield will be increased by 1 t/ha only with the sole application of improved cultural practices. When anyone intends to exceed the limit of such a yield barrier, nutrient supplement by fertilizers is prerequisite.

The Package tentatively recommends the fertilizer application rate at 40-40-40 kg/ha of N-P₂O₅-K₂O to attain the target yield of 3 t/ha. Again it should be reminded that a) Proper water control by drainage and irrigation, and b) Full application of cultural improvement practices, are prerequisite to realize it.

4-2. Timing of fertilizer application

When fertilizers are applied, they should always be efficiently absorbed and utilized by crops. Fertilizer application to rice plants in the Package is recommended as:

- a) The total quantity (40-40-40 kg/ha of N-P₂O₅-K₂O) is split into two: 2/3 (27-27-27 kg/ha) and 1/3 (13-13-13 kg/ha). The first is applied at the time of puddling just before transplanting as basal dressing. The second is at the panicle initiation stage, about two months before full maturity (harvesting time), as a top-dressing; and,
- b) Top-dressing is applied in a middle of the day. Avoid it when it rains.

As shown in the development process of yield components (Fig. 2-3), the first application promotes tillering at the early growth stage, where tillers later produce panicles, being the most important yield component. The timing of top-dressing coincides with the period when spikelets are formed on the developing panicles.

Fertilizers should not be applied to the area where water is moving, whatever the reason is. All chemical fertilizers being a kind of salts, they are easily dissolved in water. To minimize the application loss cause by water or rain, fertilizer application would possibly be split into several times.

The timing of fertilizer application depends on soil fertility. When it is relatively high, nutrients required to the initial growth of planted seedlings can be supplied from the soil. So, the first application can be made at a few weeks after transplanting. RRSR (1991) recommended the basal application at 2 weeks after transplanting at Mawirr, associated mangrove swamp and at Mange, irrigated rice field enriched with continuous fertilizer application: both sites are high in soil fertility. In contrast, nutrient status of most lowland soils is low and thus, tiller development responds to fertilizer application quickly after transplanting (Fig. 4-1).

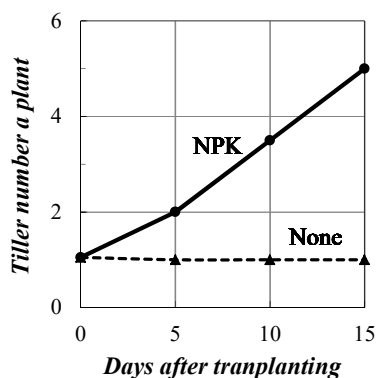


Fig. 4-1. An example of fertilizer effect on tiller development shortly after transplanting (cv. ROK 24. Pot culture with riverine soil at Tambi, Kambia district).

4-3. Uniform application of fertilizers

The method of uniform fertilizer broadcasting is:

- Divide the field into several sub-plots of nearly equal size and divide the fertilizers proportionally;
- In each sub-plot, broadcast two-thirds of the amount of fertilizers allocated for each sub-plot; and,
- Broadcast the remaining one-third to even out the distribution of the fertilizer broadcast first.

Note: The first and second broadcasting should be carried out transversely (Fig. 4-2).

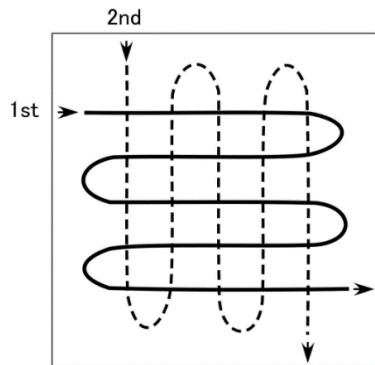


Fig. 4-2. Uniform application of fertilizers in fields.

4-4. Issues for better fertilizer choice

4-4-1. Principles of plant nutrients

Nutrients are essential to plant growth (A1.1-1). Plants grow to some extent in almost all soils under the natural condition (without fertilizer addition) as far as water and temperature are not limiting factor. The extent of plant growth depends on nutrient availability naturally supplied. When human being intends to grow plants larger than the growth depended on the natural supply, he or she needs to add nutrients. This practice is called as fertilizer application (Fig. 4-3).

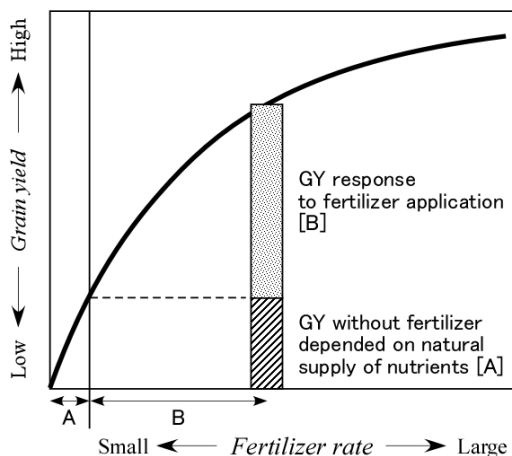


Fig. 4-3. Two components of grain yield (GY) under fertilized condition. Total production consists of A and B.

The law of the minimum shows that plant growth is limited by the nutrient of the shortest supply (Fig. 4-4). When we intend to increase crop productivity effectively and efficiently, we have to apply fertilizers according to the nutrient status of a given soil. If we add a nutrient being abundant in the soil, the addition is not effective, but a loss. At the same time, nutrient requirement varies depending on the mass of plant growth or final product. Fertilizers application rate should match the nutrient status of soils and

requirement of the plants. We are able to utilize fertilizer efficiently if we know the nutrient status of the soil. This section provides certain information on the two aspects of fertilizers: the nutrient status of soils in the country and the magnitude of yield response to fertilizer application.

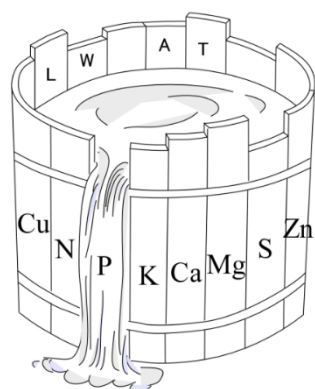


Fig. 4-4. Liebig's law of the minimum (Dobenecks barrel).
L: light, W: water, A: air, and T: temperature.

4-4-2. Soil nutrient status and grain production

1) Chemical properties of soils

Chemical analysis is useful method to grasp the general nutrient status of soils. As a preliminary approach, various soils in Kambia district were collected and analyzed. Many nutrients like phosphorus (P), sulfur (S), nitrogen (N) are frequently deficient in soils, although nutrient shortage varies among agro-ecologies (Table 4-1). Not only macronutrients but also several micronutrients like zinc (Zn) and copper (Cu) are deficient in smaller or larger extent.

Table 4-1. Frequency (%) of soils with possible nutritional problems (deficiency and excess of nutrients, and acidity) diagnosed with chemical analyses (a) in various rice agro-ecologies agro-ecologies of Kambia district.

Agro-ecology	n	Deficiency							B excess	High salt	Low pH
		N	P	K	S	Zn	Cu	Si			
Upland	12 (0)	8	17	17	50	42	17	58	0	0	8
Inland valley swamp	14 (1)	7	36	57	71	29	0	71	0	0	86
Boliland	15 (3)	20	20	27	73	47	0	53	0	0	33
Riverain grassland	2 (0)	50	50	0	50	0	0	0	0	0	50
Associated MS	6 (1)	17	50	0	33	17	0	17	0	0	100
Mangrove swamp (MS)	14 (2)	0	7	0	0	0	0	0	79	71	29

n: the number of soil entries, including plural samples at the same site (the number is in parentheses) on different dates.

2) Nutrient deficiency level evaluated by pot culture

Soils were collected countrywide (A1.4 (1)-1 and -2), and rice plants were grown in pots under various nutrient conditions for about one month. Some examples of plant growth are shown in Photo 4-1. In both soils, plant growth was poor at None (no nutrient added) and -P (no P added but N and K; +NK) treatments, while large at NPK, +S and +Zn treatments. Plant growth at -N treatment was similar to that at NPK and +S treatments in Musaia soil, but it was poorer in Rolako soil.

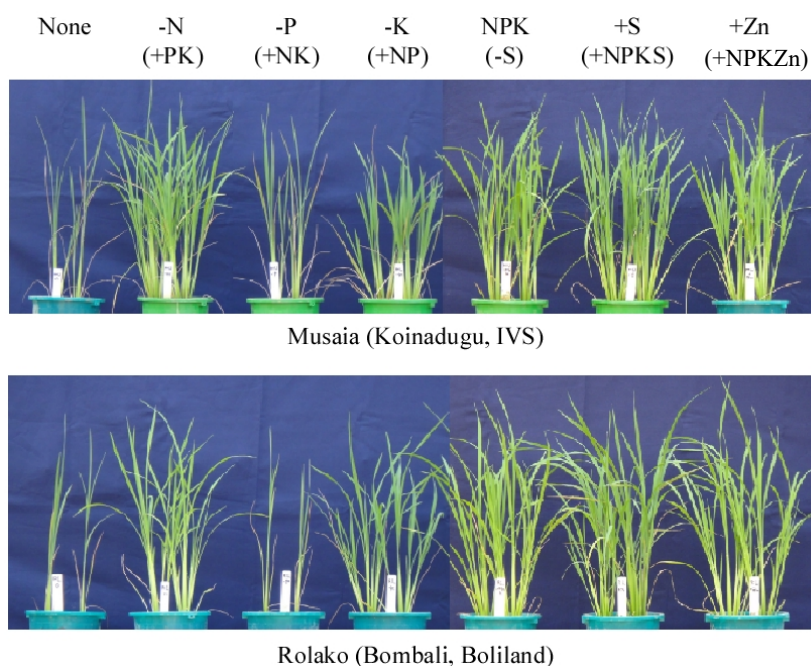


Photo 4-1. Examples of plant growth in the nutrient deficiency evaluation trial with Musaia and Rolako soils (25 days after transplanting).

The deficiency level of each element was quantified based on the relative dry matter production (DMP) between the reference treatment (NPK or NPK+S) and the nutrient treatments for each soil. The deficiency level is divided into five classes (Table 4-2). Phosphorus (P) deficiency is the severest, and widely distributed over the country. Sulfur (S), potassium (K) and nitrogen (N) are deficient in many locations, while zinc (Zn) lacks in specific sites only. No apparent difference in soil fertility is found between Kambia and other districts (A1.4 (1)-3). The deficiency level in N, P, K, S, and Zn is 30, 70, 30, 40, and 10 on average nationwide, respectively (Table 4-3).

Table 4-2. Nutrient deficiency level classified in respective soils

a) in Kambia district							b) in other districts								
Ser. no.	Soil	abbr.	Element												
			N	P	K	S	Zn	Ser. no.	Soil	abbr.	N	P	K	S	Zn
2	Robannah (u)	Ru	++	+++	+	*	-	1	Kpuabu	Kp	-	+++	+	a	a
8	Misra	Ms	-	+++	+	+	*	3	Buline	Bl	-	+++	+	+	-
9	Makaliso	Mk	-	+++	-	-	+++	4	Nyandeyama	Ny	-	-	+	+++	-
10	Kunthai	Kn	+	+++	+	-	-	5	Giema	Gm	+	+++	+	++++	-
11	Masineh	Mh	-	+	-	*	*	6	Kamaranka II	K2	-	++	-	++++	-
12	Mathon	Mt	+	+++	++	+++	-	7	Kanikay	Kk	a	+	-	+	-
13	Kamaranka	Km	-	+++	+	+++	*	23	Musaia	Mu	a	++	-	+	-
14	Karawani	Kr	++	+++	++	+	-	24	Tikonko	Tk	-	-	+	+++	-
15	Rokon	Ro	-	++	-	-	-	25	Mandu	Md	-	+++	-	-	+
16	Sinbeck	Sb	-	+++	++	+	+	26	Rolako	Rl	+	+++	+	+	-
17	Pintekili	Pt	+++	+++	+++	+++	++	29	Mayatha	My	-	+++	-	-	-
18	Robannah	Rn	+	+++	++	++	-	32	Torma-Bum	Tr	-	+	+	++	-
19	Bassia	Bs	+	+++	-	++	+								
20	Kamathothor	Kt	+	+++	++	++	-								
21	Tolokuray-U	T-U	+	+++	++	+	*								
22	Tolokuray-L	T-L	+++	+++	++	+++	+								
27	Kalintin	Kl	+	++	+	++	+								
28	Tambi	Tb	-	+++	+	*	+								
30	Robana	Rb	+	+++	-	-	-								
31	Robis-bana	Rm	-	+++	-	-	+								
33	Kibanka	Kb	-	++	+	-	-								
34	Marwirr	Mw	++	++	+	-	*								
35	Rokel	Rk	-	+	-	-	-								
36	Rosinor	Rs	+	++	+	-	a								
37	Robat	Rt	+	++	-	a	*								

Nutrient deficiency level	Legend	Deficiency level	
		from	to
Severely	++++	101	150
Highly	+++	76	100
Intermediately	++	51	75
Fairly	+	26	50
Least	-	-24	25
Likely abundance	a		
Pending	*		

Table 4-3. Rounded nutrient deficiency level in various agro-ecologies of Sierra Leone

Agro-ecology	n	Nutrient				
		N	P	K	S	Zn
Upland	3	30	90	40	50	0
Inland valley swamp	22	30	70	30	60	10
Boliland	4	20	80	30	40	20
Riverain	3	20	70	30	30	10
Mangrove swamp	5	30	60	20	10	-10
Mean (weighted)	37	30	70	30	40	10

DMP without fertilizer tends to be smaller with upland, and larger in mangrove swamp (Fig. 4-5). DMP with fertilizer is larger in boliland, riverain grassland and mangrove swamp than in IVS. Soils of relatively high fertility are found in lower areas where sedimentary materials are deposited.

