Soil Analysis Manual

June 2014

Rokupr Agricultural Research Centre (RARC)

and

Japan International Cooperation Agency (JICA)

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Ministry of Agriculture, Forestry and Food Security (MAFFS)
Sierra Leone Agricultural Research Institute (SLARI)
Rokupr Agricultural Research Centre (RARC)

Prepared by

Sustainable Rice Development Project in Sierra Leone (SRDP)
Japan International Cooperation Agency (JICA)

RECS International Inc.
NTC International Co., Ltd.

Soil Analysis Manual

Contents

1. Sample preparation

1.1 Soil sampling

Soil sampling is crucial for success in soil analyses and interpretation. First, a sample should be fit to the experiment purpose. Second, because physical and chemical properties of soils are heterogeneous in fields, one should mind how it is difficult to take a representative sample.

1.2 Drying

Air-dry samples collected as soon as possible under well-ventilated conditions. Wet samples must be spread on a sheet or a plate, less than 1 cm in thickness. Otherwise, the soils will rot and their chemical properties will change. Watch drying process and crush clods by hands carefully and frequently. Proper crushing time depends on soil's physical properties: For instance, right crushing timing is limited in clayey soils. Remove any foreign material such as organic matters, charcoal, shells, and plant seeds.

1.3 Sieving to particles less than 2.0 mm in diameter

Sieve the air-dried soil sample through a screen with 2 mm circular holes. Grind large clods with a pestle and mortal: do not crush gravel or other foreign materials. Sieve them, and repeat the procedure until no soil is left on the screen. Weigh the soil and gravel separately; calculate the proportion of gravel. Store the sieved soil in an air-tight container like a plastic bottle or bag.

1.4 Sieving to particles less than 0.5 mm in diameter

Grind the air-dried, 2 mm sieved soil with a pestle and mortar; sieve the ground soil through a 0.5 mm mesh screen.

Note: *Air-dried, 2 mm sieved soils are used for most soil analyses. Air-dried, 0.5 mm sieved soils are used for certain analyses such as total P, inorganic P and total N to avoid sampling errors because samples are small in quantity for those analyses. Always bear in mind that the samples are uniform and represent the soil to be analyzed.*

2. Moisture content

1) Principle

Most soil analyses are made on air-dried soil, but their results are routinely expressed on the dry weight basis. Therefore, the moisture content of the air-dried soil has to be determined.

2) Apparatus

a. Drying oven
b. Analytical balance with 0.001 g accuracy
c. Desiccator
d. Aluminum cups or evaporating dishes

Note on making an aluminum cup: (1) Cut an aluminum foil sheet into about 5 cm by 5 cm square, (2) put a small beaker (or rubber stopper) of about 20 mL on the square foil, and (3) fold the foil around the beaker. The cup is disposable.

3) Reagent

No reagent is necessary.

4) Procedure

(1) Dry an aluminum cup (or evaporating dish) at 105 ^{o}C for 2–3 hours in the drying oven; measure the constant weight (A gram).
(2) Put about 10 g of air-dried soil into the cup; weigh the cup with the soil in it (B gram).
(3) Dry the soil in the cup at 105 ^{o}C for 24 hours (See Appendix 3-9).
(4) Take out the cup from the drying oven, cool it in a desiccator, and weigh it (C gram).

Note that A, B and C must be weighed with 0.001 g accuracy.

5) Calculation

(1) Soil moisture content of air-dried soil (%) = $[(B - C)/(B - A)] \times 100$
(2) Soil moisture correction factor (MCF) = $(B - A)/(C - A)$
The MCF is used to correct analytical results on air-dried soil to the dry weight basis.

3. pH

3.1 pH (H_2O)

1) Principle

Soil pH (H_2O) is usually measured in a soil-water suspension of 1:2.5. Indicate the soil-water ratio in the result.

2) Apparatus

a. pH meter with glass electrode
b. Analytical balance
c. Plastics bottles (wide-mouth)

3) Reagent

a. pH buffer solutions: acid (pH ≈ 4), neutral (pH ≈ 7) and alkaline (pH ≈ 9)

Note: Consult the instrument specifications for buffer solution preparation. An alkaline buffer solution is used when alkaline soil is measured. Calibrate the pH meter as prescribed in the manufacturer's manual with the pH buffer solutions.

4) Procedure

(1) Weigh 10 g of air-dried soil (accuracy 0.1 g) and put the soil in a 100 mL bottle.
(2) Add 25 mL of distilled water and cap the bottle.
(3) Occasionally shake the bottle for 1 hour.
(4) Before opening the bottle for measurement, shake it once again.
(5) Immerse the glass electrode of the pH meter in the soil suspension.
(6) Record pH when the reading becomes stable.

5) Calculation

None.

Note that pH (H_2O) of mangrove soils largely differs from pH in situ *when the soils are air-dried. During an air-drying process, oxidizable sulfur (S) or sulfate substances like pyrite and FeS_2 are oxidized, releasing a large quantity of sulfate.*

3.2 pH (KCl)

1) Principle

Soil pH (KCl) is generally 0.5-1.5 lower than soil pH (H_2O). When ΔpH [pH (KCl) - pH (H_2O)] is -0.5 or larger, the soil is rich in salts like mangrove swamp soil or its clay characteristics differ from ordinary soils.

2) Apparatus

Refer to the section 3.1 pH (H_2O).

3) Reagents

a. See the section 3.1 pH (H_2O).

b. Dilute KOH and HCl solution to lower than 0.01 N.

c. 1 M KCl solution (pH = 7.00)

Dissolve potassium chloride (74.5 g) into distilled water (about 900 mL): Use a magnetic stirrer if available. Adjust the pH to 7.00 by adding diluted KOH or HCl solution to the KCl solution, and fill up to 1 L with distilled water.

4) Procedure

(1) [Refer to the section 3.1 pH (H_2O)].

(2) Add 25 mL of KCl and cap the bottle.

(3) (3) to (6) [Refer to the section 3.1 pH (H2O)].

5) Calculation

None.

Note: *ΔpH is calculated by deducting pH (H_2O) from pH (KCl), and it reflects the status of adsorbed cations at the surface of clay minerals in soils. If the soil is strongly acidic, the adsorbed cations are mainly H^+ and Al^{3+}, and the soil pH (KCl) is much lower than pH (H_2O) because of the released acidic cations (H^+ and Al^{3+}), which are replaced with K^+ adsorbed to the surface of negatively charged clay minerals. As a result, the ΔpH value becomes small (increase in the negativity) in strongly acidic soils.*

3.3 pH (H_2O_2)

1) Principle

pH (H_2O_2) is one of the indicators to determine *acid sulfate soils*. When an acid sulfate soil is oxidized by hydrogen peroxide, contained sulfide becomes sulfate ion and the pH decreases drastically. If pH (H_2O_2) is 3.5 or lower, the soil is likely to be rich in acid sulfate.

2) Apparatus

a. pH meter with glass electrode
b. Analytical balance
c. Hot plate
d. Tall beakers (500 mL)
e. Watch glasses

3) Reagents

a. pH buffer solutions: see the section 3.1 pH (H_2O).

b. Hydrogen peroxide solution (30%, pH = 6.00)
   The hydrogen peroxide solution is generally acidic; raise the solution pH up to 6.00 with diluted NaOH solution (0.1–0.01 N).

4) Procedure

(1) Weigh 1 g of air-dried soil (accuracy 0.01 g) and put the soil into a 500 mL tall beaker. Weigh and record the total weight of the beaker and soil. Add 10 mL hydrogen peroxide solution (pH adjusted) and cover the beaker with a watch glass. Heat the sample suspension on a hot plate at 60 ^{o}C for 15 minutes.
(2) When the solution is cooled down, weigh the beaker and add distilled water of the weight recorded in (1) plus 10 g.
(3) Transfer the soil suspension into a small beaker (30–50 mL).
(4) Immerse the glass electrode of the pH meter in the soil suspension.
(5) Record pH when the reading is stabilized.

5) Calculation

None.

6) Reference

Hasegawa, S., Ohtsu, Y., Iwanaga, Y., and Kurihara, S. (1994). A rapid method of determining pH for acid sulfate soils treated with hydrogen peroxide. *Journal of Japanese Society of Revegetation Technology*. 20, 116–122 (In Japanese).

4. Exchangeable acidity

1) Principle

Exchangeable acidity of soils represents the acidity obtained by titrating the extracted acid with alkali solution when neutral salts (e.g., KCl) are added to soils. It shows the amount of (a) acid substances like hydrogen ion in a soil solution and (b) hydrogen and aluminum ions adsorbed by soils (clay minerals, etc.). Hydrogen and aluminum ions are exchanged and exuded with cations contained in the soils by an ion exchange reaction.

2) Apparatus

a. Burette (25 or 50 mL)
b. Centrifuge
c. Centrifuge tubes (50 mL)
d. Hot plate
e. Analytical balance

3) Reagents

a. 1 M KCl (pH = 7.0)
   Refer to the section 3.2 pH (KCl).
b. 0.02 N NaOH standard solution
   Refer to Appendix 2 for the determination of the factor by titration.
c. 0.02 N HCl standard solution: ditto.
d. 4% NaF solution
   Dissolve 40 g of NaF into distilled water and fill up to 1 L.
e. 0.1% phenolphthalein indicator
   Dissolve 0.1 g of phenolphthalein powder into 100 mL of 95% ethanol.

4) Procedure

a. Extraction with 1 M KCl
   (1) Weigh 5.0 g of air-dried soil (accuracy 0.01 g) and put the soil into a centrifuge tube.
   (2) Add 30 mL of 1 M KCl solution in the tube and close the cap tightly.
   (3) Shake the tube for 1 hour on a reciprocal shaker.
   (4) Centrifuge the content at 2,000 rpm for 15 minutes.
   (5) Decant the clear supernatant carefully into a 100 mL volumetric flask.
   (6) Add another 30 mL of 1 M KCl solution to the same soil sample and shake it for 30 minutes.
   (7) Repeat the step (4) and transfer the clear supernatant into the same volumetric flask.
   (8) Repeat the step (6) two more times and pour the clear supernatant into the same volumetric flask.
   (9) Fill up to 100 mL with 1 M KCl solution.

b. Titration for H^+ and Al^{3+}

(1) Filter the extracted solution through filter paper, either Advantec No.1 or No.2. (The latter is better for the purpose.)

(2) Take 25 mL, or 50 mL if the soil pH is over 5.0, of filtrated extractant into a 250 mL Erlenmeyer flask.

(3) Add approximate 100 mL of distilled water.

(4) Boil the extractant on a hotplate to release CO_2, which affects the titration.

(5) Add 5 drops of phenolphthalein indicator.

(6) Titrate the solution with 0.02 N NaOH until it turns pink. Stir the solution, and let it stand for a while until the solution keeps permanent pink. Add a few drops of the indicator when the color disappears, and continue the titration.

(7) The amount of the base solution used is equivalent to the total amount of acidity (H^++Al^{3+}) in the aliquot taken.

(8) To the same flask, add one drop of 0.02 N HCl to bring the solution back to colorless and then add 10 mL of NaF solution.

(9) Titrate the solution with 0.02 N HCl stirring it constantly until it turns colorless.

(10) Add 1 or 2 drops of the indicator. If the solution turns pink, continue adding 0.02 N HCl until the color disappears and the solution remains clear for 2 minutes. Milli-equivalents (meq) of the acid used are equal to the amount of exchangeable Al^{3+}.

5) Calculation

a. Exchangeable acidity

(1) Exchangeable acidity (H^+ + Al^{3+}) is as follows:

$$\text{Exchangeable acidity (meq/100g dry soil)} = X \times N \times F \times E/T \times 100/S \times \text{MCF}$$

in which

X: Titration volume of NaOH (mL)

N: Normality (N) of NaOH used

F: Factor of NaOH used

E: Total volume of the extractant (100 mL)

T: The volume of an aliquot of the extractant taken (mL)

S: Soil weight (g)

MCF: Moisture correction factor

(2) Exchangeable acidity (cmol kg^{-1}) = Exchangeable acidity (meq/100g dry soil)

b. Exchangeable Al^{3+}

(1) The meq of soil exchangeable Al^{3+} :

$$\text{Exchangeable } Al^{3+} \text{ (meq/100g dry soil)} = X \times N \times F \times E/T \times 100/S \times \text{MCF}$$

in which

X: Titration volume of HCl (mL)

N: Normality of HCl used

F: Factor of HCl solution

E: Total volume of the extractant (e.g., 100 mL)

T: The volume of an aliquot of the extractant taken (mL)

S: Soil weight (g)

MCF: Moisture correction factor

(2) The cmol of soil exchangeable Al^{3+} (cmol kg^{-1}) = Exchangeable Al^{3+} (meq/100g dry soil)

c. Exchangeable H^{+}

Exchangeable H^{+} = Exchangeable acidity – Exchangeable Al^{3+}

6) Reference

Yuan, T.L. (1959). Determination of exchangeable hydrogen in soils by a titration method. *Soil Science*. 88, 164–167.

5. Lime requirement

1) Principle of the buffer solution method

To correct soil acidity to a certain level, lime materials are applied. The lime requirement, which depends on the object, is estimated. There are several methods to estimate the lime requirement; the buffer solution method is often used. A buffer curve is drawn with an addition of graded rates of lime ($CaCO_3$) to a soil, and the amount read in the curve is converted to the lime requirement in fields.

2) Apparatus

a. Air compressor
b. pH meter with glass electrode
c. Reciprocal shaker
d. Analytical balance
e. Plastics bottles (100 mL, wide-mouth)
f. Screw cock to regulate air flow

3) Reagents

$CaCO_3$ (powder)

4) Procedure

(1) Weigh air-dried soil (accuracy 0.01 g) equivalent to 20 g of dry soil (use MCF of each soil) into a 100 mL plastics bottle, and add a graded quantity of $CaCO_3$ powder (0, 20, 50, 100, 200 mg) into each bottle.
(2) Add 50 mL of distilled water into the bottle.
(3) Shake the bottle by hand for about 2–3 minutes, and leave the samples for 24 hours.
(4) Shake for 5 hours by reciprocal shaker.
(5) Aerate the soil suspension through a grass tube at 2 L min^{-1}) for 2 minutes by air compressor to purge CO_2 in the soil suspension.
(6) Measure the soil pH immediately after aeration.
(7) Plot the measured pH on a graph and draw a curve.

5) Calculation

a. The necessary quantity of $CaCO_3$ in unit field area is calculated as follows:

$$CaCO_3\ (kg\ ha^{-1}) = Ws\ (kg\ ha^{-1}) \times R\ (mg\ CaCO_3) \times 10^{-3}/20\ (g)$$
$$= R \times B \times D \times 5$$

in which

Ws: Soil weight to be neutralized by $CaCO_3$

$$Ws\ (kg\ ha^{-1}) = 10^4\ (m^2\ ha^{-1}) \times B\ (g\ cm^{-3}) \times 10^3 \times D/100\ (m) = B \times D \times 10^5$$

R: The required amount of $CaCO_3$ that is read from the buffer curve (mg $CaCO_3$/20 g dry soil)

B: Bulk density of the soil (g cm^{-3}, kg L^{-1}, or 1,000 kg m^{-3})

D: Soil depth (cm) in a field that is to be neutralized with $CaCO_3$

b. An example of calculation

Assuming that the required amount of $CaCO_3$ (*R*) is 135 mg $CaCO_3$/20 g soil to correct pH to 6.5 (Figure 1), bulk density (*B*) is 1.1 g cm^{-3}, and the soil depth (*D*) is 10 cm, lime requirement is as follows:

$$CaCO_3 \text{ (kg ha}^{-1}\text{)} = 135 \times 1.1 \times 10 \times 5 = 7{,}425 \approx 7{,}400$$

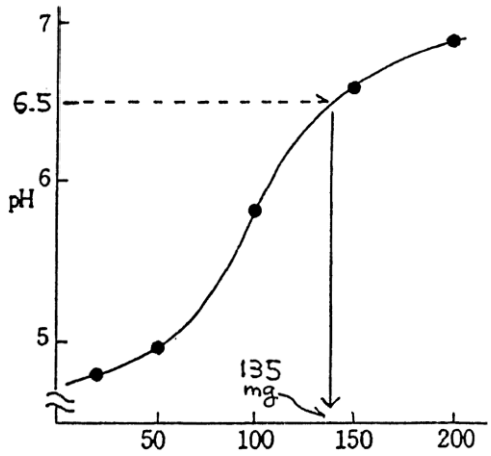


Figure 1. An example of the curve for lime requirement

6) Reference

Chiba, A. and Shinke, H. (1977). Estimation of lime requirement of soil with calcium carbonate and aeration method, *Japanese Journal of Soil Science and Plant Nutrition.* 48, 237–242 (in Japanese).

6. Electrical conductivity

1) Principle

Electrical conductivity (EC) reflects the amount of water-soluble salts in soils. Generally, there is a positive correlation between EC and salt concentration.

2) Apparatus

a. EC meter
b. Analytical balance
c. Reciprocal shaker
d. Plastics bottles (100 mL, wide-mouth)

3) Reagents

Standard KCl solution (0.01 M): 1.41 mS cm^{-1} at 25 ^{o}C and 1.22 mS cm^{-1} at 18 ^{o}C. Calibrate the EC meter as prescribed in the manufacturer's manual with the standard KCl solution.

4) Procedure

(1) Weigh 10 g of air-dried soil (accuracy 0.01 g) into a 100 mL plastics bottle.
(2) Add 50 mL of distilled water and cap the bottle.
(3) Shake by the reciprocal shaker for 1 hour.
(4) Before opening the bottle for measurement, shake by hand once more.
(5) Immerse the electrode of the EC meter in soil suspension.
(6) Read EC when the measurement is stabilized.

5) Calculation

The unit of the result displayed on the EC meter (μS cm^{-1} or mS cm^{-1}) can be converted to other unit: for instance, 10 μS cm^{-1} corresponds to 1 mS m^{-1}. Show the soil-to-water ratio in the result.

7. Cation exchange capacity

1) Principle

Cation exchange capacity (CEC) is the quantity of the total negative charges that are capable of holding soil cations. To measure the CEC in soils, cations in negative charges of soils are exchanged with ammonium ions (by NH_4^+) by adding ammonium acetate solution. After excess ammonium acetate is washed out with alcohol, adsorbed ammonium ions is replaced with sodium ions (Na^+) by sodium chloride solution. The quantity of ammonium ions is analyzed with a distilling device. Modified Schollenberger method is adopted herein.

Note that the temperature greatly affects percolation procedures (or ion exchange velocity and capacity); it is hard to obtain stable measurement unless the temperature is controlled.

2) Apparatus

a. A set of apparatus for measuring CEC (Figure 2) composed of a solvent tube (A), a percolation pipe (B) and a receptor (C).
b. Analytical balance
c. Burette (25 mL or 50 mL)
d. Micropipette (1,000–5,000 μL)
e. Automatic distilling apparatus (Kjeltec)

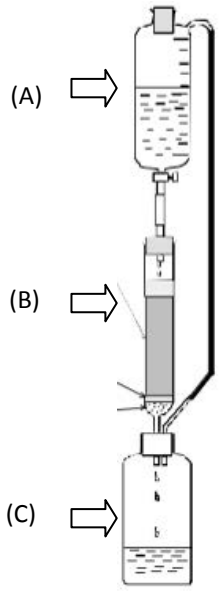


Figure 2. Apparatus for measuring CEC

3) Reagents

a. Ammonium acetate (1 M = 1 mol L^{-1})

Dilute 67 mL of aqueous ammonia in distilled water (300–400 mL) and fill up to 500 mL to prepare 2 M ammonia solution. Take 58 mL of concentrated acetic acid solution in distilled water (300–400 mL) and fill up to 500 mL to prepare 2 M acetic acid solution. Mix the same quantity of both solution and adjust to pH 7.0 with diluted aqueous ammonia or acetic acid. Alternatively, it is possible to prepare 1 M solution by dissolving 77.08 g of ammonium acetate (powder) in distilled water, filling up to 1 L and adjusting the solution pH to 7.0.

b. Ethyl alcohol (C_2H_5OH, ethanol, ca. 80%, pH=7.0)

Take 800 mL of concentrated ethyl alcohol (99–99.9%) in a 1,000 mL beaker and add 200 mL of distilled water to prepare 80% ethanol solution. Adjust the solution pH around 7.0 with diluted aqueous ammonia (diluted by about 100 times) with a pH indicator paper, bromothymol blue (BTB): BTB pH test paper is commercially available.

c. Sodium chloride solution (10%)

Dissolve 100g of sodium chloride in distilled water (about 800 mL) and fill up to 1,000 mL.

d. Diluted sulfuric acid (0.02 N)

Determine the factor of the acid by an acid-base titration with methyl red as an indicator; refer to Appendices 1 and 2.

e. Sodium hydroxide solution (about 10%)

Dissolve 1.5 kg of sodium hydroxide in 1,500 mL distilled water little by little by stirring with a long grass rod. The container (beaker) should be kept cooling with running water to prevent the mixing solution from heating.

f. Mixed pH indicator of bromocresol green and methyl red.

Dissolve 0.5 g of bromocresol green and 0.1 g of methyl red in 100 mL of 95% ethanol with a magnetic stirrer.

g. Boric acid solution (4%)

Dissolve 40 g of boric acid in 1,000 mL of distilled water with a magnetic stirrer. Add the mixed indicator to be 0.5% concentration.

Preparation of the ammonia capturing solution: Mix 100 mL of boric acid solution (4%) with 120 mL of distilled water. When they are mixed, the solution is pale red. Add 0.05 N NaOH slowly with measuring pipette (10 mL), and record the quantity required for the color change to pale blue from pale red. For example, when 3.0 mL of 0.05N NaOH is used, the amount of NaOH per 1,000 mL of the solution is 3.0 (mL) × 1,000 (mL) / 100 (mL) = 30 mL.

Note that the concentration of boric acid solution varies from 1% to 4% depending on the amount of ammonia to be captured: Select a proper concentration by estimating CEC of samples provided.

4) Procedure

a. Preparation of apparatus and solution extraction for cation measurement

(1) For soil percolation, an apparatus shown in Figure 2 is used.

(2) Weigh 2–5 g of air-dried soil (accuracy 0.01 g) on paraffin paper; take a small quantity for clayey soil. It is unnecessary to take a fixed weight, but record the weight accurately. If the soil is clayey, add about 1–2 g of cleaned quartz sand to help percolation.

(3) Put a small piece of absorbent cotton at the bottom of the percolation pipe (B), put filter paper on it and make the filter layer surface flat (adjust its thickness to about 4 mm).

b. Percolation with ammonium acetate (for ion exchange by NH_4^+).

(1) Pour 50 mL of 1 M ammonium acetate solution into the solvent tube (A).

(2) Close the bottom of percolation pipe with parafilm and pour a small amount of ammonium acetate solution from A to one half of the pipe height. Add the weighed soil gently from the top not to produce bubbles.

(3) Connect the percolation pipe (B) with the solvent tube (A) and the receptor (C), and drop the ammonium acetate solution from the solvent tube (A).