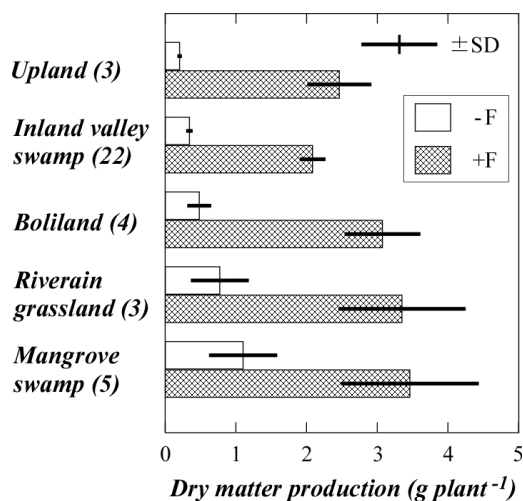


Fig. 4-5. Dry matter production (DMP) with (+F) and without (-F) fertilizers in various agro-ecologies. The number of soil entries in respective agro-ecologies was in parentheses.

3) On-farm fertilizer trials

Fertilizer trials were conducted at FBO group farms of seven IVSs in Kambia district in the rainy season, 2013, and in the dry season 2013-2014 (A1.4 (2)-1). Rice plants were grown with and without fertilizer, applying full improved cultural management practices. Four fertilized treatments, combining 20-60 N, 40-100 P₂O₅, 40 K₂O, and 0-10 S kg/ha, were set, referring to the results of pot experiment. The mean of fertilized treatments was at 30 N, 55 P₂O₅, 40 K₂O and 6 S kg/ha respectively. As a result, no apparent difference in grain yield among treatments was observed.

Grain yield with and without fertilizer varies respectively 2.1-4.0 and 1.2-2.7 t/ha and there is a positive relationship between them (Fig. 4-6). Grain yield with fertilizer is lower under poor water control condition than under well controlled condition. Mean yield response to fertilizer application (Rf) is 1.1 (0.6-1.8) t/ha under well water controlled condition. The highest yield was 4.0 t/ha when the natural supply was high.

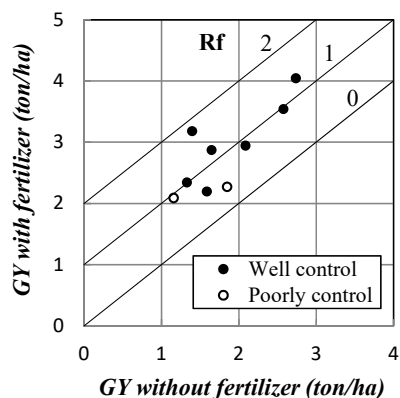


Fig. 4-6. Relationship between grain yield (GY) with and without fertilizer. Rf: response to fertilizer application (t/ha). 'Well and poorly control' are on water control conditions.

4) Fertilizer trials in the past: literature review

Various fertilizer trials have been carried out in Sierra Leone during her long history of rice research at RARC in close collaboration with IITA, FAO, UNDP, EC, etc. Published data (A1.4 (3)) were compiled to find soil fertility variation countywide through rice production and response to fertilizer application. Fertilized rate ranged from 30-20-20 to 120-80-80 kg/ha.

Grain yield in upland varied 0.5-3.2 (mean: 1.7) and 0.2-2.3 (0.9) t/ha respectively, under with and without fertilizer application, and that in IVS did 0.5-4.0 (mean: 2.2) and 0.2-2.5 (1.2) t/ha respectively, under the same conditions as upland (Fig. 4-7). In general, when the grain yield was larger without fertilizer, it was larger with fertilizer too. Yield response was -0.5-2.0 (0.7) t/ha in upland and 0.0-2.8 (0.9) t/ha in IVS.

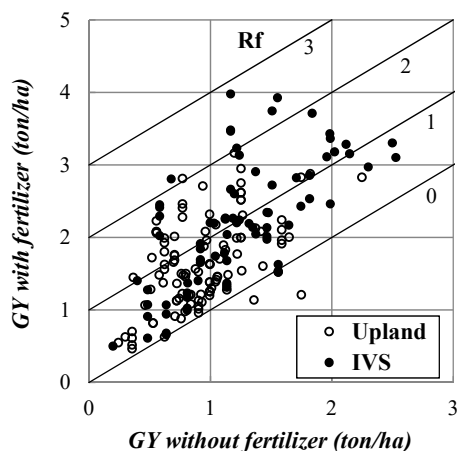


Fig. 4-7. Relationship between grain yield (GY) with and without fertilizer (A1.4 (3)-1). Rf (isogram): response to fertilizer application (t/ha).

Although the grain yield without fertilizer varied much, its distribution was more frequent within the range of 0.5-1.0 t/ha in upland and 1.0-1.5 t/ha in IVS respectively (Fig. 4-8). All results were based on a kind of research experiments so that even the plot without fertilizer was assumed to be managed with some improved cultural practices. The fact suggests that it is not easy to obtain grain yield higher than 2 t/ha without fertilizer.

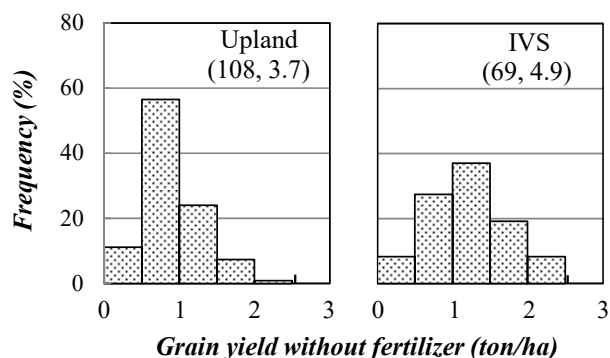


Fig. 4-8. Frequency of grain yield of rice plants grown without fertilizer in upland and inland valley swamp (IVS). The former and the latter figures in parentheses signify respectively the total number of entries and the average number of trials in each entry.

Yield response to fertilizer application varies from -0.5 to 2.0 (mean: 0.7) t/ha in upland and from 0.0 to 2.8 t/ha (mean: 0.9) in IVS, respectively (Fig. 4-7). Response to fertilizer application in upland was smaller at low rates and increased with an increase of application rates (Fig. 4-9). In contrast, the response was maintained at a similar level, 0.8-1.0 t/ha regardless of fertilizer rates in IVS. The phenomenon of the latter is unusual: why rice yield did not respond to an increase of fertilizer rate. The result might be affected with various reasons: water control, cultivars, etc., or human error.

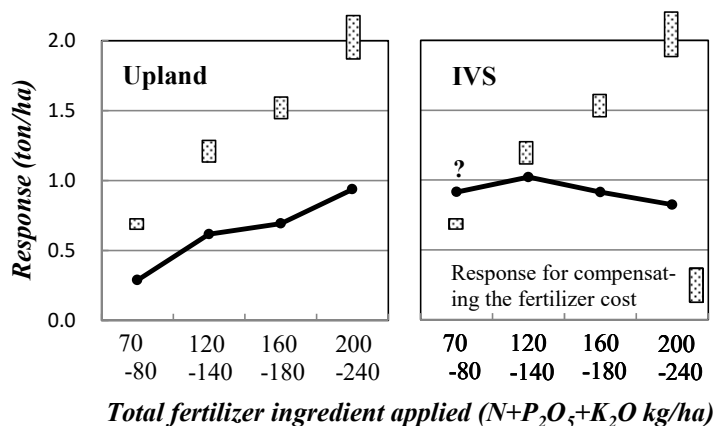


Fig. 4-9. Yield response to various fertilizer application rates in upland and inland valley swamp (IVS) (A4-4).

Grain yield without fertilizer entirely depends on soil fertility. Fertility trend among regions is inconsistent as far as the past fertilizer trials are concerned. For example, the productivity in IVS is larger and that in upland is smaller in the southern region (Fig. 4-10). The tendency is contrary to the other regions. The productivity inconsistency denotes that the soil fertilizer little differed among regions in a broad sense. The fact is also supported by the result of pot trials (A1.4 (1)-3).

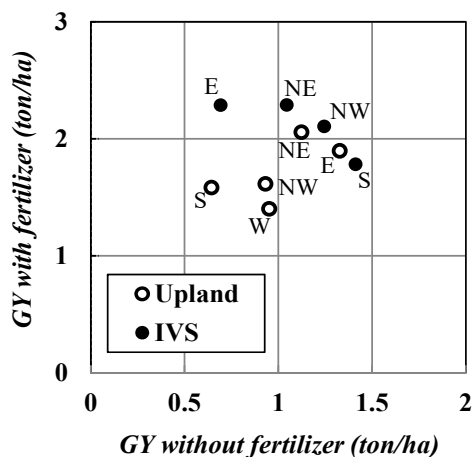


Fig. 4-10. Relationship of grain yield (GY) with and without fertilizer in various regions (A4-4). Abbr.: NE, Northeast; NW, Northwest; S, Southern; E, Eastern; W, Western.

4-5. Ways to wise fertilizer use

4-5-1. Fundamentals

SRDP supported and monitored FBO's farming activities and grain yield from the 2011 rainy season to 2013-2014 dry season. Grain yield largely varied among FBO farms and its variation showed a bimodal tendency with a large peak at 0.5-1 t/ha and 1.5-2.5 t/ha (Fig. 4-11). To find the reasons for a large variation in productivity among FBO farms, cultural management between a high-yielding FBO group (higher than 2.5 t/ha) and a low-yielding group (lower than 1 t/ha) was compared.

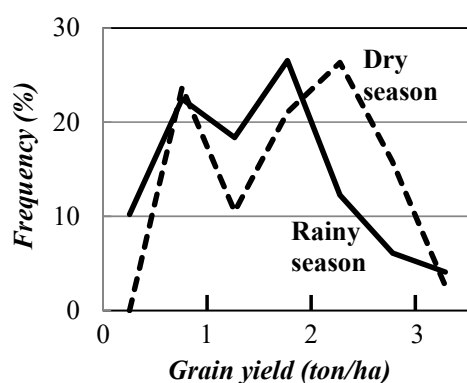


Fig. 4-11. Frequency distribution of grain yields in FBO communal farms in Kambia district.

As for farming practices, shallow planting was more frequently practiced by the high-yielding group than the low-yielding one, and proper leveling (land smoothing) percentage was also higher by the former (Table 4-4). At the same time, the proportions of cropping calendar preparation, germination test, and land preparation before sowing were high in FBOs who obtained high yield. These practices show farmers' challenging attitude towards farming activity, and their effort was rewarded with better yield. Respective farming activities will contribute to yield improvement at a limited extent, but integrated practices will greatly help to enhance productivity.

Table 4-4. Proportion (%) of recommended farming activities practiced by high- and low-yielding FBO farms.

Farming activity	High yielders (≥ 2.5 ton/ha)	Low yielders ($1.0 \leq$ ton/ha)
Cropping calendar preparation	44	0
Germination test	50	5
Use of young seedlings	100	56
A few seedlings/hill	94	45
Shallow planting	100	20
Field leveling	88	10
Land preparation before sowing	88	24
Bund and drainage maintenance	81	36

4-5-2. Yield response to fertilizer and cost recovery

When fertilizers are applied, grain yield more or less increased (Figs. 4-6 and 4-7). The cost of fertilizer rate at 40-40-40 kg/ha of N-P₂O₅-K₂O is nearly equivalent to the price of one ton of rough rice at the farm gate at present: Refer to Chapter 8. Economic Analysis on Rice Production. This fact implies that the rice business is almost break-even if the yield response is 1 t/ha with the said quantity of fertilizer.

Figs. 4-6 and 4-7 show that the averaged response to fertilizer application is about 1 t/ha in many cases. Therefore, a chance to make net profit by fertilizer application is small at present.