(4) Properly adjust the cock to percolate for 4–20 hours (e.g., one drop for every 5–10 seconds). Note that fast percolation leads to incomplete ion exchange.

(5) When the percolation is completed, close the receptor (C) and fill up the percolated solution to 100 mL with distilled water. The solution is used for measuring exchangeable Ca, Mg, K and Na.

c. Cleaning

(1) Pour 25 mL of 80% ethanol (pH adjusted to 7.0) into the solvent tube (A).

(2) Clean the inner wall of the percolation pipe (B) with ethanol, and then wash out excess ammonia. Dispose the spent solution. The procedure is the same as described in the percolation procedure with an ammonium acetate solution, so is the time setting.

d. Percolation with sodium chloride for measuring CEC

(1) Pour 50 mL of NaCl (10%) into the solution cleaning container (A).

(2) Set the percolation pipe (B) that is completed with ethanol cleaning.

(3) Drop NaCl to exchange and discharge the adsorbed NH_4^+. This solution is used for the measurement of cation exchange capacity (CEC sample solution).

e. Distillation of nitrogen (with an automatic distilling device)

(1) Fill the concentrated sodium hydroxide solution in a tank equipped with a distilling device.

(2) Pour 10 mL of ammonia capturing solution into a 100 mL Erlenmeyer flask. Place the flask in the distilling device.

(3) Distill an aliquot of the CEC sample solution. The solution changes its color from pale red to blue when it becomes alkaline from captured ammonia.

(4) When distillation is completed, remove the flask from the device. Wash the glass tube with distilled water from a wash bottle.

f. Titration

(1) Fill a burette with 0.02 N standard sulfuric acid solution.

(2) Read the titration volume when the capturing solution becomes pale red from blue.

5) Calculation

CEC is calculated as follows:

$$\text{CEC (meq kg}^{-1}\text{ soil)} = N \times F \times (T - B) \times E/A \times 1{,}000/S \times \text{MCF}$$

in which

N: Normality of H_2SO_4

F: Factor of H_2SO_4

T: Sample's titration (mL)

B: Blank's titration (mL)

E: Total volume of CEC sample (mL)

A: Volume of CEC sample distilled (mL)

S: Weight of soil sample analyzed (mg)

MCF: Moisture correction factor

8. Available phosphate

8.1 Bray-1 method

1) Principle

Available P is extracted by a mixture of HCl and NH_4F. Phosphate in the extractant is determined calorimetrically by the molybdenum blue method. The theory of the method is based on determining molybdenum blue, which is generated from heteropoly compounds reduced by ascorbic acid after the reaction of phosphate ion with a mixture of ammonium molybdate and L-Antimony potassium tartrate (synonym: potassium antimony tartrate trihydrate).

2) Apparatus

a. Spectrophotometer
b. Cuvette(s)
c. Test tube mixer
d. Magnetic stirrer
e. Analytical balance
f. Micropipettes (100–1,000 μL and 1,000–5,000 μL)
g. Dispenser
h. Plastics bottles (wide-mouth)
i. Test tubes
j. Funnels (larger than 60 mm in diameter)

3) Reagents

a. Regents to extract available phosphate in soil

(4) Ammonium fluoride solution (1 M)

Dissolve 3.7 g of ammonium fluoride (NH_4F) in distilled water (about 80 mL), and fill it up to 100 mL. Store the solution in a plastics bottle, which is effective for up to three months.

(5) Diluted hydrochloric acid (0.5 M)

Take 20.2 mL of concentrated hydrochloric acid (HCl), and carefully mix it with distilled water (about 400 mL) stirring. Cool it down, and fill up to 500 mL.

(6) Extractant

Take 30 mL of 1 M ammonium fluoride solution and 50 mL of 0.5 M hydrochloric acid into about 800 mL of distilled water. Mix it and fill up to 1,000 mL. The final concentration of the extractant should be 0.025 M HCl and 0.03 M NH_4F.

b. Reagents to measure phosphate (the molybdenum blue method)

(1) Diluted sulfuric acid (2.5 M)

Take 140 mL of concentrated sulfuric acid (H_2SO_4) and dilute it in about 800 mL of distilled water: The sulfuric acid solution should be gently mixed with water with careful stirring. Cool it down to room temperature and fill up to 1,000 mL.

(2) Ammonium molybdate solution (4%)

Completely dissolve 40 g of ammonium molybdate [$(NH_4)_6Mo_7O_{24}$ $4H_2O$] in 1 L of hot distilled water mixing with a stirrer. Cool it down to room temperature.

(3) Ascorbic acid solution (0.1 M)

Dissolve 1.76 g of ascorbic acid in 100 mL of distilled water. Use the solution within 24 hours; otherwise the reducing power is lost.

(4) L-Antimony potassium tartrate solution (about 0.27%)

Dissolve 0.27 g of L-Antimony potassium tartrate in 100 mL of distilled water. Prepare only the necessary quantity of the solution, for it easily turns moldy.

(5) Coloring reagent (chromogenic solution mixture)

Mix the four solutions prepared above together: diluted sulfuric acid (100 mL), ammonium molybdate (30 mL), ascorbic acid (60 mL), and L-Antimony potassium tartrate (10 mL). Effective concentration is up to 2.0 ppm P_2O_5.

c. Phosphate standard solution

Dry potassium dihydrogen phosphate (KH_2PO_4) at 110 ^oC overnight (for at least 8 hours. See Appendix 3-9). Take 1.9174 g of dried KH_2PO_4 and put it in about 900 mL of distilled water. Fill up to 1,000 mL to prepare 1,000 ppm P_2O_5 standard solution, and keep it in a glass bottle or tube. Take 10 mL of the solution and dilute it with distilled water by 50 times (fill up to 500 mL). The final concentration of the standard solution should be 20 ppm P_2O_5.

4) Procedure

a. Extraction of available phosphate

(1) Weigh 2.0 g of air-dried soil (accuracy 0.01 g) into a 100 mL plastics wide-mouth bottle.
(2) Add 14.0 mL of the extractant.
(3) Shake it vigorously for 1 minute.
(4) Filtrate the extractant with filter paper (Whatman 42).

b. Absorbance measurements

(1) Take 1–10 mL of the filtrate and put it in a test tube. The volume, which depends on the concentration, is up to 2.0 ppm in the test tube.
(2) Add 4 mL of the coloring reagent in the test tube.
(3) Fill up to 25 mL with distilled water, including the extractant and coloring reagent.
(4) Mix the content of test tube with a test tube mixer.
(5) After 15 minutes, measure phosphate concentration in a set of tubes by the spectrophotometer at 710 nm or 880 nm.
(6) Prepare a standard solution: Take graded amounts (0, 0.5, 1.0, 1.5, 2.0, and 2.5 mL) of the phosphate standard solution and repeat the steps (1) through (5) for a sample solution. Find the relationship between phosphate concentration and absorbance by drawing it in graph. The reaction curves should be drawn whenever any sample was measured.

5) Calculation

Bray-1 P is calculated as follows:

$$\text{Bray-1 P (mg } P_2O_5 \text{ kg}^{-1}) = (X - B) \text{ x } 25/1{,}000 \text{ x } E/F \text{ x } 1{,}000/S \text{ x MCF}$$

in which

X: Sample's P concentration in test tubes (ppm)

B: Blank's P concentration in test tubes (ppm)

E: Volume of extractant (14 mL)

F: Volume of an aliquot taken to test tubes (mL)

S: Weight of soil sample used (2 g)

MCF: Moisture correction factor

8.2 Truog method

1) Principle

Calcium phosphate and magnesium phosphate in soils easily dissolve under acidic conditions. The Truog method adopts diluted H_2SO_4 (pH=3.0) as an extractant.

2) Apparatus

a. Spectrophotometer
b. Cuvette(s)
c. Micropipettes (100–1,000 μL, 1,000–5,000 μL)
d. Dispenser
e. Test tube mixer
f. Magnetic stirrer
g. Reciprocal shaker
h. Analytical balance
i. Plastics bottles (250 mL)
j. Test tubes
k. Funnels (larger than 60 mm in diameter)

3) Reagents

a. Extractant (0.002 N H_2SO_4, pH=3.0)

(1) Diluted sulfuric acid

i) 0.1 N H_2SO_4: Take 3 mL of concentrated H_2SO_4 and put it in 1,000 mL of distilled water (so that the normality of the acid becomes about 0.1 N). Determine the exact concentration of the diluted H_2SO_4 with an acid-base titration (i.e., determine the factor of the acid. See Appendix 2).

ii) 0.002 N H_2SO_4: Calculate the necessary volume of distilled water as follows:

Necessary volume of distilled water = 10,000 (mL) x *A* (normality) − 20 (mL)

in which

A: The exact concentration of the H_2SO_4 (0.1 N x factor)

= 0.1 N x 1.050 = 0.105 N, when the factor is 1.050

In this case, the necessary volume of distilled water to prepare 1,000 mL of 0.002 N H_2SO_4 is

10,000 (mL) x 0.105 – 20 (mL) = 1,030 (mL).

Therefore, mix 20 mL of 0.1 N H_2SO_4 with 1,030 mL of distilled water to prepare 0.002 N H_2SO_4 (the factor = 1.000) as an extractant.

(2) Extractant with ammonium sulfate (as a pH buffer)

To prepare about 1,000 mL of the extractant, the necessary weight of ammonium sulfate is

A (normality) x 30 (g)

in which

A: The exact concentration of H_2SO_4 (0.1 N x factor)

When 0.105 N H_2SO_4 is used, the necessary weight is 0.105 x 30(g) = 3.15 (g)

Therefore, dissolve 3.15 g of $(NH_4)_2SO_4$ into the diluted H_2SO_4 described above (factor = 1.050) for the extractant.

b. Reagents to measure phosphate: Refer to the section 8.1. Bray-1 P.

c. Phosphate standard solution: Refer to the section 8.1. Bray-1 P.

4) Procedure

a. Extraction of available phosphate

(1) Weigh 0.5 g of air-dried soil (accuracy 0.01 g) and put it into a plastics bottle (250 mL vol.); put 100 mL of the extractant into the bottle.

(2) Shake the bottle by a reciprocal shaker for 30 minutes, and filtrate the extractant with filter paper (Whatman 41).

b. Absorbance measurements

Refer to Measurement in the section 8.1. Bray-1 method.

5) Calculation

Truog P is calculated as follows:

$$\text{Truog P (mg } P_2O_5 \text{ kg}^{-1}) = X \times 25/1{,}000 \times E/F \times 1{,}000/S \times \text{MCF}$$

in which

X: Sample's P concentration in test tubes (ppm)

E: Volume of extractant (100 mL)

F: Volume of an aliquot taken to test tubes (mL)

S: Weight of soil sample taken (0.5 g)

MCF: Moisture correction factor

9. Phosphate adsorption coefficient

1) Principle

Phosphate fertilizers applied to fields are largely adsorbed by active aluminum and iron, clay minerals and organic matters in the soils and mostly become unavailable to crop plants. The proportion of phosphorus absorbed by plants is usually 5 to 15% of the amount applied. Phosphate adsorption coefficient **(**PAC) is a good indicator of effective P fertilizer application through understanding the quantity of P adsorbed by soils. The PAC herein is defined as a balance of P concentration before and after equilibrating P in the solution with the known P concentration.

2) Apparatus

a. Spectrophotometer
b. Cuvette(s)
c. Micropipettes (100–1,000 μL, 1,000–5,000 μL)
d. Dispenser
e. Test tube mixer
f. Analytical balance
g. Plastics bottles (wide-mouth)
h. Test tubes
i. Funnels (larger than 60 mm in diameter)

3) Reagents

a. Phosphate solution

(1) Diammonium phosphate (2.5%)

Dissolve 25 g of diammonium phosphate [$(NH_4)_2HPO_4$] in 1,000 mL of distilled water. Because the pH of this solution is usually around 8, adjust the pH to 7.0 with diluted phosphoric acid (acid-water ratio = 1:1): About 5 mL of the diluted acid is needed to each 1 L solution.