4-5-3. Standard fertilizer rate and its modification

1) Standard fertilizer rate

The result of the pot experiment is unable to reflect directly the field nutrient condition. Yet, deficiency level of the nutrients in soils show the potential status, or the field nutrient status in the long run. Overall nutrient deficiency level estimated by the pot trial is around 30 N, 70 P₂O₅, 30 K₂O, and 40 S (Table 4-3), where P deficiency was severe and widely prevails. The result suggests that favorable fertilizer composition would be 30-70-30-40. Yet, the recommended fertilizer rate in the Package is tentatively set at 40 N- 40 P₂O₅- 40 K₂O kg/ha, because single source of P and S fertilizers is currently unavailable in the market. The equal nutrient composition like 40-40-40 matches NPK compound fertilizer (15-15-15) readily available in the present market.

At the same time, a high dose of fertilizer like 80-80-80 kg/ha is not adopted, because heavy dose of fertilizer does not necessarily enhance production (Fig. 4-9) under the present condition, and because of the law of diminishing return (Fig. 4-12): the smaller the input, the larger the return.

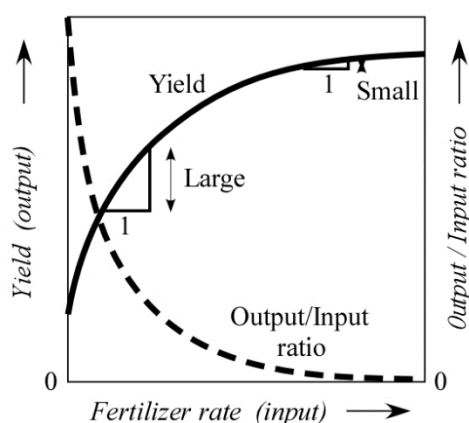


Fig. 4-12. The law of diminishing return (Mitscherlich, 1909).

2) Fertilizer adjustment on soil fertility

The recommended fertilizer rate must be modified according to the soil fertility. The standard rate is not more than the value reflecting the general nutrient status in the soils and the compromised result considering various conditions. In fact, soil nutrient status differs little among regions in broad perspective (Table 4-2, Fig. 4-10, and A1.4 (1)-3).

Nevertheless, soil productivity differs more or less, not only among regions but also among adjacent plots even in a same IVS (e.g., Figs. 4-6, 4-7 and 4-8). There is no backbone to support plot-wise soil diagnosis in the country. Thus, it is recommended to apply the standard rate of the fertilizer to the field in the beginning, of which soil fertility is unknown, and observe the result whether the rate was reasonable. The rationality here denotes whether the fertilizer dose produce sufficient incremental yield to bear net profit or not. Based on the analyses, he may increase or reduce the fertilizer rate in the succeeding cropping. An option of no fertilizer use could be chosen. Needless to say, application of full package of improved cultural practice and water control are prerequisite.

4-5-4. Soil fertility and response to fertilizer

Grain yield without fertilizer varies greatly. For example, in IVS, its variation was 1.3-2.8 t/ha by the fertilizer trials (Fig. 4-6) and 0.2-2.7 t/ha in the literature review (Fig. 4-7). All these trials were assumed to be conducted applying the same culture practices, and thus, grain yield variation is mainly derived from the difference in soil fertility.

Let's assume that there are two sites differed in soil fertility, which is equivalent to produce grain yield as 1.5 and 2.5 t/ha under the improved cultural practice, and their grain yield reaches 3 t/ha with fertilizer application. Yield response to fertilizer application is 1.5 and 0.5 t/ha respectively (Fig. 4-13). In the example, while the former surely would have yielded much profit, the latter would have involved a loss. In fertilizer application, it is not a critical issue how high the yield (like 3 t/ha) is produced, but it is a main concern whether fertilizer applied brings a sufficient yield response to recover the cost and make a profit. Yield itself largely depends on natural soil fertility. We should strictly pursue how efficiently fertilizer promotes productivity.

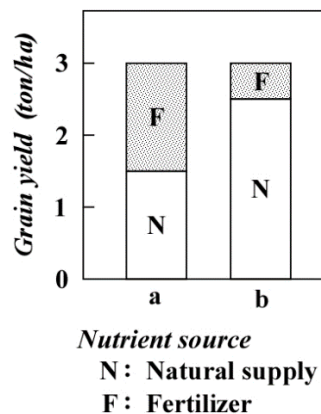


Fig. 4-13. Grain production with different responses to fertilizer application under two natural supply statuses Rice plants were grown with improved culture management in both cases.

4-5-5. Related matters

1) Season choice

Rice in Sierra Leone is generally grown in the rainy season, when rainfall reaches as much as 2,000 mm or even more during the cropping period. Besides, fully developed IVS rice fields are uncommon: only three irrigated rice fields are currently available at Lambayama, Makali, and Mange, where total acreage is about 100 ha. In the majority of lowlands, rice culture is practiced under the rainfed condition without proper water control. Hence, fertilizer application during the rainy season holds a high risk of washing away. Under the present situation, fertilizer application may had better be confined to the dry season cropping, when the chance to obtain higher yield is high (Fig. 4-11).

2) Nutrient supply through organic matter

Nutrients contained in organic matter are as effective as those in chemical fertilizers for rice plants (Fig. 4-14). Farmers in Sierra Leone are used to apply a kind of compost to their vegetables. They would have acquired how to maintain soil fertility through their experiences, and understand its importance for better production. Compost incorporation into rice fields, however, would be unrealistic due to a large requirement. In several areas, farmers are smart enough to utilize nutrient contained in weeds for rice culture: see the box column 'Weed control relevant to nutrient replenishment'. Nutrient manipulation with green manure is unknown.

3) Sowing density in nursery

Sowing density in the nursery could be increased up to 2 kg/10 m² if the fertilizer is applied in the main field. Competition may be occurred between the seedlings in the nursery under the dense condition, but the growth is recovered after transplanting when enough nutrients are supplied in the main field.

4) Soil acidification by fertilizer application

It is well-known that over-use of chemical fertilizers often induces soil acidification. Yet, the recommended fertilizer rate in the Package will not cause the problem, because the quantity is small enough to simply supplement the shortage so that all nutrients added will be absorbed by a crop. Besides,

it is well known that soil pH is neutralized under the submerged condition regardless of the original pHs (Fig. 4-15).

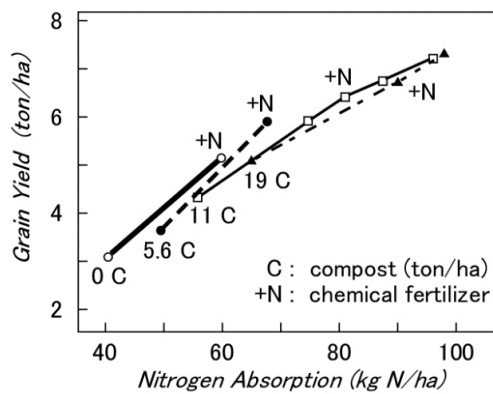


Fig. 4-14. Relationship between nitrogen absorption and grain yield with various combinations of organic matter and chemical fertilizer (ammonium sulfate). Average of 1953-1958 (Shiga).

<There is no difference in yield production between organic and chemical fertilizers.>

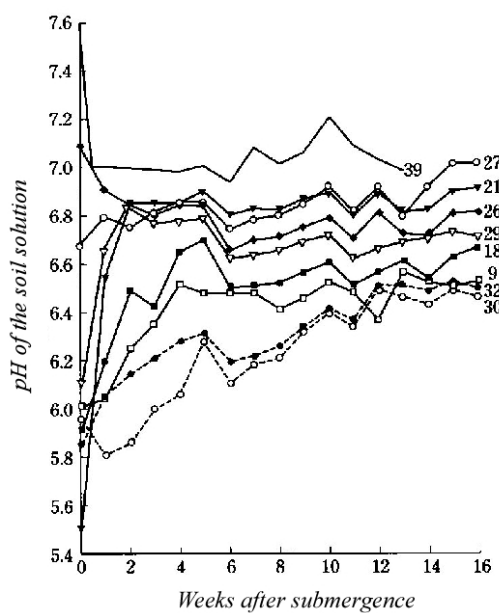


Fig. 4-15. pH changes after submergence (Ponnamperuma et al, 1966). No. 9, 18, 21, etc. signifies the soil entry number.

4-5-6. Suggested scientific approach for future development

Grain yield can be as large as 4 t/ha when we apply the full package of cultural improvement with sufficient dose of fertilizers. Yet, the maximum yield has hardly exceeded beyond that level. Some causes out of cultural practices must have hindered the productivity. Further, the result obtained through the pot trials has not yet verified in the field. Hence, many research issues remain unclear how we can efficiently approach to increase productivity. Several topics suggested in a scientific aspect are the following.

1) Periodical planting throughout a year

Among various factors controlling crop production (A1.2-1), two external factors, solar radiation and temperature, are hardly manipulated with human power. Temperature will not be a limiting factor in the country (A1.5-1). Solar radiation is only a source for dry matter production, and hence rice productivity is greatly affected with it as examples in Asia and Africa clearly show (A1.2-2 to A1.2-4). Because of heavy rainfall in the middle of main rice cropping period, sunshine hours are less in Sierra Leone (A1.5-1). Solar radiation will be a main cause of low productivity in the country. Periodical (every 4-month or monthly) planting will find the effect of solar radiation on plant growth and grain yield. The trial should be carried out under full water control. Radiation measurement is prerequisite.

2) Phosphorus trial in field

The pot trial result shows that the P deficiency prevails in the country. P adsorption coefficient (PAC) as large as 10 g P kg⁻¹ is not rare by the chemical analysis. The value is equivalent to 23,000 (= 10 x 1,000 x 2.3) P₂O₅ kg ha⁻¹, assuming that the specific gravity of a soil is 1 g cm⁻³ and field depth is 10 cm. To amend the P deficiency in fields, 10% of PAC equivalent is commonly proposed, so that the maximum application rate must be 2,300 P₂O₅ kg ha⁻¹, or up to 1,000 P₂O₅ kg ha⁻¹ at least. PAC analysis of various soils will provide valuable information to establish the standard fertilizer rate.

3) S treatment

Sulfur is deficient in many soils as has been observed (Tables 4-1 and 4-2). Its deficiency is very likely when we consider general soil background and the evidences in neighboring countries (Yamaguchi, 1997 and 1999). It can be one of the important elements limiting the yield in the country.

4) Fertilizer trial with various combinations of nutrients

A series of fertilizer trials should be carried out with various combinations of nutrients at a wide variation of their rates. As described previously, nutrient composition in addition to the fertilizer rate is critical to maximize the efficiency. For example, the mean yield response to fertilizer application was as low as 0.4-0.6 t/ha in ADPK trials, where P proportion was one quarter or one half of N (A1.4 (2)-2). Anyone should be in mind that scientific approach is different from economic one as a preliminary stage of fertilizer trials. Once we obtain the maximum limit, we are able to easily fit the result for the real demand.

H₂S injury

In some patches close to the fringe of a mangrove swamp, hydrogen sulfide (H₂S) toxicity is found, which disturbs the respiratory metabolism of plants killing them even at a low level. Because the areas affected by H₂S are specific and identified and also mitigation measures are costly, it is advised not to grow rice in such areas. Sulfate is reduced under submerged condition as redox potential (Eh) decreases (A1.3-3).

Weed handling and iron toxicity

Weed control plays a key role in rice cultivation regardless of agro-ecologies. By plowing organic matter (e.g., the weeds) into the soil, nutrients are released because organic matter is decomposed. However, the decomposition process only occurs where there are well-aerated conditions.

Under reduced (oxygen-deficient) conditions as in case of submergence, ferrous is converted into ferric iron. The decomposition of organic matter leads to an increase in ferric iron in the soil, which the rice plants absorb, especially when there is a deficiency of minerals in the soil.

A healthy rice plant can tolerate a certain level of iron since it actively excludes ferric iron. When the ferric concentration in the soil exceeds the threshold (300 mg Fe²⁺ L⁻¹ soil solution) or when the nutritional conditions of the plant are unfavorable, however, the plant will suffer from iron toxicity (Tanaka and Yoshida, 1970).

Iron layer on the water surface is often observed in lowlands. Typical Fe toxicity symptom on plants was scarcely found, however, especially in the rainy season, probably because of runoff by heavy rain. If thick layer is found, drainage helps to wash out and oxidize ferric iron. Yet, it is difficult to drain water from fields in the lower part of lowlands and this requires lengthy and laborious work. The farmers should try to remove as many of the weeds from the main field as possible to keep them from being mixed into the soil and prevent iron toxicity where it is expected.

5. Cropping Calendar

5-1. Cropping season

Because of the long rice culture history (200-300 years?), farmers maintain various indigenous cultivars with different traits (Table 3-1). In addition, many cultivars have been recently introduced from multiple sources, and RARC has released several varieties, too. For selecting cultivar(s) to plant on their farms, farmers should consider several criteria: growth duration, plant characteristics to be adapted to the environments given, product use (for home consumption or marketing), and fertilizer response if it is available.

Farmers must first select a cultivar of the most appropriate growth duration that will well fit the given natural condition (e.g., water condition relevant to topography), which holds primary importance among all plant traits. Fig. 5-1 presents several examples of cropping seasons of cultivars with different growth duration. All characters other than growth duration will be selected among cultivars with similar growth duration.