Because the P concentration of this original solution is usually higher than the P_2O_5 concentration defined (which should be 13,440 ppm), the solution needs to be diluted. Based on the phosphate concentration of the solution measured by the vanado-molybdenum yellow method, adjust the phosphate concentration to 13,440 ppm (= 5,869 P mg/L). For example, when P_2O_5 concentration is *A* ppm in the original solution, the necessary volume (mL) of distilled water to prepare 1,000 mL solution of 13,440 ppm is [*A*/3,440) -1] x 1,000 (mL).

b. Vanado-molybdenum yellow solution

(1) Ammonium metavanadate solution (about 0.5%)

Dissolve 1.25 g of ammonium metavanadate (NH_4VO_3) in 250 mL of distilled water, cool the solution down to room temperature, and gently add 250 mL of nitric acid.

(2) Ammonium molybdate solution (about 6.25%, nearly saturated)

Dissolve 25 g of ammonium molybdate [$(NH_4)_6Mo_7O_{24}$ $4H_2O$] in 400 mL of hot distilled water (60–70 ^oC) and cool the solution down to room temperature.

(3) Coloring reagent (effective concentration up to 40 ppm P_2O_5)

Mix the ammonium molybdate solution with the ammonium metavanadate solution: Fill up to 1,000 mL and preserve the mixed solution in a brown bottle.

c. Phosphate standard solution

Dry potassium dihydrogen phosphate (KH_2PO_4) at 110 ^oC overnight (for at least 8 hours: See Appendix 3-9). Take 1.9174 g of dried KH_2PO_4, dissolve it in about 900 mL of distilled water, and fill up to 1,000 mL to prepare 1,000 ppm P_2O_5 standard solution. Finally, take 10 mL of the solution and dilute with distilled water to 10 times the volume (100 mL). The final (diluted) concentration of the standard solution is 100 ppm P_2O_5.

4) Procedure

a. Equilibration of P adsorption by soils

(1) Convert the weight of air-dried soil to oven-dried soil to be 12.5 g with an accuracy of 0.01 g, and put it into a 100 mL wide-mouth plastics bottle.

(2) Add 25 mL of 2.5% diammonium phosphate solution to the bottle, leave it for 24 hours with occasional shaking, and then filtrate the solution with filter paper (Whatman 41).

b. Absorbance measurement

(1) Put 2 mL of the filtrate into a 100 mL volumetric flask and fill it up to the mark with distilled water (at a dilution rate of 50 times).

(2) Take 5 mL of the diluted filtrate and put it in a test tube. The appropriate volume depends on the concentration of the sample solution: preferably less than 0.8 mg P_2O_5.

(3) Add 5 mL of the coloring reagent into the test tube.

(4) Fill up to 25 mL.

(5) Mix the contents of the test tube with a test tube mixer.

(6) Between 10 minutes and 3 hours after mixing, read the absorbance of the solution by the spectrophotometer at 440 nm.

(7) Identify the P standard curve: Take graded amounts (0, 2.0, 4.0, 6.0, 8.0, and 10.0 mL; i.e., 0–1 mg P_2O_5 contained) of the phosphate standard solution (100 ppm P_2O_5) and repeat the steps (2) to (5) for sample preparation. Draw the relationship between P concentration (0–100 ppm) and the absorbance.

5) Calculation

PAC is calculated as follows:

$$\text{PAC (mg } P_2O_5 \text{ kg}^{-1} \text{ soil)} = [(13{,}440 \times 25/1{,}000) - (Q \times 25/1{,}000 \times 100/T \times 25/F)] \times 1{,}000/S$$
$$= \{13{,}440 - [Q \times 2{,}500/(T \times F)]\} \times 25/S$$

in which

Q: Sample's phosphate concentration in test tubes (0–100 P_2O_5 ppm)

T: Diluted filtrate taken to a test tube (mL): i.e., 5 mL in the above procedure

F: Filtrate taken to a 100-mL volumetric flask (mL): i.e., 2 mL in the above procedure

S: Dry weight of soil sample taken (g): i.e., 12.5 g in the above procedure (12.5 g)

When T = 5 mL, F = 2 mL and S = 12.5 g as in the above procedure,

PAC (mg P_2O_5 kg^{-1} soil) = (13,440 – 250 x Q) x 2

Note that the result should be rounded off to the nearest hundred (2 to 3 significant digits, e.g., 8,300 or 12,800 mg P_2O_5/kg). The maximum is 26,900 mg P_2O_5/kg (= 11.7 g P/kg).

10. Phosphorus fractionation

1) Principle

There are basically two methods for fractionating total P, inorganic P and organic P: extraction method and ignition method. Herein, the ignition method modified by Nonaka (1991) is described. Organic P in this method is calculated by the difference between total P and inorganic P.

2) Apparatus

a. Spectrophotometer
b. Cuvette(s)
c. Electric furnace
d. Crucible
e. Micropipettes (100–1,000 μL, 1,000–5,000 μL)
f. Dispenser
g. Test tube mixer
h. Reciprocal shaker
i. Analytical balance
j. Plastics bottles (100 mL)
k. Test tubes
l. Funnels (larger than 60 mm in diameter)

3) Reagents

a. Extraction solution

Dilute concentrated H_2SO_4 to prepare 1 N solution. When the normality (N) of the H_2SO_4 is 36 N, the necessary volume of concentrated H_2SO_4 to prepare 1,000 mL of 1 N H_2SO_4 is 1,000 (mL)/36 (N), that is, about 28 mL.

Gently add 28 mL of the concentrated H_2SO_4 into about 900 mL of distilled water. Cool it down, and fill up to 1,000 mL.

b. Vanado-molybdenum yellow solution (a coloring reagent)

Refer to the section 9. Phosphate adsorption coefficient.

c. Phosphate standard solution

Refer to the section 9. Phosphate adsorption coefficient.

4) Procedure

a. Total P

(1) Ignition and extraction

a) Weigh 1.0 g of air-dried fine soil with 0.01 g accuracy.
b) Put the soil sample into a crucible, and ignite it at 350^{o}C for 1 hour in an electric furnace.
c) Take out the crucible and allow it to cool down to room temperature.
d) Take the soil out of the furnace and put it into a plastics bottle; add 50 mL of 1N H_2SO_4 to the bottle.
e) Shake it with a reciprocal shaker for 16 hours (See Appendix 3-9). Filtrate the extractant with filter paper (Whatman 41).

(2) Absorbance measurement

a) Take 1–10 mL of the filtrate and put it in a test tube. (The appropriate volume depends on the P concentration; the preferable amount of P_2O_5 in a sample ranges from 0.1 to 1 mg.)

b) Apply 4) Procedure in the section 9. Phosphate adsorption coefficient.

b. Inorganic P

(1) Extraction procedure

Inorganic P is extracted with 1N H_2SO_4, and thus apply the total P extraction procedure, a), d) and e), described above.

(2) Absorbance measurement

Refer to the section 9. 4) b).

5) Calculation

a. Total P is calculated as follows:

$$\text{Total P (mg } P_2O_5 \text{ kg}^{-1}) = X \times 25/1{,}000 \times E/F \times 1{,}000/S \times \text{MCF}$$

in which

X: Sample's P concentration in test tubes (ppm)

E: Volume of the extractant (50 mL)

F: Volume of an aliquot taken to test tubes (mL)

S: Weight of soil sample taken (1 g)

MCF: Moisture correction factor

b. Inorganic P is calculated as follows:

$$\text{Inorganic P (mg } P_2O_5 \text{ kg}^{-1}) = X \times 25/1{,}000 \times E/F \times 1{,}000 / S \times \text{MCF}$$

in which

X: Sample's P concentration in test tubes (ppm)

E: Volume of extractant (50 mL)

F: Volume of an aliquot taken to test tubes (mL)

S: Dry weight of soil sample taken (1 g)

MCF: Moisture correction factor

c. Organic P is calculated as follows:

$$\text{Organic P (mg } P_2O_5 \text{ kg}^{-1}) = \text{Total P} - \text{Inorganic P}$$

6) Reference

Nonaka, M. (1991). Accumulation and behavior of inorganic and organic phosphorus in some Japanese soils. *Memoirs of the Faculty of Agriculture, Niigata University.* 28, 1–103 (In Japanese with English summary).

11. Organic carbon

1) Principle

When organic carbon is heated with a mixture of dichromate and sulfuric acid, it is oxidized to CO_2:

$$2Cr_2O_7^{2-} + 3C + 16H^+ \rightarrow 4Cr^{2+} + 3CO_2 + 8H_2O$$

Dichromate consumption is proportional to the amount of carbon reacted. By titrating the remaining dichromate with a standard iron (II) solution after reaction, the amount of organic C can be calculated.

2) Apparatus

a. Block digester (heater)
b. Cooling apparatus
c. Analytical balance
d. Glass funnels
e. Micropipette (1,000–5,000 μL)
f. Kjeldahl tubes (50 mL)
g. Burette (25 or 50 mL)

3) Reagents

a. Chromic acid mixture (0.4 N)

Dissolve 40 g of potassium dichromate ($K_2Cr_2O_7$) in 1,000 mL of distilled water, and add 1,000 mL of concentrated sulfuric acid a small amount at a time while cooling the container with running water to prevent the mixture from heating.

b. Standard potassium dichromate solution (0.2 N)

Dissolve 9.802 g of potassium dichromate after drying at 105 ^oC in distilled water and fill up to 1,000 mL. The solution is stable for a long time.

c. Sulfuric acid (1:2 acid-water ratio)

Dilute sulfuric acid with distilled water at the ratio of 1:2 by volume.

d. Ammonium ferrous sulfate (0.2 N)

Dissolve 80 g of ammonium ferrous sulfate [$Fe(NH_4)_2(SO_4)_2 \cdot 6H_2O$] in 1,000 mL of distilled water, which contains 20 mL of sulfuric acid.

Because the titer of this solution decreases during storage, it is essential to determine the actual strength (factor, *F*) of the solution daily by titrating with 0.2 N standard potassium dichromate solution. Add 10 mL of sulfuric acid to 20 mL (1:2) of 0.2 N standard potassium dichromate solution and add 0.5 mL of 0.2% phenylanthranilic acid solution to the mixture. Titrate the final mixture with 0.2 N ammonium ferrous sulfate solution. *F* value is the amount of titration divided by 20.

e. Phenylanthranilic acid solution (0.2%)

Take 200 mg of N-phenylanthranilic acid ($C_{13}H_{11}O_2N$) and 200 mg of anhydrous sodium carbonate in a 100 mL beaker, dissolve them by adding 5 mL of distilled water, and then add distilled water to prepare 100 mL of the solution.

4) Procedure

a. Weigh 50–400 mg of air-dried fine soil with an analytical balance (record the weight) and put it into a Kjeldahl tube. Adjust the soil weight to contain 4–6 mg carbon (C).
b. Add 10 mL of 0.4 N chromic acid mixture into the tube with a whole pipette (volumetric pipette) and place a small glass funnel. *Blank* measurement is essential: Prepare several tubes added with chromic acid mixture (without a soil sample).
c. Prepare approximately 5 L of chilled water for cooling the sample.
d. Place the tube in a block heater that is set at approximately at 200 ^{o}C.
e. Heat the tube for 30 minutes.
f. Take out the tubes from the digester; cool them at room temperature for a few minutes and then with chilled water for about 30 seconds.
g. Transfer the contents from the tube to an Erlenmeyer flask. Rinse the tube with approximately 10 mL of distilled water and pour the rinsed water into the flask.
h. Add 2.5 mL of phenylanthranilic acid just before titration, and titrate with 0.2 N ammonium ferrous sulfate solution. The color changes from mulberry to bright green as the end point. When the titration value is less than one half of the blank titration, reduce the amount of the soil sample or increase the amount of 0.4 N chromic acid mixture.

5) Calculation

a. The organic carbon by percentage is calculated as follows:

$$\text{Organic carbon (\%)} = (B - X) \times F/S \times 1{,}000 \times 0.058 \times \text{MCF}$$

in which

B: Blank's titration (mL)
X: Sample's titration (mL)
F: Factor of ammonium ferrous sulfate solution
S: Weight of soil sample (air-dried soil) taken (mg)
0.058: the ratio of organic carbon to humus, Organic C/Humus = 5.8%
MCF: Moisture correction factor

b. The organic carbon content (%) is converted as follows:

$$\text{Organic carbon (g kg}^{-1}\text{)} = \text{Organic carbon (\%)} \times 10$$

12. Total nitrogen

1) Principle

When nitrogen-containing compounds are heated with sulfuric acid, organic N is digested to ammonium-N: the Kjeldahl digestion method. Potassium sulfate is added to increase the temperature and a copper agent to promote digestion. The concentration of ammonia is measured by titration after steam distillation under the alkaline condition.

There are two methods to determine ammonia concentration. By the first method, ammonia is captured with a known concentration of sulfuric acid, and the remaining sulfuric acid after distillation was titrated with alkali solution. By the second, boric acid solution is used to capture ammonia, and the amount of ammonia captured is directly titrated with sulfuric acid solution. This manual adopts the latter taking advantage of its ease: no requirement for determining the exact concentration and amount of boric acid solution.

2) Apparatus

a. Kjeldahl's tube (50 mL)
b. Burette (25 or 50 mL)
c. Digestion block heater
d. Magnetic stirrer
e. Analytical balance
f. Mortar and pestle
g. Sieve (0.5 mm)
h. Automatic distilling device (Kjeltec)
i. Erlenmeyer flasks (100 mL)

3) Reagents

a. Concentrated sulfuric acid
b. Digestion promoter
   Mix 90% of potassium sulfate and 10% of copper sulfate, and grind them with a mortar and pestle.
c. Sodium hydroxide solution (ca. 10%): Refer to the section 7. CEC.
d. A mixed pH indicator of bromocresol green and methyl red: Refer to the section 7. CEC.
e. Ammonia capturing solution (boric acid solution): Refer to the section 7. CEC.
f. 0.02 N sulfuric acid
   Determine the factor of the solution by an acid-base titration with methyl red as an indicator.

4) Procedure

a. Digestion (preparation of sample solution)
   (1) Weigh 0.1 to 2.0 g (maximum 5.0 g) of soil and put it into in a Kjeldahl tube. Add 10 mL of concentrated sulfuric acid. Shake the flask periodically for 30 minutes or longer. Prepare the tube with sulfuric acid solution (without soil) as a blank.
   (2) Place a set of tubes into the block heater.
   (3) Set the temperature to low at the beginning. As digestion progresses, the bubbling subsides and

white smoke comes out.

(4) Soon after the white smoke appears, add 2–3 g of the digesting promoter, and increase the heater temperature: Consult the technical manual for the programing of the block digester. When the digestion is completed, allow the tubes to cool, dilute the solution by adding 10–20 mL distilled water, and leave it again to cool. During the dilution procedure, rinse the inner wall at upper part of the tubes.

(5) Add distilled water to fill up to 100 mL.

b. Distillation of nitrogen with an automatic distilling device

(1) Take the whole or a part of the digested sample solution and set it into the device.

(2) Pour 10 mL of the ammonia capturing solution (4% boric acid solution) into a 100 mL Erlenmeyer flask. Place the flask in the distilling device.

(3) When distillation is completed, remove the flask from the device. Wash the glass tube with distilled water from a wash bottle.

c. Titration

Refer to the section 7. CEC. Bear in mind that the blank titration value should be 0.2 mL or less.

5) Calculation

a. The total nitrogen concentration by percentage is as follows:

$$\text{Total N (\%)} = 14.007 \times 0.02 \times F \times (T - B) \times 100/A \times 100/S \times \text{MCF}$$
$$= 2{,}801 \times F \times (T - B) \times \text{MCF}/(A \times S)$$

In which

14.007: mole weight of nitrogen (g)

0.02: Normality of H_2SO_4 used in titration

F: Factor of 0.02 N H_2SO_4

T: Titration by the sample aliquot (mL)

B: Titration by the blank (mL)

A: Volume of distilled aliquot (mL)

S: Weight of soil sample digested (mg)

MCF: Moisture correction factor

b. Total nitrogen concentration (%) is converted as follows:

$$\text{Total N (g kg}^{-1}) = \text{Total N (\%)} \times 10$$

13. Particle size composition

1) Principle of the pipette method

The amount of clay, silt and sand in a soil can be inferred from the composition of particle sizes. Stokes' law is adapted to calculate the speed of soil particles settling down in a suspension. When the particles fall to a certain depth within some period of time by gravity in the suspension, the time is given by the following:

$$T = 1.8 \times 10^{-7} \times H \times N/[D^2 \times G\ (P - S)]$$

in which

- D: Diameter of the particles (m)
- P: Density of the particles (Mg m^{-3})
- S: Density of the suspension (Mg m^{-3})
- N: Viscosity of the suspension (mPa s)
- H: Distance of the fall (m)
- T: Time required for the fall (s)
- G: Acceleration of gravity (m s^{-2})

The key of the procedure is to make sure that the particles are completely detached from soil organic matters and evenly dispersed in the suspension to prevent attraction or cohesion between the particles.

2) Apparatus

a. Shaking bottle (500 mL)
b. Suction tube
c. Reciprocal shaker
d. Timer
e. Drying oven
f. Analytical balance
g. Hot plate
h. Sieve (0.5 mm or 0.2 mm)
i. Desiccator
j. Tall beakers (500 mL)
k. Watch glasses
l. Hole (measuring) pipette (10 mL)
m. Griffin beakers (50 mL),
n. Evaporating dishes or crucibles (preferred to be light weight)

3) Reagents

a. Hydrogen peroxide (30% or 6%)
b. Sodium hexametaphosphate
   Dissolve 40.8 g of sodium hexametaphosphate into 1,000 mL of distilled water.
c. Ethanol (concentrated solution, used as an antifoaming agent)

4) Procedure

a. Decomposing soil organic matter

(1) Take about 10 g of air-dried soil (record the weight with an accuracy of 0.01 g) and put it in a 500 mL tall beaker and add about 50 mL of water.
(2) Add 5–10 mL of 30% hydrogen peroxide.
(3) Cover the beaker with a watch glass and leave it for 30–60 minutes.
(4) When the initial vigorous reaction stops, heat and decompose the organic matter on a hot plate at about 80 ^{o}C. When the soil contains a large quantity of organic matter, caution is needed because the initial reaction and foaming are intense. The reaction subsides with an addition of a small amount of alcohol.
(5) When the foaming subsides and the supernatant fluid becomes clear, the decomposition is completed. If the decomposition is likely to be insufficient, add 5–10 mL of hydrogen peroxide and heat the beaker again.
(6) When the vigorous reaction is finished, keep heating the beaker for at least 2 more hours to complete the decomposition.

Note 1: Tap water can be used throughout the procedure.

Note 2: As the decomposition progresses, the soil color changes from brown to grayish white and the supernatant turns slightly green and transparent. Yet, in some types of soil, the supernatant does not become clear even when the decomposition is finished. Complete decomposition generally takes about 2–5 hours: Time required depends on the content of soil organic matter.

b. Collecting coarse sand (0.2–2 mm diameter)
(1) Place a 0.2 mm mesh sieve on a shallow dish and transfer the soil sample into the sieve. The sample attached on the inner wall of the tall beaker is rubbed with a tool such as a glass rod with a rubber tube attached to the tip.
(2) Wash the sample with water from a wash bottle and thoroughly because clay is attached on the surface of sands.
(3) Transfer the suspension in the dish to a shaking bottle once and continue to clean the coarse sand on the sieve. Bear in mind that the suspension of the shaking bottle does not exceed 450 mL.
(4) Transfer the cleaned coarse sand to a beaker (or evaporating dish); dry it at 105 ^{o}C and then cool it in a desiccator, and weigh it (*A* g).

c. Colleting silt fraction (plus clay fraction)
(1) Add 25 mL of sodium hexametaphosphate solution as dispersant to the bottle, and shake it for 2 hours with a rubber stopper in a reciprocal shaker. Fill the bottle up to 500 mL with water while washing the sample attached to the stopper.
(2) Measure the suspension temperature and confirm the settling time referring to the silt column of Table 1 (e.g., 2 minutes and 7 seconds at 25 ^{o}C).
(3) Vigorously shake the bottle for one minute by hand, place it on a laboratory firm table, and count the standing time by a timer or stopwatch.
(4) At a time specified with temperature, insert a marked pipette (10 mL) into the suspension 5 cm deep from its surface; close the pipette top during insertion.

(5) Gently take 10 mL of the suspension for 10 seconds, and transfer the solution to a beaker (or evaporating dish), of which the weight has been recorded before the use.

(6) Collect the soil particles attached on the inside of the pipette by rinsing with water, dry the beaker at 105 °C, and then weigh it (*B* g).

Table 1. Time required for clay and silt particles to subside 5 cm in the water

Temperature	Clay (0.002 mm)		Silt (0.02 mm)		Temperature	Clay (0.002 mm)		Silt (0.02 mm)	
°C	Hour	Minute	Minute	Second	°C	Hour	Minute	Minute	Second
5	6	3	3	38	21	3	53	2	20
6	5	52	3	31	22	3	48	2	16
7	5	41	3	25	23	3	42	2	13
8	5	31	3	18	24	3	37	2	10
9	5	21	3	13	25	3	32	2	7
10	5	12	3	7	26	3	27	2	4
11	5	3	3	2	27	3	23	2	2
12	4	55	2	57	28	3	18	1	59
13	4	47	2	52	29	3	14	1	56
14	4	39	2	47	30	3	10	1	54
15	4	32	2	43	31	3	6	1	51
16	4	25	2	39	32	3	2	1	49
17	4	18	2	35	33	2	58	1	47
18	4	11	2	31	34	2	55	1	45
19	4	5	2	27	35	2	51	1	43
20	3	59	2	23	36	2	48	1	40

d. Collecting clay fraction

(1) After the silt (and clay) fraction is collected, vigorously shake it for one minute without adding water.

(2) Repeat c. (4), (5), and (6) above and collect the clay sample at the time shown in Table 1 (e.g., 3 hours and 32 minutes at 25 °C).

(3) Dry the fine sand in a beaker at 105 °C and weigh it (*C* g).

e. Blank weight of sodium hexametaphosphate

(1) Pour 25 mL of sodium hexametaphosphate solution in three shaking bottles, fill them to the mark (500 mL) with water and shake them similarly to the soil sample.

(2) Collect 10 mL of the solution from each shaking bottle, and then put it to a beaker (or evaporating dish) separately.