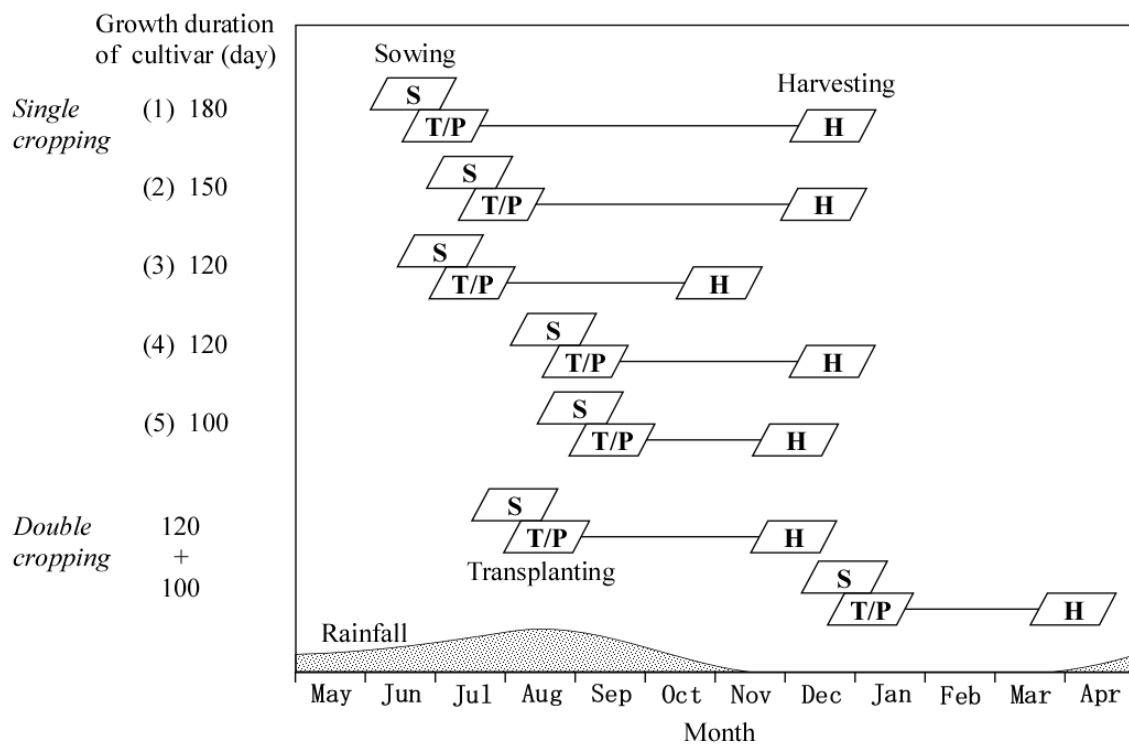


Fig. 5-1. Choice of cropping seasons in inland valley swamp. Rainfall period and intensity are approximated to the countywide average.

Longer growth duration (at least 4.5 months) cultivars will preferably be used in the rainy season to minimize the loss of applied fertilizer by rain. When the farmers practice double cropping, the rainy season crop should be harvested by the end of December. In the dry season, shorter growth duration cultivars would often only be the choice due to water shortage during its ripening stage.

When a cultivar is photoperiod-sensitive, one must consider that the growth duration varies with planting season (A1.1-2). In Pakiamp, for instance, total growth duration (from sowing to full maturity) is longer than 150 days when it is sown early June, and becomes about 120 days when it is sown early August (Fig. 5-2).

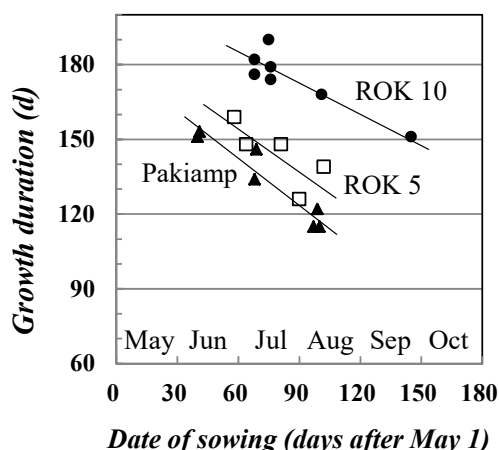


Fig. 5-2. Growth duration (from sowing to full maturity) of selected cultivars affected with sowing dates in rainy seasons (SRDP, 2014).

Proper cropping season varies from place to place depending on natural condition, cultivar used, and culture system. Fig. 5-3 shows the variation of rice cropping season countrywide for reference. One should find the best choice subject to the own condition.

5-2. Farming calendar

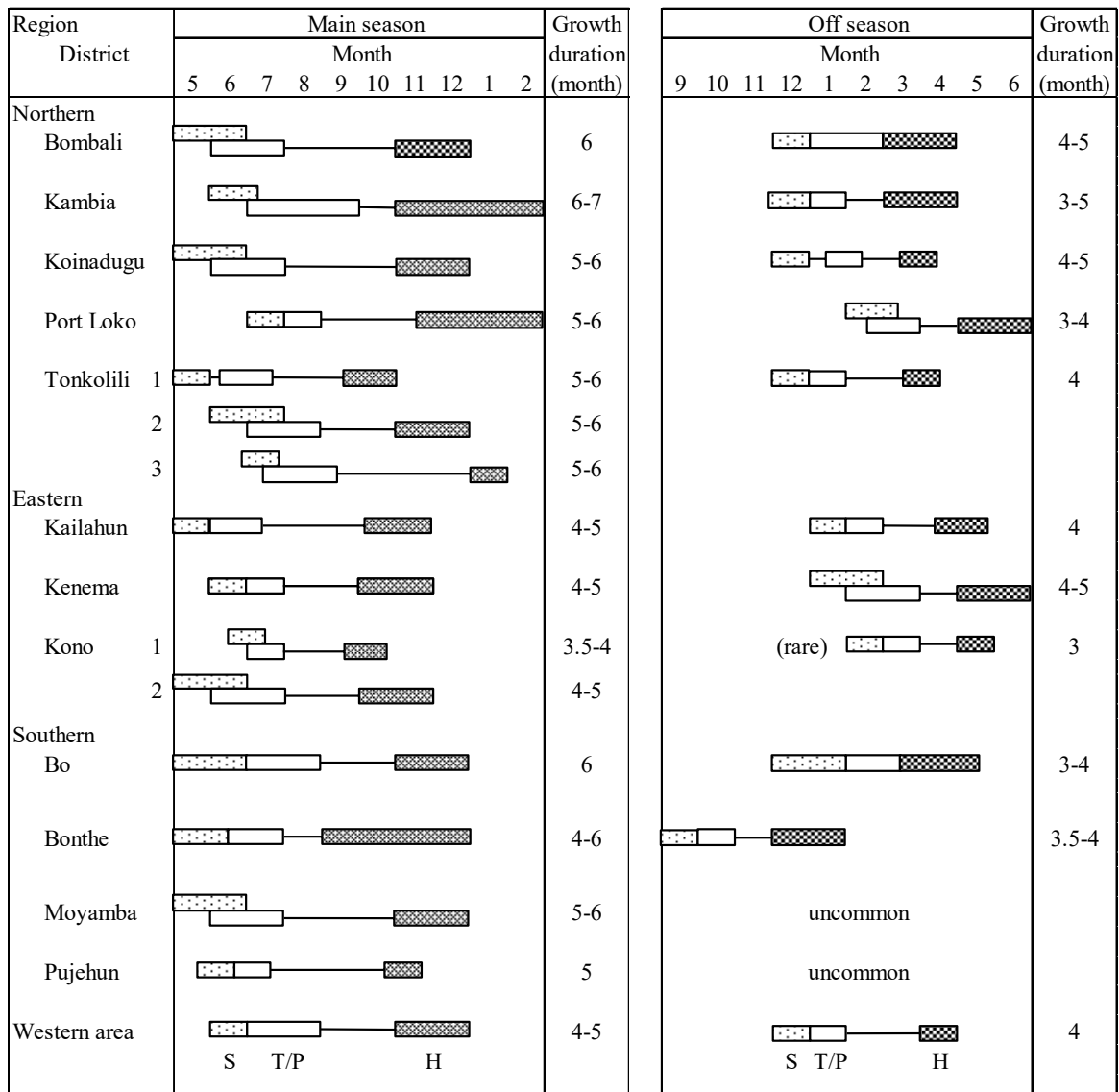
As for transplanted lowland rice cultivation, the timely transplanting of healthy seedlings is of primary importance in ensuring good production. The optimal nursery period is 2-3 weeks. In practice, however, the transplanting of old seedlings, sometimes two months old, is not rare mainly due to delay in land preparation, especially plowing. Farmers often sow the seeds on nursery bed before completing plow.

All the field activities should be planned in advance before the planting season starts, taking into account all conditions like cultivars, the availability of labourer and input, the area of land to be cultivated, and also all necessary burden in upland cultivation. In planning activities for rice culture in lowlands, first cultivar to be used and transplanting date should be set, while one should consider to avoid the peak rainy season for top dressing and to fit sunny days for the ripening stage (Table 5-1, A1.5-1). Then, counting backwards from the nursery period, the sowing date in the nursery is determined. The plowing of the main field should be completed before sowing the seeds in the nursery since plowing is the most laborious and time-consuming work in lowland rice cultivation.

Seed dormancy

Almost of all cultivars possess seed dormancy no matter what the degrees may be. This is favorable trait for rice plants by preventing germination during ripening stage even though temperature and moisture condition is suitable for it. Furthermore, the trait protects shattered and dropped seeds on the ground from unusual germination: if they germinate, they might be killed with drought during the coming dry season. Yet, it is unfavorable character when one intends to plant year round.

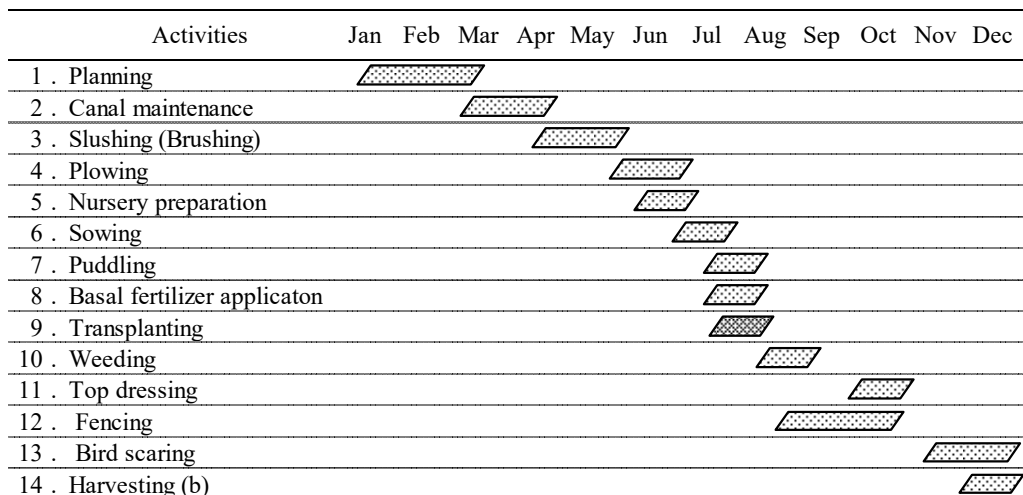
Heat or acids artificially break the dormancy, but such treatment is impracticable by ordinary farmers. Seed dormancy is gradually diminished with time of storage. In general, the period of dormancy is longer by strong photoperiod-sensitive cultivars (sometimes a few months under natural condition), and shorter by weak photoperiod-sensitive cultivars (e.g., 2-4 weeks). Modern high-yielding cultivars are selected to possess weak dormancy, because they are released to be good for double cropping a year.



S: sowing, T/P: transplanting, H: harvesting.

Fig. 5-3. Some examples of rice cropping season in inland valley swamp in various districts of Sierra Leone. Information collected during the training on TP-R for MAFFS staff by SRDP/JICA in 2014.

Table 5-1. Proposed farming calendar for rice cultivation in IVS ecology (a).



a) Cultivar of 5-month growth duration with transplanting method.

b) Including threshing, winnowing, drying, and bagging.

6. Seed production

The use of quality seed is another precondition to obtaining a high yield. Quality here corresponds to high purity and high germination rate. The main topic in this section is the former. As for the seedling raising, refer to Section 3-3.

1) Securing pure seeds

Sorting-out of mixed seeds at planting time is better to be done, but it is insufficient and too late because the procedure allows only the elimination of grains different in appearance like shape and color. Plant stature, growth duration, tillering habit and other important characters relevant to dry matter production are impossible to eliminate after harvesting. At the same time, farmers often complain a mixture of their own seeds and appeal the seed shortage. However, as there is no responsible seed producer in the country at present, it is only the farmers who take the responsibility of all these issues.