(3) Dry each solution at 105 °C and weigh it. The average weight of the three dried solutions is taken as the sodium hexametaphosphate weight (*K* g).

f. Collecting fine sand (0.02–0.2 mm diameter)

(1) When the silt and clay samples are collected, fill the solution to around the mark (500 mL).
(2) Measure the suspension temperature and confirm the settling time from the silt column of Table1 (e.g., 2 minutes and 7 seconds at 25 ^{o}C).
(3) Vigorously shake the bottle and put it on a table.
(4) At a time specified with temperature, insert a suction tube into the suspension 5 cm deep from its surface; discharge and discard the suspension to the depth with a siphon.
(5) Repeat the steps (1) to (4), 5 to 10 times as necessary, until the surface 5 cm of the supernatant becomes clear.
(6) When the fine sand sinks to the bottom, transfer the sand to a beaker (or evaporating dish) with the water, decant and dispose the extra supernatant, dry the fine sand fraction at 105 ^{o}C, and weigh it (D g).

Note that the tare weight (weight of the beaker or evaporating dish) should be based on the average of two measurements: before and after weighing soil fractions especially of silt and clay.

5) Calculation and texture classification

a. Weight of each fraction:

Coarse sand (g) = A
Fine sand (g) = D
Silt (g) = $[(B - K) - (C - K)] \times 50$
Clay (g) = $(C - K) \times 50$

b. Verification of the result obtained

If the balance between the total weight of four fractions (coarse and fine sands + silt + clay) and the initial sample dry weight (air-dried weight corrected with the moisture content) is within an error of ±5% of the soil dry weight sampled, the relative percentage of each fraction can be calculated. If it is not, repeat the analysis.

c. Relative percentage of each fraction (%)

Assuming that the total amount of the particles (coarse and fine sands + silt + clay) is equal to T (g), the relative percentage of each fraction is calculated as follows:

Coarse sand (%) = (Coarse sand (g)/T) x 100
Fine sand (%) = (Fine sand (g)/T) x 100
Silt (%) = (Silt (g)/T) x 100
Clay (%) = (Clay (g)/T) x 100

d. Soil texture classification

The soil texture can be classified into several groups based on the relative percentage of the respective fraction (Figure 3).

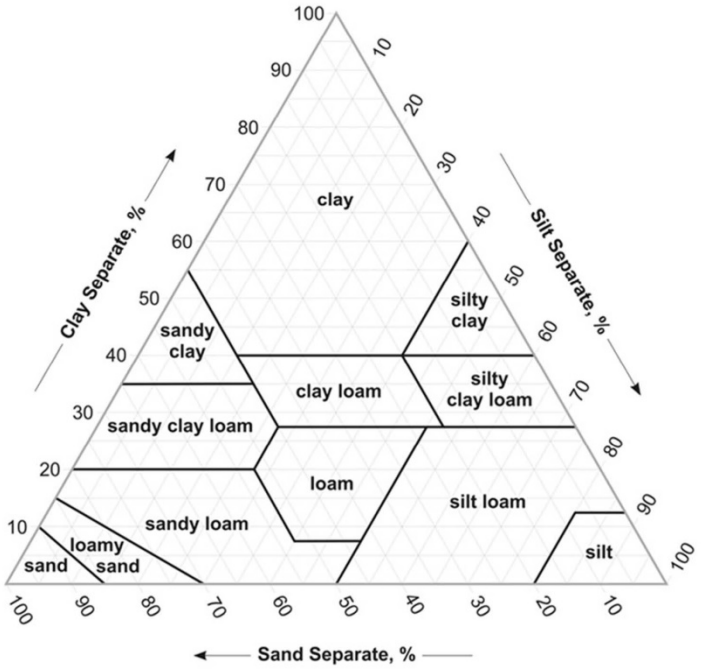


Figure 3. Soil texture classification triangle

Appendix 1. Concept of acid-base titration

1) What is acid-base titration?

Acid-base titration is a basis of the volumetric analyses to determine the concentration of an unknown acid or base based on the known concentration of base or acid.

2) Titration curve

A titration curve generally contains the volume of a titrant as the independent variable (X axis) and the pH of the solution as the dependent variable (Y axis) produced during a titration. The titration curve profiles the characteristics of an acid and base combination. It helps select a proper pH indicator reagent for volumetric analysis.

3) Four types of acid-base titration

There are four types of acid-base titrations with the combination of strong or weak acids and bases, depending on the dissociation strength. Strong acids are represented with hydrochloric acid, sulfuric acid, etc.; weak acids with oxalic acid, acetic acid, etc.; strong bases with sodium hydroxide, potassium hydroxide, etc.; and weak bases with aqueous ammonia, etc.

Type a. Combination of strong acid and strong base

Changes in pH near the equivalent point (the neutralization point) are large (Figure 4a). It is easy to determine the end point of titration. An indicator selection should be fit to change the color at pH 3–10. Methyl red with a transition range around the neutral pH is used as an indicator, for example (Table 2).

Type b. Combination of strong acid and weak base

Changes in pH near the equivalence point are smaller than Type a (Figure 4b). Because of hydrolyzation of the formed salt, the solution shows acidity at the neutralization point. Methyl orange (color change at pH = 3.1–4.4, Table 2) is a common indicator.

Type c. Combination of weak acid and strong base

Changes in pH around the equivalence point are smaller than Type a (Figure 4c). Because of hydrolyzation of the formed salt, the solution is basic (alkaline) at the neutralization point. Phenolphthalein, of which the color change occurs on the alkaline side (at pH = 8.3–10.0), is often used.

Type d. Combination of weak acid and weak base

Because it is difficult to determine the end point of titration (Figure 4d), this type of combination is not applicable to volumetric analysis.

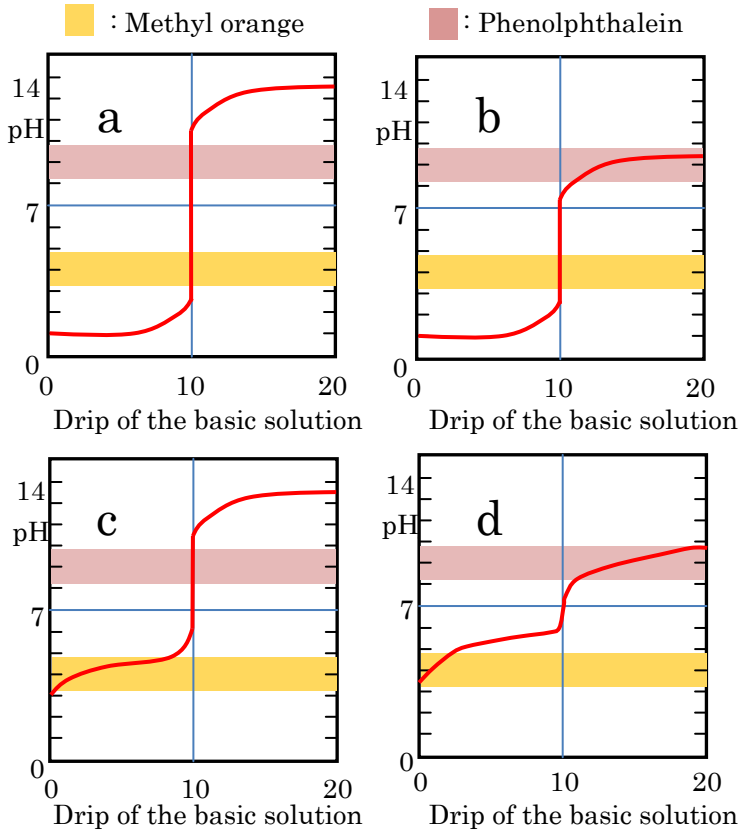


Figure 4. Four types of acid-base titration curves

Note: Lower (pH = 3.1–4.4) and upper (pH = 8.3–10.0) zones represent the transition range of methyl orange and phenolphthalein, respectively.

Table 2 Some examples of pH indicators

pH indicator	Low pH color	Transition pH range	High pH color	Solvent	Indicator concentratoin (%)
Methyl orange	Red	3.1 - 4.4	Yellow	Water	0.1
Bromocresol green	Yellow	3.8 - 5.4	Blue	20% ethanol	0.1
Methyl red	Red	4.2 - 6.3	Yellow	60% ethanol	0.2
Phenolphthalein	Colorless	8.3 - 10.0	Red	60% ethanol	0.2

Ordinry usage: 2-4 drops.

Appendix 2. Calculation method for preparing acid standard solution.

1) Objective

Acid-base titration always requires the measurement of a correct normality of acid and base solution. The factor of the solution should be defined with a stable reagent. Oxalic acid dehydrate, $(COOH)_2 \cdot 2H_2O$ (molecular weight = 126.07 g; ionic valence = 2), is employed in this text.

2) Methodology

a. Calculate the necessary weight of the powder reagent for preparing 1 L solution with 0.1 N. If one-tenth mole weight (12.607 g) of oxalic acid is dissolved in distilled water and filled up to 1 L, the molarity of the solution is 0.1 M. Oxalic acid is divalent because it releases 2 molecules of hydrogen ions. Normality is molality × 2 (i.e., 0.05 M = 0.1 N). To prepare 0.1 N oxalic acid solution, dissolve 6.3035 (= 12.607/2) g in distilled water and fill up to 1 L.

However, it is impossible to exactly weigh 6.3035 g because the maximum weighing precision of the balance in the RARC laboratory is 0.001 g. Because of this, use an approximate weight to prepare necessary solution and calculate the exact normality based on the weight recorded. Alternatively, prepare the standard solution of 1 L with 1 M and dilute it.

b. Prepare standard acid solution at graded rates based on 0.1 N solution

The necessary concentration of standard solution varies with the analytical item (e.g., 0.1 N, 0.05 N, 0.01 N, etc.) Dilute the base solution (0.1 N or 1 N) to any concentration desired.

c. The factor needs to be measured frequently in the base standard solution because the base solution absorbs CO_2 in the atmosphere.

Appendix 3. General notes

1) Manual contents: The present manual is based on the actual soil analyses that an SRDP expert performed in the chemical laboratory of RARC during his stay from January to April in 2013. He completed all analytical items listed in this manual. He analyzed about 50 soils with RARC counterparts, and through the work he successfully transferred the technical know-how to them. Exchangeable cations were not analyzed, however, due to the malfunction of the atomic absorption spectrophotometer and the flame photometer in the laboratory.

2) Reference materials: Consult all available textbooks on soil analysis. There are various methods for the respective soil analyses; there are advantages and disadvantages in each method. Define the method used when presenting the analytical results. Also, carefully examine the results obtained in the laboratory before applying them to fields.

3) Confirmation of analytical results: Always compare the results you obtained with those reported elsewhere. Soils are heterogeneous, so are their chemical and physical properties. Yet, the variation is within a certain range. For instance, C/N ratio is 10–15 in the majority of soils: it should be larger than 6 (full of microorganisms) and smaller than 60–80 (full of organic matter like rice straw). Also, remember that critical deficient and toxicity concentrations in soil diagnoses help justify the analytical results.

4) When you try to apply a new analytical method, analyze only several samples even if there are hundreds of samples, and then verify your results with others'. If the results fall outside the expected range, check every procedure performed step by step. Further, estimate the spectrophotometric absorbance or a titration value before calculating the results by fully understanding analytical procedures and soil properties.

5) Normality (N) is used as a measure of concentration when preparing acid or alkaline solution for volumetric analysis. For others, morality (M, mol L^{-1}) is used, as a matter of practical convenience.

6) Sample volume: In colorimetric analyses, sample volume is arbitrary in some methods but not in others because the coloring condition is sensitive to pH, for example. Examine the condition carefully.

7) Solution dilution: Solution should not be diluted more than 10 times at a time to avoid a dilution error. When 100 times dilution is needed, perform a double dilution: Dilute 10 times and then dilute another 10 times.

8) Significant digits or figures in chemical analysis should be 2–3. Round a calculated result to the nearest whole number.