All subsistence farmers should rely on the seeds that they produce. They themselves are only able to guarantee the purity and viability of the seeds. For the present level of grain yield (about 1 t/ha), mixed cultivars would not substantially affect the production. Because of this, many farmers do not pay much attention to the purity of the seeds they use.

Mixing seeds of different cultivars, however, makes it difficult to determine the timing of the harvest. Under the present conditions that the shattering rate is high in many cultivars, the farmers are destined to lose part of the expected production of either early or late maturing cultivars if the seeds that they use are not pure. Panicle harvesting commonly practices in the eastern parts of the country helps avoid the problem, although labour burden is much larger than harvesting by sickles.

2) Seed multiplication field and roguing

Recommended hill spacing is 30 cm x 30 cm (square planting) and a single plant per hill in seed multiplication fields. This practice easily makes to rogue off-type plants in frequent walking around in fields on foot. Roguing frequency is twice each during the vegetative growth and ripening stages in addition to one roguing at heading or flowering. Pull out or rogue any off-type plants (hills) that are different from the majority of the plants in the field.

At present, the farmers sometimes rogue off-type plants (often by cutting the panicles only) shortly before the harvesting time and use them for food: saving wastage of the transplanted rice. With this practice, late maturing genotypes cannot be rogued since the grains of these types are able to germinate even though they are not fully matured. It is wise that when the maturity of plants is obviously late at harvesting time, farmers are used to remain them in the field until next round of harvesting. Yet, the practice is tedious and time consuming.

3) Seed handling

One should pay full attention to keep the seed purity obtained in the field in harvest and post-harvest processes: cutting, threshing, drying, bagging and storage. Among various reasons for seed mixture, mechanical mixture is the most possible and preventive. Cleaning of the threshing ground and storage bags are the first to do.

4) Self stock of seeds

Seed supply is the lifeline of the farmers. If the required quantity of seeds cannot be stocked in a single year, the farmer must make efforts to stock at least a portion of the required quantity every year. Through such efforts, farmers will eventually be able to secure their own seeds within a few years.

Seed viability

Seeds require temperature and water (moisture) for their germination. When the two conditions are provided, seeds start various biochemical activities ready for germination using stored energy, and gradually lessen their viability and vigor (seed deterioration) with time prolonged. Under the tropical lowland condition, temperature is usually adequate for plant growth. Hence, rice seeds are ready to start germination whenever they get moistened.

In Sierra Leone, air humidity is kept high during the long rainy season. Rice seeds are put in bags, which are piled up one on top of another during storage so that poor ventilation easily induces seeds moistening. Hence, seed viability (germination rate) is often decreased, or even totally lost, when the seeds are passed over a rainy season. In some cases, mold infects the storing seeds. Whenever one intends to grow dry season culture, seed production of intended cultivars is strongly recommended during a preceding rainy season, although many experienced farmers have practiced the seed renewal.

Panicle-harvested bunches are stored by hanging them from a crossbeam in a cooking place by some farmers. This storage method is favorable for grains or seeds, because the hanging above fire and smoke make free from moisture and insects. Seed quantity recommended by the Package (Table 3-3) is much less than the conventional methods, sickle harvesting farmers can adopt the above-mentioned method for seed storage.

7. Lowland development and water control

Land development is essential for lowland rice culture. Proper water control helps grow plants healthy, make fertilizer use efficient, and eventually produce high yield. Because rice in the country is mainly grown in the rainy season, proper water control is a must. The total rainfall amounts to about 2,000 mm during a growth season in many areas (A1.5-2). Daily rainfall exceeding 200 mm is not rare during the peak rainy season in many locations of Sierra Leone (A1.5-3).

Heavy rain causes flood, which wash applied fertilizer away from the field. To prevent such losses, drainage construction, bund making, and land leveling, are required in lowland rice fields. Without proper water control measures, fertilizer application is not recommended.

7-1. Bund (dike) construction

Running water in rice fields causes the soil to erode, nutrients to leach out, and transplanted seedlings to flow away. Fertilizer application under running water should be avoided in such areas. To avoid or minimize the negative effects of running water, the water should be controlled.

Small-scale bunds and drainage structures are recommended in lowland rice fields. First, water drainage needs to be considered. Bunds are constructed after slashing or plowing. Because there is no hydrological data at present, engineers should work together with the farmers in the field, consulting the farmers about their experience and observation on rainfall and water discharge.

7-2. Land levelling

Lowland rice fields should be levelled to make water control easy. Height difference in a plot is ideally within 5 cm, or 10 cm at its maximum, though the land levelling work is really a laborious.

When a plot size is 100 m x 100 m with 0.2 m height difference (Fig. 7-1), for example, the soil volume (or weight) needed to be levelled is:

$$100 \times 100/2 \times 0.1 \times \frac{1}{2} = 250 \text{ m}^3 \text{ or} \\ = 250 \text{ ton (assuming that the specific weight is } 1 \text{ g/cm}^3\text{)}$$

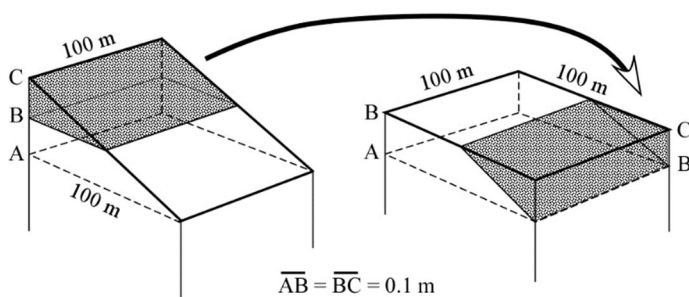


Fig. 7-1. Levelling of a sloping field (acreage: 1 ha).

Plot levelling requires a hard work because such a large quantity of soil is needed to move 50 m distance (an average) in the case of the above-mentioned example. Therefore, it is recommended that bunds are always constructed along contour line whenever one intends to develop lowlands (Fig. 7-2).

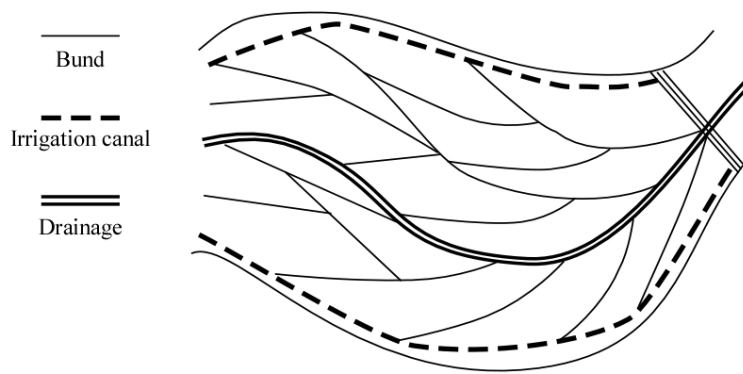


Fig. 7-2. An example of contour bunding in a small inland valley swamp.

Whatever a plot size becomes small, levelling the plot holds a priority. Because all field works like plowing, transplanting and harvesting are manually practiced at present, small plot size does not hinder the work efficiency. Only when the plot size is too small and inconvenient for mechanization, one can extend the plot size.

7-3. Water control for fertilizer application

It should be common knowledge that the majority of chemical fertilizers easily dissolve in water. Chemical fertilizers must not be put into running water, since the effects are disastrous. Keep shallow water depth when one applies fertilizers.



Phot 7-1. A primitive but effective barrage.

8. Economic analysis of rice production

8-1. Basic information and conditions on economic analysis

- 1) Primary data necessary to estimate cost-benefit analysis are:
 - a) Labour requirements in respective farming activities;
 - b) Family labourer and hired labourer;
 - c) Daily wage (income);
 - d) Cost of variables; and
 - e) Rough rice price.
- 2) Cost and benefit are analyzed on the presumption that:
 - a) Agro-ecologies is lowlands (mainly IVS) with a transplanting system;
 - b) Farming activities are manually practiced as the majority of farmers do;
 - c) Grain yield is 1 t/ha under the conventional farming system, is to increase to 2 t/ha with the improved cultural practices, and further to 3 t/ha with fertilizer application (Figs. 1-1 and 1-2); and,
 - d) Land rental, if any, and/or contribution to the community, etc., are not subtracted from grain production.
- 3) Basic information obtained
 - a) Labour requirement for rice culture: Information on labour cost and the results in literature were summarized in Table 8-1, including the results in Sierra Leone and other countries. The total labour requirement for one rice culture varied much, 102-484 person-d/ha. The values were mainly based on conventional farming. The total labour cost in Case 5 is small because extensive agriculture farming would have been practiced. Case 9, a case of traditional practices in Japan showing a modest labour requirement, utilizes draft animals for land preparation. Larger values (440-484 person-d/ha) in cases 2 and 8 were difficult to explain. Cases 3 and 4 seem to provide more or less reasonable labour requirements by manpower.

Table 8-1. Labor requirement for rice farming depended on mostly manual work.

Case	1	2	3	4	5	6	7	8	9	
Country	Sierra Leone						Ghana	Uganda	Japan	
Agro-ecologies	Upland	IVS	IVS	IVS	Boli	MS	Lowland	Lowland	Irrig.	
Grain yield (ton/ha)	0.8-1.3	1.2	-	2.2-2.7	0.96	1.9	Ghana	2.5	3.8	
Total labor (person-d/ha)	205-238	440	308	274-356	112	136	102	484	260	
Labor proportion (%)	Land preparation (clearing, plowing, maintaining bunds and canals, puddling, etc.)									
	-	46	35	-	-	11	-	28	-	
	Crop establishment (nursery preparation, uprooting, transplanting, etc.)									
	-	17	28	-	-	36	-	9	-	
	Crop care (weeding, bird scaring, etc.)									
	-	17	10	-	-	0	-	44	-	
	Harvesting (harvesting and threshing, winnowing, drying, bagging, etc.)									
	-	20	28	-	-	53	-	20	-	
Note						(a)			(b)	(c)
Reference	Spencer (1981)	SRDP (2013)	SRDP (2014c)	Spencer (1981)	Spencer (1981)	JICA (1983)	Kijima (2013)	Kijima (2013)	Kyuma (2011)	

- no data. a) By manual farming. b) 30% for bird scaring. c) 1945-1950. Plowed with cattle. Spent 20% for manual weeding. Abbreviations: Boli: boliland, MS: mangrove swamp, Irrig.: irrigated rice field.

- b) When family labourers are not enough to complete any specific farm work in a required time, the farmers mobilize labourers from outside to supplement the workforce. According to the interview survey, the daily wage (income) of a hired labourer is reported at Le 20,000 per person-day with lunch in case of individual employment¹. Family labourers are not paid, and there are many cases of exchanging work without paying in a community.
- c) The number of active agricultural family members is assumed at 2.8 persons/HH (Table 1-1).
- d) The cost of variables (tools, bags, etc.) is estimated at Le 419,000/y (Table 8-2). The cost of NPK compound fertilizer (15-15-15) is Le 10,200/kg as the market price in 2022. Seed requirement is 30 kg/ha (Table 3-3), which are supposed to be supplied from their own product. The cost of seeds is the same as the price of rice: Le 4,960/kg.

Table 8-2. Cost for expendables (a)

Item	Unit price (Le/ piece)	Life span (y)	No. of pieces needed (/ha.y)	Total cost (Le/ha)
Hoe	95,000	2	5	237,500
Knife (sickle)	45,000	4	2	22,500
Tarpaulin, palm mat, etc.	150,000	3	1	50,000
Winnower	15,000	5	3	9,000
Rice bag (b)	5,000	1	20	100,000
Total				419,000

a) obtained from interview from a service provider.

Expendables cost except rice bags is the same regardless of production.

b) Rough rice capacity = 50 kg/bag. Grain production of 1 t/ha needs 20 bags

- e) Mean farm gate price of rough rice was Le 4,960/kg averaged over the four districts based on the end-line survey results in February 2022.

8-2. Cost-benefit analysis

8-2-1. Costs

- 1) The total cropped area of a subsistence farm is calculated at 3.0 ha/HH based on 1.6 ha/HH of a rice field (including 0.7 ha/HH of upland rice) (Table 1-1), assuming that upland crops were grown in other two places, each of which has the same size as the upland rice area.
- 2) Based on the following assumptions, the total capacity of farm works is calculated at about 870 (= 2.8 x (4/5) x 300 x 1.3) person-d/HH.
 - a. Four-fifth (4/5) of the persons in agricultural work (2.8/HH, Table 1-1) are engaged in farming (others in processing palm oil, cassava flour, etc.),
 - b. Net farm farming days are 300 d/year (10 months/year),
 - c. Thirty percent of labour requirement depends on hired labourers (in land preparation, weeding, and harvesting),

As the total cropped area is 3.0 ha / HH, the average labour requirement per unit of farm area is calculated at about 290 (= 870/3.0) person-d/ha).

¹ Data for the individual labourer was obtained from the Kambia District. In many cases, labourers are collected by a foreman whom the farmer normally ask the work. In this case, a group of labourers will be organized and sent to the farm, and the farmer pay the cost to the foreman, not to the labourers. Cost of each labourer is less than that of individual labourer, according to the interview.

- 3) Labour requirements for land preparation, crop establishment, crop management, and harvesting are assumed respectively at 40, 25, 15, and 20% based on Table 8-1. As the total labour requirement is set as 290 person-d/ha, labour requirement in respective activities is calculated at 115, 73, 42, and 60 person-d/ha.
- 4) Labour cost is estimated at Le 14,000/person-day, 70% of the individual labour cost assuming that the labourers are mobilized as a group and that the each labourer's cost is 80% of the individual labourer. The labour cost per unit field area is then calculated at Le 4,640,000 (= 16,000 x 290)/ha.
- 5) Thus, the total cost is estimated at Le 5,207,800/ha by summing costs of labourer, variables (Le 419,000/ha, Table 8-2), and seeds (Le 148,800/ha; 30 kg x Le 4,960/kg).

8-2-2. Benefit under the conventional farming

1) Gross benefit

Based on the estimated rice grain yield of 1.0 t/ha under the conventional farming system and the farm gate price of rough rice at Le 4,960/kg, the sale price of the whole production is calculated at Le 4,960,000/ha.

2) Net benefit

The net benefit of rice production under the conventional farming system becomes Le -247,800 (4,960,000 - 5,207,800)/ha, showing a negative balance.

Farmers would have accepted it, as most of the production is destined for home-consumption, loan repayment, and seed for next season, which are not for sale. Also, since the labour cost includes that of the family labourers, actual household expenditure will not be negative. When one wants to orient rice production to business, incremental production has to come with profit.

8-3. Cost-benefit analysis of different culture systems

Based on the result of the cost-benefit analysis under the conventional farming system presented in the previous section, the analysis under two other practices is made. Presumptions for the analysis are enumerated below.

- a) Labour requirement in land preparation and crop management works increases in improved cultural management, as bund and canal maintenance work and weed management are added. That in harvesting works also increases due to yield increase. Total labour requirement and its distribution by farming activities under an improved cultural management system and fertilizer application are assumed as shown in Table 8-3.

Labour requirements in crop management increase under fertilizer application as the works for fertilizer application and water management are added.

Table 8-3. Assumed labour requirements and their distribution by activities

	Conventional management		Improved management		Improved management + fertilizer application	
	Person-days	%	Person-days	%	Person-days	%
Land preparation	115	40	138	36	138	33
Crop establishment	73	25	73	19	73	17
Crop management	42	15	80	21	90	21
Harvest	60	20	90	24	120	29
Total	290	100	381	100	421	100

- b) The cost of variables was the same as in Table 8-2 except for the number of rice bags, which is proportionally adjusted with a yield level.
- c) The fertilizer (N-P₂O₅-K₂O) dose is set at 40-40-40 kg/ha with the NPK compound fertilizer (15-15-15).

1) Cost-benefit analysis in three cultural systems

Production cost, the value of rough rice, and net profit under three cultural systems are shown in Fig. 8-1. Because the total cost essentially increases with an application of fertilizer, net profit by improved culture much increases than that of conventional farming. Fertilizer application increases the net profit further, but not as much as the cultural improvement.

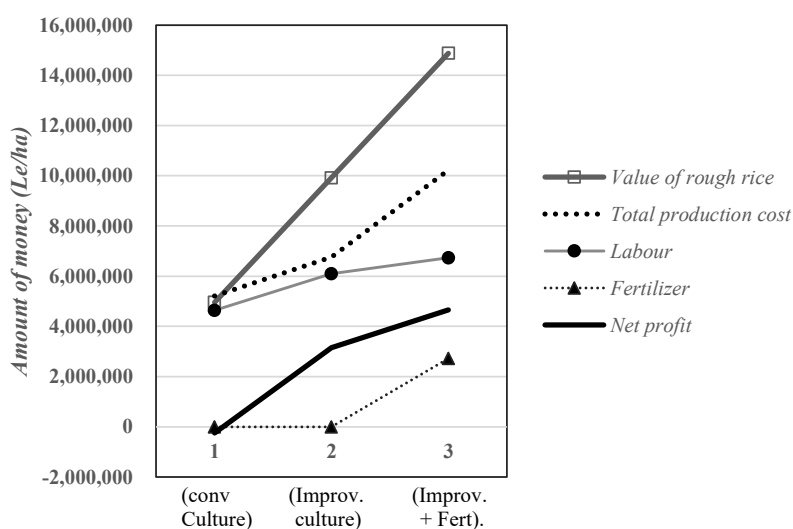


Fig. 8-1. Production cost, value of rough rice, and net profit under conventional rice culture and under improved culture system with and without fertilizer.

8-4. Sensitivity analysis of fertilizer application

8-4-1. Sensitivity analysis relevant to yield response

1) Background

Fertilizer cost at 40-40-40 kg/ha of N-P₂O₅-K₂O is about Le 2,720,000 (i.e. 10,200 x 40/0.15) with NPK compound fertilizer (15-15-15). An increase in the costs of labourers and variables as a result of fertilizer application is Le 660,000/ha². The total of cost increase is equivalent to the market value of 0.68 (i.e. 3,380,000 / (4,960 x 1,000)) t/ha of rough rice. A proportion of the equivalent value of rice and fertilizer and labour costs is defined herein simply as a fertilizer recovery ratio. When 0.68 t/ha of increment is attained with 40-40-40 kg/ha of fertilizer, as in the above case, the fertilizer recovery ratio is one.

When the fertilizer recovery ratio is less than one, or the yield increment (the response) with fertilizer is less than 0.68 t/ha, the fertilizer cost will not be recovered. The response varied 0.6-1.8 (an average of 1.1) t/ha under the well-controlled water condition by the SRDP fertilizer trial (Fig. 4-6) and 0.0-2.8 (0.9) t/ha in IVS by various past fertilizer trials by RARC (Fig. 4-7). These results show that farmers can secure a certain profit if the fertilizer response attains the average.

² Labour cost in fertilizer management, water management, and harvest (40 person-days/ha), and rice bag (20 units).

2) Suggestion to fertilizer application

Rice productivity must first be enhanced with improved culture practices and then fertilizer application follows. Improved culture system alone provides about Le 3,160,000 worth profit per hectare (Fig. 8-1). By applying fertilizers, the yield response should be larger than 1.08 t/ha (Fig. 8-2), when one intends to earn the same or larger profit than the one obtained with the adoption of improved culture practices over the conventional system. As many past examples show, an opportunity to realize such a large response is infrequent (Figs. 4-6 and 4-7).

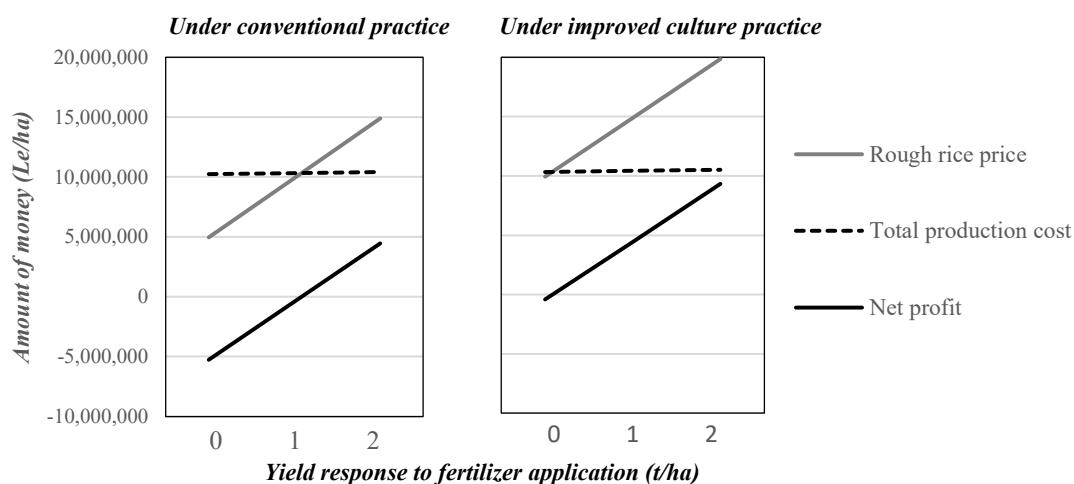


Fig. 8-2. Sensitivity analysis of production cost and profit as a function of yield increment by fertilizer application under conventional and improved culture systems.

8-4-2. Sensitivity analysis on fertilizer cost, labour cost, and rice price

Fertilizer cost, labour cost, and rice price are major variables to control the profit. A sensitivity analysis was made to examine how those variables affect the profit (Table 8.4).

Under the current economic condition where fertilizer cost is Le 10,200/kg, where the labour cost is Le 16,000/d, and where rough rice price is Le 4,960/kg³, net profit of more than Le 4,500,000/ha is secured. Under the current high rice price which favors the producers, even the cost of fertilizer increases by 50%, net profit of Le 3,000,000/ha will be secured.

Table 8-4. Sensitivity analysis on the fertilizer cost, labour cost, and rice price

Cases	Value of rough rice	Labour cost	Fertilizer cost	Total production cost	Net Profit
Current Situation (a)	14,880,000	6,736,000	2,720,000	10,223,800	4,656,200
Fertilizer cost increases by 50% (b)	14,880,000	6,736,000	4,080,000	11,583,800	3,296,200
Labour cost increases by 20% (c)	14,880,000	8,083,200	2,720,000	11,571,000	3,309,000
(b) + (c), (d)	14,880,000	8,083,200	4,080,000	12,931,000	1,949,000
Value of rough rice decreases by 20% (e)	11,904,000	6,736,000	2,720,000	10,223,800	1,680,200
(b) + (e)	11,904,000	6,736,000	4,080,000	11,583,800	320,200
(d) + (e)	11,904,000	8,083,200	4,080,000	12,931,000	-1,027,000

Unit: Le /ha.

³ The current price of rough rice: Le 4,960/kg, may be too high considering the recent international market price of white rice, between US\$400 and 500/ton. However, since the figure was the average value of those obtained from many farmers in the four districts during the end-line survey, no revision is made.

9. Appendices

A1. Useful information on plant, soil, climate, etc.

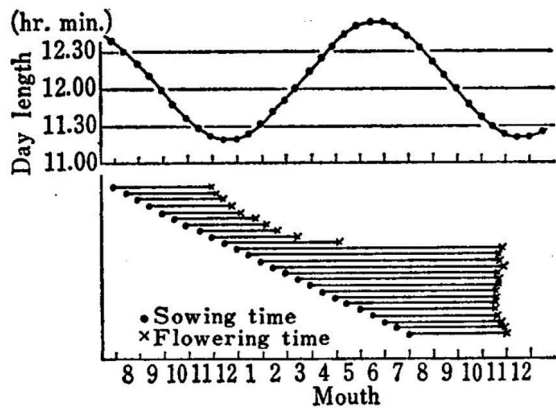
A1.1. Plant physiology

A1.1-1. Essential elements of higher plants

Group	Element
Macro-element	C, H, O N, P, K, S, Ca, Mg
Micro-element	Fe, Mn, Zn, Cu, B, Mo, Cl, (Ni ?)

Beneficial elements: Si, Na, Al, Co, Ni, Se

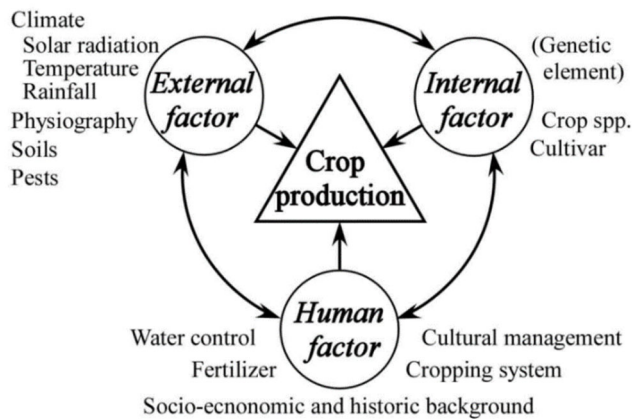
<Element essentiality signifies that plants does not survive without it.>



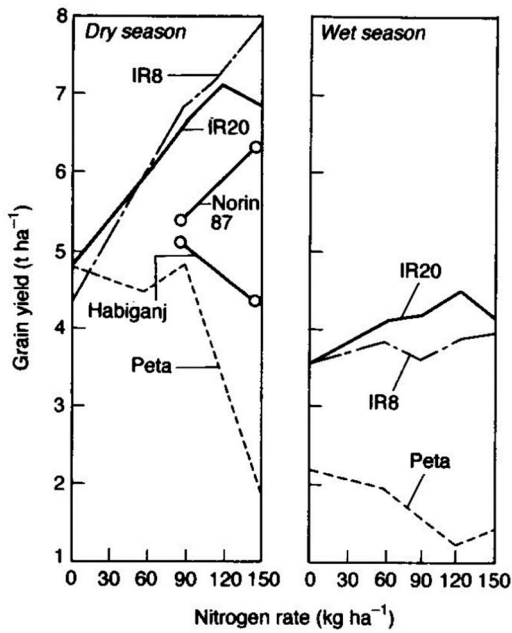
A1.1-2. Growth duration of photoperiod-sensitive cultivars (Neang Meas) affected with day length at Battambang Neang Meas, Cambodia (Sato, 1960).