9) Electricity supply: At present, the power supply condition at the RARC is inconvenient or even nearly impossible for many routine chemical and physical analytical procedures (e.g., 24-hour drying or shaking). Analyses that require electricity need to be scheduled according to the procedural steps and their timing. For example, final weighing should be made shortly before power-supply interruption after a few hours of continuous drying. Shaking period will be accumulative

10) Solution storage: Any solution prepared in a volumetric flask should not be kept in it. As soon as a solution is prepared, it must be transferred to and stored in a storage bottle or a flask. Cleaning of

volumetric flasks is a difficult task in chemical analysis: It is a costly apparatus, and you may lose your credibility as an analyst if other professional chemists observe your practice.

Appendix 4. The result of soil analysis in Sierra Leone

Location			Agro-ecology	General										
District	Chiefdom	Village		Moisture Content (%)	pH (H_2O)	pH (KCl)	pH (H_2O_2)	Electrical Conductivity (mS/m)	Exchangeable Al^{3+} (meq/100g)	Exchangeable H^+ (meq/100g)	Bulk density	T-P (mg/kg)	P_2O_5 (Truog) (mg/100g)	P_2O_5 (Bray 2) (mg/100g)
Kambia	Magbema	Kamaranka	IVS	3.8	4.66	3.8	-	7.5	1.2	2.7	0.865	699	1.61	2.4
Kambia	Magbema	Sinbeck	IVS	5.6	4.78	4.0	-	3.7	2.0	2.3	0.839	840	1.16	3.7
Kambia	Tonko Limba	Kalintin	Boliland	0.5	5.00	3.9	-	1.8	<0.1	1.2	1.209	108	1.03	1.5
Kambia	Masungbala	Robennah	IVS	2.0	4.88	4.0	-	1.8	1.1	1.9	1.003	227	0.94	3.6
Kambia	Mambolo	Robana	Riverine	2.4	5.28	4.4	-	4.1	<0.1	0.6	1.137	203	1.56	2.3
Kambia	Samu	Kibanka	Ass. MS*	5.5	5.09	4.4	5.3	9.7	0.4	1.6	0.813	687	0.83	5.1
Kambia	Magbema	Marwirr	Ass. MS	3.3	4.88	3.7	5.0	17.1	1.1	2.4	0.907	693	1.74	5.3
Kambia	Bramaia	Tolokuray (upper)	IVS	1.5	4.92	3.9	-	4.9	<0.1	1.5	0.994	343	1	1.9
Kambia	Bramaia	Tolokuray (lower)	IVS	0.6	4.91	4.0	-	1.6	<0.1	1.3	1.16	142	0.72	1.3
Kambia	Gbinleh Dixon	Mathon	IVS	0.6	4.94	3.8	-	1.5	<0.1	1.3	1.205	139	1.1	3.2
Kambia	Magbema	Kawaranni	IVS	0.7	4.88	4.1	-	1.3	0.2	1.6	1.203	123	1.03	2.5
Kambia	Samu	Makaliso	IVS	1.1	4.85	4.2	-	3.3	0.3	1.6	1.139	285	0.94	2.0
Kambia	Gbinleh Dixon	Kunthai	IVS	3.7	4.9	4.0	-	2.1	1.8	2.1	0.954	529	1.15	3.6
Kambia	Tonko Limba	Bassia	IVS	3.5	4.91	4.1	-	3.2	1.1	2.1	0.785	660	1.35	2.9
Kambia	Tonko Limba	Kamathothor	IVS	1.1	4.76	3.8	-	3.3	0.3	1.8	1.094	218	1	3.2
Kambia	Mambolo	Misra	IVS	3.0	4.88	4.1	-	3.6	1.3	1.5	0.85	572	1.03	4.2
Kambia	Magbema	Robat	Ass. MS	4.1	4.13	3.6	3.6	39.3	1.6	2.3	0.89	514	0.54	0.8
Kambia	Samu	Rosinor	Mangrove swamp	3.7	4.24	4.0	2.8	300	<0.1	0.9	0.947	333	0.64	1.5
Kambia	Mambolo	Rokel	Mangrove swamp	2.6	5.62	4.8	4.9	55.6	<0.1	0.4	1.145	503	1.68	2.5
Kambia	Masungbala	Pintekili	IVS	1.1	5.27	4.2	-	11.1	0.1	1.8	1.037	383	1.62	3.3
Kambia	Magbema	Rokon	IVS	4.4	4.59	3.8	-	4.7	3.2	2.2	0.731	991	2.16	5.5
Kambia	Gbinleh Dixon	Masineh	IVS	2.4	4.98	4.1	-	2.6	0.6	2.2	0.87	619	1.93	2.7
Kambia	Tonko Limba	Tambi	Boliland	2.6	5.27	4.2	-	0.6	0.5	1.9	1.01	240	2.99	3.8
Kambia	Mambolo	Robis	Riverine	6.9	4.83	4.3	-	5.4	1.7	2.0	0.69	764	0.55	3.1
Tonkolili	Kholifa Rowalla	Mayatha	Boliland	1.7	-	4.1	-	2.4	1.2	2.0	-	327	-	3.8
Bombali	Gbanti-Kamaranka	Kamaranka II	IVS	1.3	5	4.1	-	0.8	<0.1	2.0	1.04	320	0.78	1.2
Koinadugu	Follosaba Dembeli	Musaia	IVS	2.3	4.96	3.6	5.8	1.5	<0.1	2.5	1.02	418	0.46	0.7
Bombali	Biriwa	Kanikay	IVS	4.6	4.99	3.6	-	2.6	0.3	2.9	0.9	518	0.72	1.6
Bombali	Makari Gbanti	Rolako	Boliland	1.2	4.73	3.9	-	1.2	1.9	2.2	1.14	222	1.01	2.5
Bonthe	Bum	Torma Bum	Riverine	4.9	5.04	4.1	-	1.9	2.3	2.3	0.6	1590	4.1	24.6
Bo	Kakua	Tikonko	IVS	0.7	4.84	3.7	-	2.2	<0.1	2.0	1.15	343	3.81	11.2
Bo	Valunia	Mandu	IVS	1.0	4.75	3.8	-	2.5	<0.1	2.7	1.08	320	1.24	2.0
Kenema	Gaura	Kpuabu	Upland	1.8	4.84	3.8	-	3.5	0.3	2.9	0.98	273	0.91	0.6
Kenema	Dama	Giema	IVS	2.2	4.8	3.8	-	5.0	<0.1	2.0	0.93	480	1.05	1.5
Kenema	Gorma Mende	Nyandeyama	IVS	4.2	4.54	3.8	-	6.2	1.4	3.2	0.83	1040	1.21	2.4
Port Loko	Masimera	Buline	Upland	3.3	5.45	4.3	-	2.3	<0.1	1.4	0.96	521	1.18	1.1

* Associated mangrove swamp

Appendix 4. The result of soil analysis in Sierra Leone

Location			Agro-ecology	General									
District	Chiefdom	Village		Exchangeable Ca (mg/kg)	Exchangeable Mg (mg/kg)	Exchangeable K (mg/kg)	Exchangeable Na (mg/kg)	Water soluble Ca (mg/kg)	Water soluble Mg (mg/kg)	Water soluble K (mg/kg)	Water soluble Na (mg/kg)	Water soluble SO_4^{2-} (mg/kg)	Mg/K
Kambia	Magbema	Kamaranka	IVS	19.0	12.2	3.9	9.4	56.49	18.37	3.4	2.23	17.3	12.62
Kambia	Magbema	Sinbeck	IVS	7.0	2.7	5.1	8.8	26.11	6.82	6.64	1.86	12.8	2.39
Kambia	Tonko Limba	Kalintin	Boliland	1.3	0.2	4.3	14.6	15.33	2.98	4.91	3.1	2.4	1.41
Kambia	Masungbala	Robennah	IVS	2.4	0.7	4.4	5.8	12.15	2.6	4.85	1.33	6.2	1.25
Kambia	Mambolo	Robana	Riverine	16.4	6.8	2.0	11.2	134.69	29.78	5.67	3.23	38.1	12.26
Kambia	Samu	Kibanka	Ass. MS*	33.2	13.4	3.6	21.4	108.85	23.27	6.48	4.52	156	8.38
Kambia	Magbema	Marwirr	Ass. MS	7.9	5.3	8.6	18.9	54.67	25.04	9.18	4.45	232	6.37
Kambia	Bramaia	Tolokuray (upper)	IVS	20.9	13.3	5.4	6.9	55.93	18.14	3.16	1.26	23.4	13.41
Kambia	Bramaia	Tolokuray (lower)	IVS	6.0	3.3	2.8	5.2	18.34	5.62	2.04	1.09	3.3	6.43
Kambia	Gbinleh Dixon	Mathon	IVS	3.9	2.0	2.4	3.5	11.3	3.57	1.37	0.79	3.5	6.08
Kambia	Magbema	Kawaranni	IVS	3.7	1.9	4.9	4.2	9.46	3.02	2.47	0.93	3.5	2.85
Kambia	Samu	Makaliso	IVS	2.6	1.1	6.6	5.9	6.65	1.64	2.96	1.25	7.3	1.29
Kambia	Gbinleh Dixon	Kunthai	IVS	4.3	2.4	2.9	5.9	22.58	9.73	5.3	2.61	19.3	4.28
Kambia	Tonko Limba	Bassia	IVS	9.3	4.4	9.5	7.1	23.53	5.2	5.73	1.54	7.4	2.11
Kambia	Tonko Limba	Kamathothor	IVS	7.9	2.7	3.7	6.4	18.38	3.35	2.44	1.29	10.6	3.2
Kambia	Mambolo	Misra	IVS	5.5	2.5	5.0	5.8	17.05	4.55	3.35	1.01	23.0	3.17
Kambia	Magbema	Robat	Ass. MS	26.7	57.9	20.1	229	48.95	70.73	14.72	48.72	447	11.22
Kambia	Samu	Rosinor	Mangrove swamp	254	530	61.1	2390	147.34	219.79	30.07	489.55	3530	17.07
Kambia	Mambolo	Rokel	Mangrove swamp	10.4	24.7	25.1	490	100.3	150.38	30.43	118.46	377	11.54
Kambia	Masungbala	Pintekili	IVS	3.5	1.0	5.2	7.3	29.58	7.34	3.76	1.62	45.4	4.56
Kambia	Magbema	Rokon	IVS	8.4	5.6	15.4	11.0	15.27	5.91	10.68	2.23	53.3	1.29
Kambia	Gbinleh Dixon	Masineh	IVS	9.0	5.1	6.0	7.9	29.04	9.82	4.98	1.67	6.8	4.6
Kambia	Tonko Limba	Tambi	Boliland	1.7	0.6	1.8	2.8	6.12	1.01	2.96	0.84	2.1	0.79
Kambia	Mambolo	Robis	Riverine	11.1	3.2	3.0	17.7	14.8	2.72	5.15	4.23	59.2	1.23
Tonkolili	Kholifa Rowalla	Mayatha	Boliland	2.7	0.8	4.7	4.7	-	-	-	-	6.4	-
Bombali	Gbanti-Kamaranka	Kamaranka II	IVS	4.2	1.1	2.8	2.6	13.18	2.29	2.28	0.73	3.1	2.34
Koinadugu	Follosaba Dembelia	Musaia	IVS	2.6	0.8	1.8	12.9	45.82	11.54	3.33	3.33	4.6	8.09
Bombali	Biriwa	Kanikay	IVS	7.2	2.0	2.3	14.7	74.66	13.75	4.36	3.88	6.5	7.36
Bombali	Makari Gbanti	Rolako	Boliland	6.0	1.7	2.6	2.2	11.51	2.4	2.86	0.59	5.2	1.96
Bonthe	Bum	Torma Bum	Riverine	6.5	2.5	5.2	5.1	35.23	6.11	10.26	1.66	3.5	1.39
Bo	Kakua	Tikonko	IVS	10.6	1.3	6.0	5.8	26.44	2.18	3.38	1.16	9.0	1.5
Bo	Valunia	Mandu	IVS	11.5	2.3	6.7	7.6	25.27	3.66	4.32	1.38	7.2	1.97
Kenema	Gaura	Kpuabu	Upland	12.7	6.1	12.9	2.4	57.24	13.12	8.28	0.72	16.5	3.7
Kenema	Dama	Giema	IVS	23.2	10.2	5.2	10.6	51.96	15.61	3.42	2.2	7.0	10.66
Kenema	Gorma Mende	Nyandeyama	IVS	24.0	9.4	14.9	13.0	36.21	9.45	9.29	2.5	3.4	2.37
Port Loko	Masimera	Buline	Upland	9.5	2.8	9.6	1.1	92.85	12.67	9.31	0.59	<0.5	3.17