<Growing period of photoperiod-sensitive cultivars becomes short with short day length.>

A1.2. Agronomy

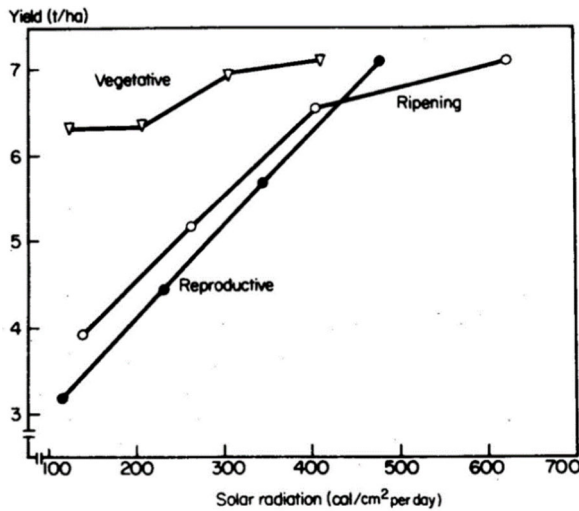


A1.2-1. Factors controlling crop production.

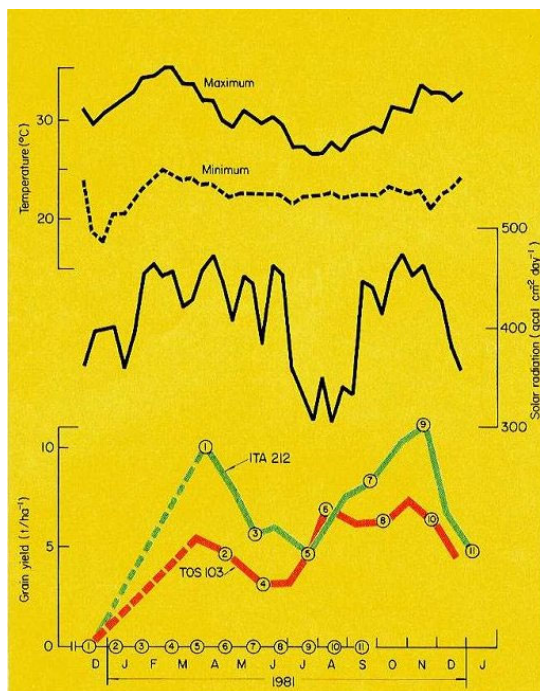


A1.2-2. Fertilizer response in dry and wet season at IRRI (Greenland, 1997).

<Grain yield is higher in dry season cropping than in the rainy season, due to larger solar radiation.>



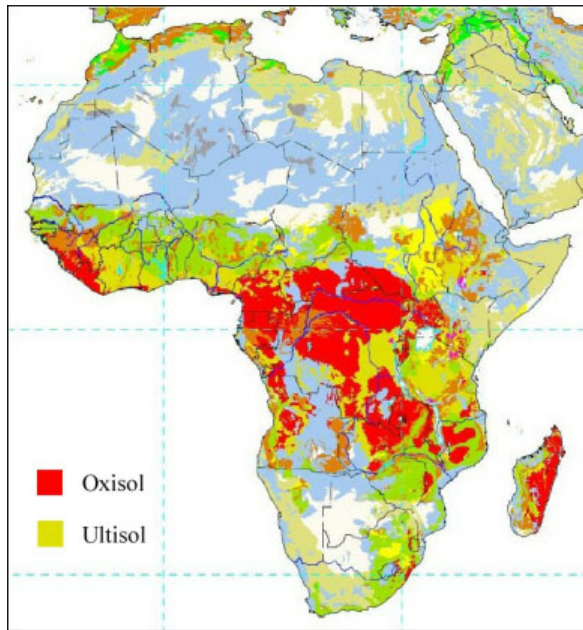
A1.2-3. Grain yield affected with solar radiation at different growth stages (Yoshida, 1981).



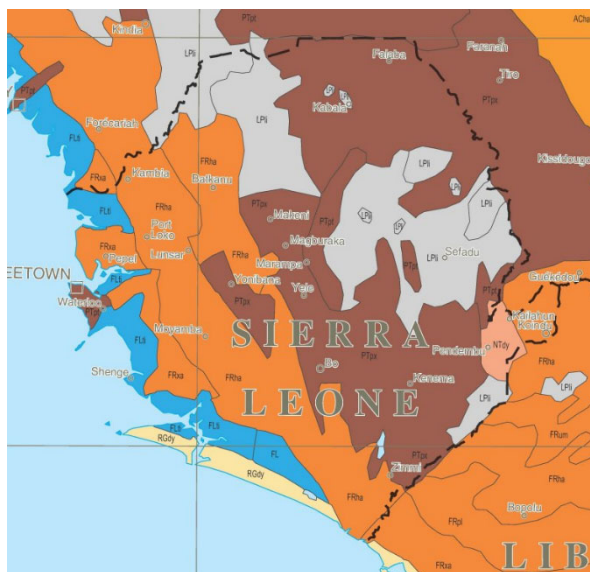
A1.2-4. Grain yield affected with solar radiation by monthly plantings of rice plants at IITA (Yamaguchi, 1981).

<Grain yield is higher when rice plants are grown under larger solar radiation condition.>

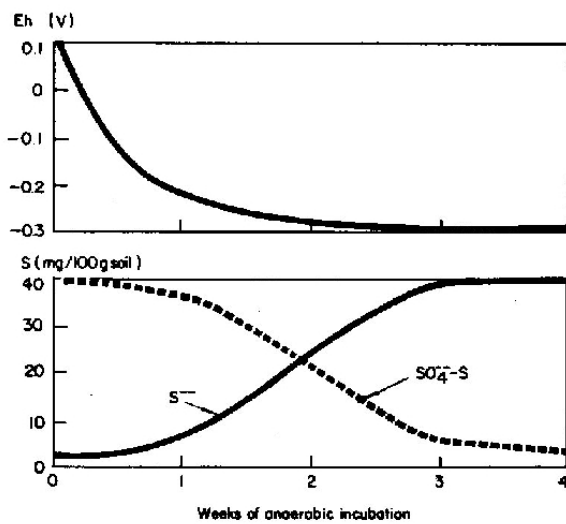
A1.3. Soil Science



A1.3-1. Soil map of Africa (Soil taxonomy, 2005).



A1.3-2. Soil Map of Sierra Leone (EC, 2013).

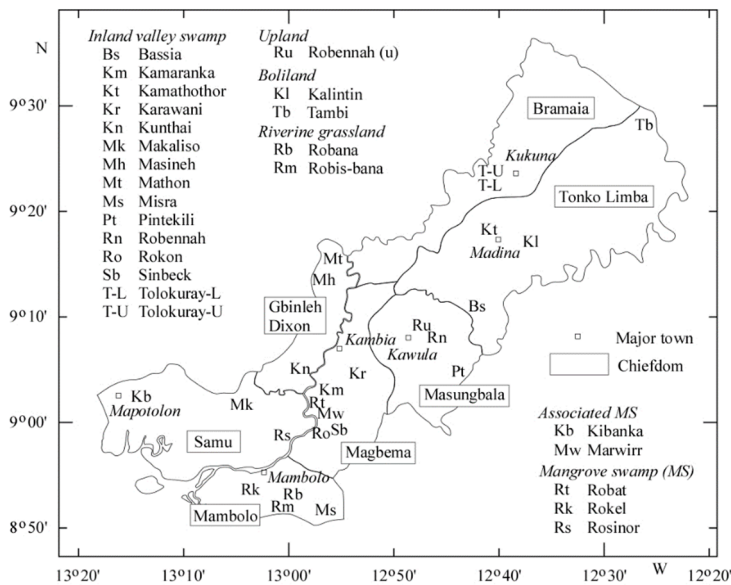
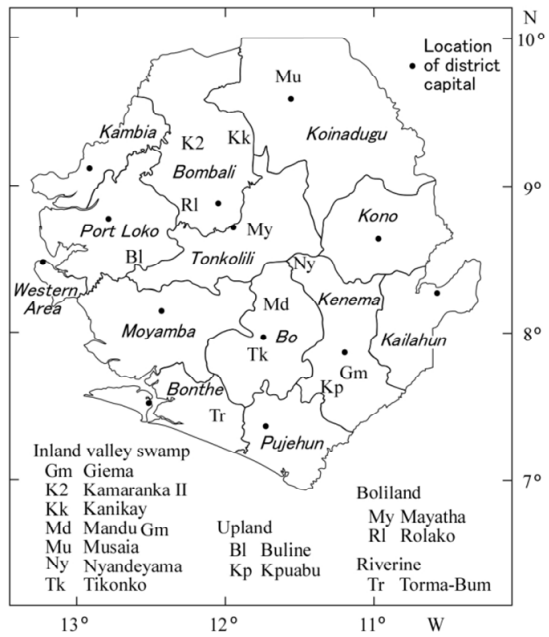


A1.3-3. Relationship between Eh and sulfate reduction under submergence (Yamane and Sato, 1961).

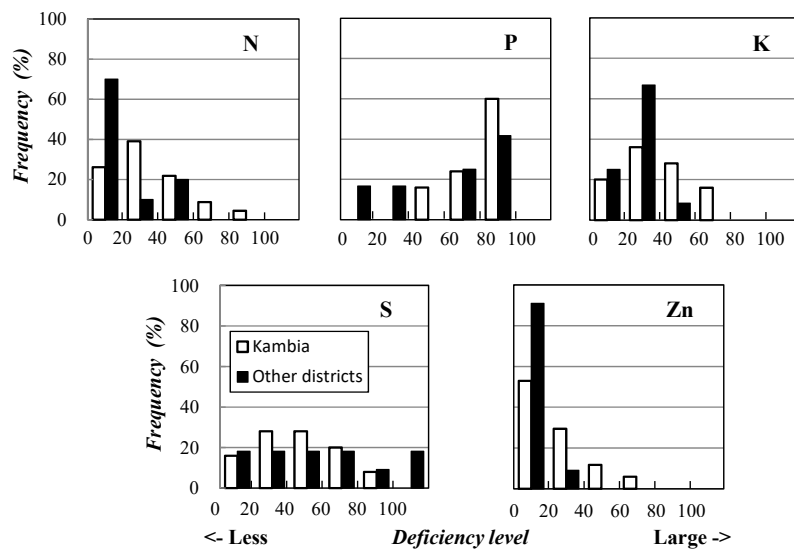
A1.4. Fertilizer trials

A1.4 (1) Pot trials

A1.4-1. Soil collection sites in various districts other than Kambia.



A1.4 (1) -2. Soil collected in Kambia district.



A1.4 (1)-3. Frequency of nutrient deficiency levels in Kambia and other districts.

A1.4 (2) Fertilizer trials in fields by SRDP

A1.4 (2)-1. Fertilizer trials at seven IVSs in Kambia district

Fertilizer treatment (N-P ₂ O ₅ -K ₂ O-S kg/ha)		Trial site (village)	Cropping season	
			Rainy 2013	Dry 2013 -2014
1	0- 0- 0- 0	1 Fayale	*	
2	60- 40-40- 0	2 Laya	*	*
3	20- 40-40- 0	3 Masiaka		*
4	20- 40-40-10	4 Masineh	*	*
5	20-100-40-10	5 Rotifunk		*
		6 Tawuya		*
		Munu		
		7 Tolokuray	*	

A1.4 (2)-2. Total fertilizer applied, ingredient composition, mean grain yield and yield response to fertilizer application in fertilizer trials by ADPK and SRDP.

Project	Agro-ecology	No. of sites	Year	Crop season	Total ingredient (kg/ha)	Ingredient proportion (N =100)				Mean grain yield (ton/ha) (c)		Mean response (ton/ha)
						N	P ₂ O ₅	K ₂ O	S	-F	+F	
ADPK	(a)	(a)	2007	Rainy	91	100	25	25	0	0.9	1.3	0.4
			2008	Rainy	101	100	53	53	0	1.4	2.0	0.6
SRDP	IVS	4	2013	Rainy	130 b)	100	242	167	25	1.9	2.8	1.0
			2014	Dry	130 b)	100	242	167	25	1.8	2.9	1.0

a) Number of sites in each ecology: 2 and 2 in upland, 3 and 2 in IVS, 1 and 1 in boliland and 2 and 3 in mangrove swamp respectively in 2007 and 2008.

b) Average of 60-40-40-0, 20- 40-40-0, 20-40-40-10, and 20-100-40-10 kg/ha of N-P₂O₅-K₂O .

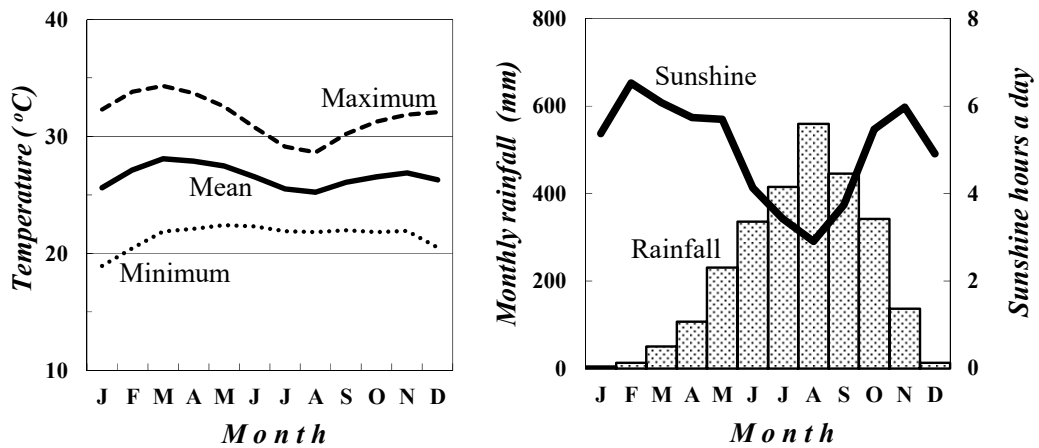
c) -F: without fertilizer, +F: with fertilizer.

A1.4 (3) Experiment results reported by RRSR, IITA, FAO, etc. in Sierra Leone

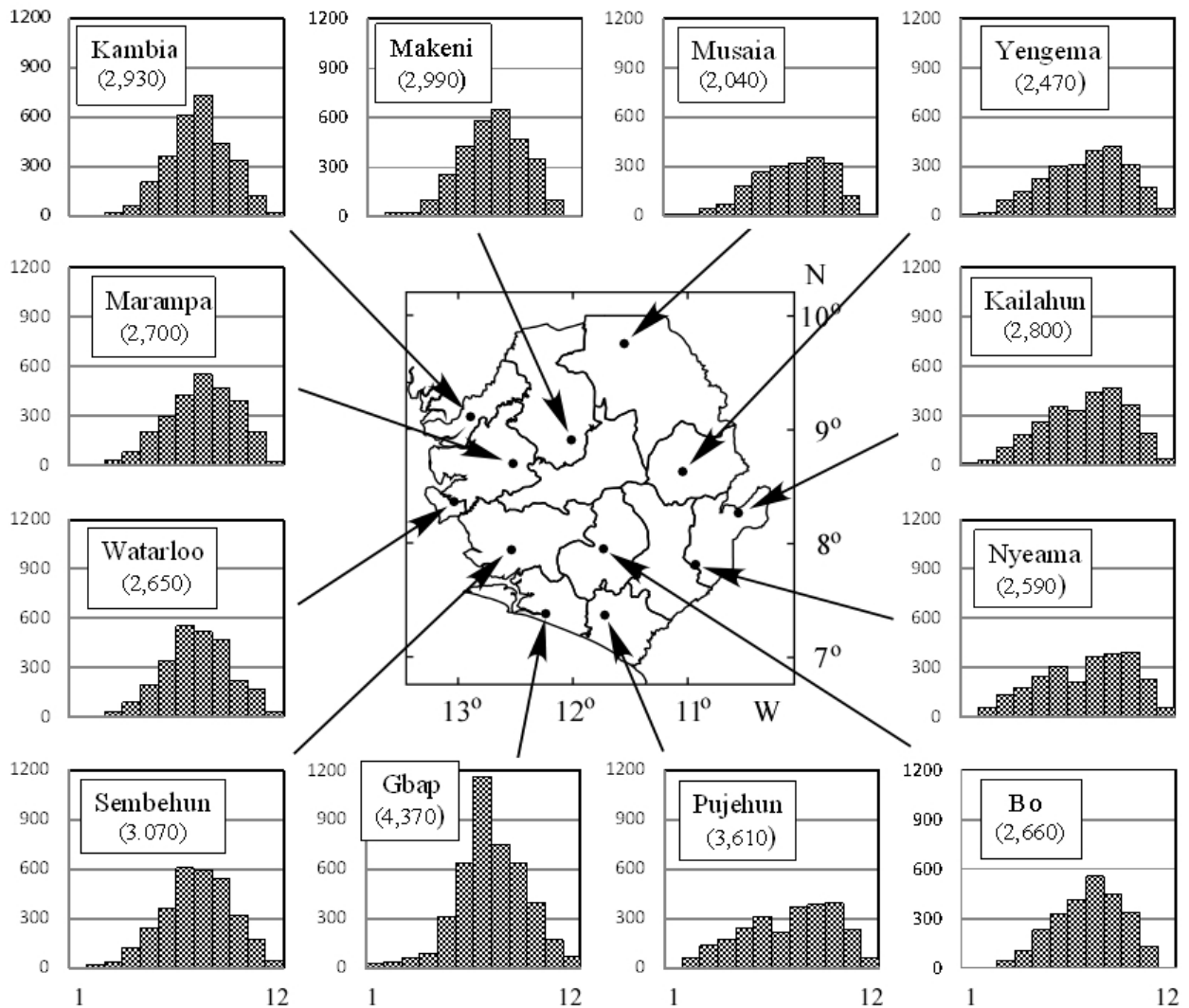
A1.4 (3)-1. References for compiling gain yield and the yield response to fertilizer application of rice plants in Sierra Leone

RRSR Annual Report	RRSR, 1975 (workshop)
1972	1989
1978	1990
1980	1991
1983-1984	1992
1984-1985	1993
1985	1994
1986	1996-1999
1988	2009-2010
	IITA Ann. Rep., 1976
	UNDP/FAO/IITA, 1984
	FAO/IITA, April 1976 (5)
	FAO/IITA, October 1976 (6)
	EEC/RRSR, 1994

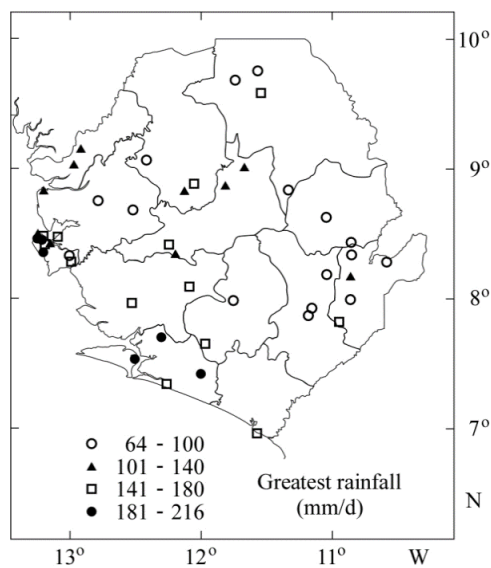
A1.5. Climate



A1.5-1. Monthly changes of temperature, rainfall and sunshine hours at Bo (7°58' N, 11°45' W) (Meteorological Dept., 2014). Averaged over 1981-2007 with missing data differed in climatic elements.



A1.5-2. Monthly rainfall (mm) at the selected stations in Sierra Leone. Total rainfall in parentheses (Illustrated on the basis of British West African Meteorological Services, 1960 and Meteorological Dept., 2014).



A1.5-3. Greatest rainfall a day in 1960 (British West African Meteorological Services, Sierra Leone, 1960).

A1.6. Statistics

A1.6-1. Current grain yield of rice culture in Sierra Leone

Data source	Grain yield (ton/ha)
PEMSD (2013)	1.2-1.96
FAO (2013)	1.8
AHTS	0.47
Peters (GIZ, 2014)	0.5-1.5
SRDP (a)	0.5-1.0

a) Estimation based on the baseline survey (ADPK), field trials at FBO sites, SRDP fertilizer trials and experiment results reported by RARC, etc. for the past 40 years.

A2. Terminology

brown spot	<i>Cochliobolus miyabeanus</i> (<i>Helminthosporium oryzae</i>)
bund	dike in the lowland rice fields
bush fowl	<i>Francolins bicoloratus</i>
cultivar	variety and line
case-worm	<i>Nymphula depunctalis</i> , <i>Parapoynx stagnalis</i>
crawling grass	<i>Paspalum vaginatum</i> , indigenous species in the area. In the local language, 'kireh-kireh (or kiri-kiri)'.
cutting-grass	<i>Thyronomis swinderiannus</i> . In other regions of West Africa, it is called grass-cutter.
DMRT	Duncan's multiple range test
gall midge	<i>Orseolia oryzae</i> (<i>Pachydiplosis oryzae</i>)
leafhopper	<i>Nephotettix</i> spp.
leaf scald	<i>Metasphaeria albescens</i> , <i>Fusariumn ivale</i> & <i>Rhynchosporium oryzae</i>
oil palm	<i>Elaeis guineensis</i>
paddy	rough rice; unhulled rice
plant-hopper	<i>Nilaparvata</i> spp., <i>Sogatella</i> spp.
puddling	breaking up soil clods and flattening the surface of rice fields with water after plowing (digging); harrowing (tilling) rice fields under the water to prepare for transplanting.
rice blast	<i>Magnaporthe grisea</i> (<i>Pyricularia oryzae</i>)
rice bug	<i>Scotinophra</i> spp.
ripening	synonym of grain filling
ripened percentage	the ratio (percentage) of the number of filled grains to that of total spikelets. An antonym of sterile percentage (roughly).
stalked-eye fly	<i>Diopsis thoracica</i>
stem-borer	<i>Chilo</i> spp., <i>Maliarpha</i> spp., <i>Sesamia</i> spp.
water duck	'ealele' in Temne
weaver	<i>Ploceus cucullatus</i> , <i>Quelea quelea</i>

A3. Conversion table

bag	1) Fertilizer: Mostly 50 kg/bag and sometimes 25 kg or 40 kg/bag. 2) Milled rice: 24 dozens of cups/bag.
cup	The most common measurement unit (container) for milled rice. The unit weight is adopted as 250 g/cup by MAFFS, but it is 260-300 g/cup in commercial market.
bushel (bu)	1) Rough rice (paddy): The official rate is 25 kg/bu. However, the going rate varies from 34 to 52 kg/bu among households, villages and chiefdoms in Kambia district, for example. 2) Cropped area: Field area of 1 bushel is assumed to be equal to 1 acre, sown with 1 bu (volume) of rice seeds. Measured area was 0.7±0.3 (mean±SD) ha/bu in Kambia district.
ha	10,000 m ² ≐ 2.47 acre (1 acre ≐ 4,047 m ²).
kerosene tin	30 lbs (= 13.5 kg) at the official rate. Commonly used in the eastern region. Often simply called as tin.
kg	about 2.2 lbs
Le	Leone, currency unit in Sierra Leone. Le4,500 ≐ US\$1.00 (late 2013 to early 2014)

m	about 3.3 feet = 1.09 yard
MJ	1 MJ m ⁻² = 23.9 cal cm ⁻²
Three pence pan	It is often called as TP. 3.5 lbs/TP = 1.6 kg/TP (rough rice) at the official rate. The unit varies 1.8-3.5 kg/TP among households, villages and chiefdoms in Kambia district. TP is used for measuring the field size too based on the quantity or rough rice volume.

A4. Abbreviations

ADPK	Agricultural Development Project in Kambia district, Sierra Leone
AHTS	Agricultural Household Tracking Survey
d	day
DAT	days after transplanting
DMP	dry matter production
EC	electrical conductivity
EC	European Commission
FAO	Food and Agriculture Organization of the United Nations
FBO	Farmer Based Organization
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GoSL	Government of Sierra Leone
HH	household
IITA	International Institute of Tropical Agriculture
IRRI	International Rice Research Institute
IVS	inland valley swamp
JICA	Japan International Cooperation Agency
MAFFS	Ministry of Agriculture, Forestry and Food Security, Sierra Leone
NERICA	New Rice for Africa
PAC	phosphorus adsorption coefficient
PEMSD	Planning, Evaluation, Monitoring and Statistics Division
RARC	Rokupr Agricultural Research Centre
RRSR	Rice Research Station, Rokupr (presently RARC)
SLARI	Sierra Leone Agricultural Research Institute
SRDP	Sustainable Rice Development Project in Sierra Leone
TARC	Tropical Agricultural Research Center, Japan
TP	Three-pence pan
TP-R	Technical package on rice production
T/P	transplanting
UNDP	United Nations Development Programme
UNICEF	United Nations Children's Fund
USDA	US Department of Agriculture
WARDA	West Africa Rice Development Association (Presently Africa Rice)
WFP	United Nations World Food Programme
WHO	World Health Organization
y	year

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