* Associated mangrove swamp

Appendix 4. The result of soil analysis in Sierra Leone

Location			Agro-ecology	General				Micro nutrient					Nitrogen
District	Chiefdom	Village		Ca/Mg	Available SiO_2 (mg/100g)	CEC (me/100g)	Fe_2O_3 (%)	HCl-Extracable (ppm)	HCl-Extracable (ppm)	Easily reducible (ppm)	Hot water soluble B (ppm)	Autoclave extractable- (mg/100g)	NH^{4+}-N (mg/100g)
Kambia	Magbema	Kamaranka	IVS	2.21	9.7	16.86	0.80	2.82	2.08	4.79	1.29	14.41	4.878
Kambia	Magbema	Sinbeck	IVS	2.75	14.6	16.02	1.49	3.29	4.26	2.46	0.76	11.59	4.571
Kambia	Tonko Limba	Kalintin	Boliland	3.69	1.4	3.36	0.18	0.28	0.46	2.95	0.53	4.96	1.488
Kambia	Masungbala	Robennah	IVS	3.35	3.4	6.77	0.45	0.67	0.87	1.81	0.43	5.21	2.509
Kambia	Mambolo	Robana	Riverine	3.25	9.1	11.39	0.52	0.16	1.78	21.13	0.94	6.79	2.605
Kambia	Samu	Kibanka	Ass. MS*	3.36	53.1	13.77	0.76	0.45	1.69	14.96	0.75	4.9	2.955
Kambia	Magbema	Marwirr	Ass. MS	1.56	11.4	17.28	1.18	3.14	1.76	6.44	0.81	17.98	24.378
Kambia	Bramaia	Tolokuray (upper)	IVS	2.21	3.4	8.68	0.31	1.51	1.05	3.81	0.73	6.81	1.738
Kambia	Bramaia	Tolokuray (lower)	IVS	2.34	2.2	3.31	0.12	0.67	0.36	0.96	0.36	3.49	0.72
Kambia	Gbinleh Dixon	Mathon	IVS	2.27	1.7	2.92	0.24	1.24	1.37	0.82	0.45	3.65	1.014
Kambia	Magbema	Kawaranni	IVS	2.25	3.0	3.71	0.05	0.36	0.33	0.38	0.48	2.78	0.88
Kambia	Samu	Makaliso	IVS	2.91	2.8	4.67	0.32	0.47	0.57	0.24	0.78	7.82	3.197
Kambia	Gbinleh Dixon	Kunthai	IVS	1.66	12.7	11.14	1.31	2.44	0.89	2.12	0.46	3.72	1.948
Kambia	Tonko Limba	Bassia	IVS	3.25	10.1	16.89	0.31	0.89	1.31	0.31	0.71	10.07	2.633
Kambia	Tonko Limba	Kamathothor	IVS	3.94	2.4	5.8	0.19	0.51	1.7	1.65	0.81	6.39	2.109
Kambia	Mambolo	Misra	IVS	2.69	10.3	8.42	0.65	1.33	2.33	3.89	0.62	6.7	2.59
Kambia	Magbema	Robat	Ass. MS	0.49	13.6	21.22	3.31	2.07	0.78	2.24	2.39	10.84	4.149
Kambia	Samu	Rosinor	Mangrove swamp	0.48	18.9	19.45	1.42	1.52	1.65	6.96	4.64	5.17	2.712
Kambia	Mambolo	Rokel	Mangrove swamp	0.47	28.7	18.99	2.08	1.59	3.95	68.91	3.37	6.89	2.69
Kambia	Masungbala	Pintekili	IVS	2.89	3.5	7.06	0.16	1.97	0.4	1.28	0.98	19.25	17.839
Kambia	Magbema	Rokon	IVS	1.85	12.8	20.96	1.57	1.14	1.74	1.44	0.76	11.16	2.783
Kambia	Gbinleh Dixon	Masineh	IVS	2.12	10.1	11.48	0.87	4.86	1.63	3.3	0.55	7.52	1.496
Kambia	Tonko Limba	Tambi	Boliland	4.35	19.1	9.68	0.16	0.29	0.29	0.29	0.35	3.36	1.13
Kambia	Mambolo	Robis	Riverine	3.91	58.6	19.22	1.99	0.48	0.77	0.51	0.39	3.72	1.979
Tonkolili	Kholifa Rowalla	Mayatha	Boliland	-	17.1	-	1.04	-	-	-	-	-	-
Bombali	Gbanti-Kamaranka	Kamaranka II	IVS	4.13	9.4	6.34	1.15	1.67	1.12	1.09	0.49	3.42	1.606
Koinadugu	Follosaba Dembelia	Musaia	IVS	2.85	25.8	11.05	3.22	5.51	1.4	17.31	0.41	3.25	1.907
Bombali	Biriwa	Kanikay	IVS	3.9	24.2	16.96	2.50	3.38	2.62	37.77	0.63	6.3	3.159
Bombali	Makari Gbanti	Rolako	Boliland	3.44	4.2	8.11	0.36	0.58	0.38	1.13	0.54	3.19	0.723
Bonthe	Bum	Torma Bum	Riverine	4.14	37.6	25.3	1.57	0.94	2.29	45.52	0.34	4.3	0.936
Bo	Kakua	Tikonko	IVS	8.72	2.8	6.22	0.41	1.45	8.67	4.09	0.58	4.65	0.644
Bo	Valunia	Mandu	IVS	4.96	6.6	6.09	0.23	0.67	6.17	4.05	0.51	4.71	0.824
Kenema	Gaura	Kpuabu	Upland	3.13	4.6	10.92	1.18	0.49	1.03	9.71	1.38	6.44	1.826
Kenema	Dama	Giema	IVS	2.39	6.9	8.63	0.46	3.09	0.87	2.82	0.64	7.73	1.609
Kenema	Gorma Mende	Nyandeyama	IVS	2.75	9.6	19.11	0.72	1.98	0.97	2.68	0.63	13.93	2.446
Port Loko	Masimera	Buline	Upland	5.26	8.2	12.52	0.92	0.43	0.62	57.7	0.78	7.36	1.877

* Associated mangrove swamp

Appendix 4. The result of soil analysis in Sierra Leone

Location			Agro-ecology	Nitrogen		Carbon	Sulfur		Particle size composition			
District	Chiefdom	Village		NO_3-N (mg/100g)	T-N (%)	T-C (%)	T-S (%)	SO_4^{2-} (mg/kg)	Coarse sand	Fine sand	Silt	Clay
Kambia	Magbema	Kamaranka	IVS	0.032	0.473	7.77	0.131	25.7	11.2	33.75	13.12	41.94
Kambia	Magbema	Sinbeck	IVS	0.021	0.438	6.72	0.147	30.2	14.91	20.05	18.69	46.35
Kambia	Tonko Limba	Kalintin	Boliland	0.028	0.105	1.37	<0.005	2.8	2.93	49.4	30.31	17.36
Kambia	Masungbala	Robennah	IVS	0.03	0.159	2.80	0.015	7.8	17.38	34.56	15.71	32.34
Kambia	Mambolo	Robana	Riverine	0.017	0.243	2.83	0.037	50.4	18.53	46.38	10.94	24.14
Kambia	Samu	Kibanka	Ass. MS*	0.021	0.364	5.38	0.273	973	15.81	25.06	28.24	30.9
Kambia	Magbema	Marwirr	Ass. MS	0.021	0.327	4.25	0.106	316	1.36	4.15	31.48	63.02
Kambia	Bramaia	Tolokuray (upper)	IVS	0.011	0.243	5.55	0.086	24.3	12.87	58.48	6.71	21.94
Kambia	Bramaia	Tolokuray (lower)	IVS	0.012	0.095	1.43	0.007	4.7	12.45	61.45	7.4	18.69
Kambia	Gbinleh Dixon	Mathon	IVS	0.009	0.103	1.46	0.005	5.0	40.92	37.83	3.95	17.3
Kambia	Magbema	Kawaranni	IVS	0.012	0.097	1.52	0.006	5.0	34.22	38.38	6.01	21.38
Kambia	Samu	Makaliso	IVS	0.013	0.19	2.82	0.018	9.1	41.36	28.58	3.59	26.47
Kambia	Gbinleh Dixon	Kunthai	IVS	0.038	0.213	2.79	0.011	72.1	15.04	5.78	22.04	57.15
Kambia	Tonko Limba	Bassia	IVS	0.039	0.405	7.72	0.216	12.4	22.2	34	8.93	34.87
Kambia	Tonko Limba	Kamathothor	IVS	0.021	0.167	3.04	0.028	12.6	14.37	62.02	6.35	17.26
Kambia	Mambolo	Misra	IVS	0.02	0.276	4.28	0.110	32.8	31.46	23.53	8.15	36.86
Kambia	Magbema	Robat	Ass. MS	0.021	0.401	6.99	0.143	827	1.64	3.32	26.05	68.99
Kambia	Samu	Rosinor	Mangrove swamp	0.026	0.187	4.47	0.447	3950	0.88	1.8	48.63	48.69
Kambia	Mambolo	Rokel	Mangrove swamp	0.034	0.168	2.70	0.147	408	24.85	5.82	23.04	46.29
Kambia	Masungbala	Pintekili	IVS	0.027	0.223	3.00	0.027	45.7	16.86	40.26	8.92	33.96
Kambia	Magbema	Rokon	IVS	0.036	0.545	7.73	0.169	160	2.64	7.7	28.7	60.97
Kambia	Gbinleh Dixon	Masineh	IVS	0.076	0.318	4.96	0.132	16.1	17.84	32.73	11.33	38.11
Kambia	Tonko Limba	Tambi	Boliland	0.028	0.205	3.59	0.006	6.9	15.58	33.12	22.4	28.9
Kambia	Mambolo	Robis	Riverine	0.029	0.461	6.04	0.129	969	4.94	8.83	46.77	39.46
Tonkolili	Kholifa Rowalla	Mayatha	Boliland	-	-	3.44	0.019	32.8	-	-	-	-
Bombali	Gbanti-Kamaranka	Kamaranka II	IVS	0.047	0.181	2.80	0.009	31.5	33.16	28.38	9.24	29.22
Koinadugu	Follosaba Dembelia	Musaia	IVS	0.052	0.169	3.05	<0.005	15.8	18.31	13.18	20.48	48.02
Bombali	Biriwa	Kanikay	IVS	0.038	0.327	5.10	0.019	17.7	14.83	13.65	46.76	24.76
Bombali	Makari Gbanti	Rolako	Boliland	0.058	0.154	2.61	0.008	6.7	19.49	28.89	2.18	49.45
Bonthe	Bum	Torma Bum	Riverine	0.603	0.472	6.36	0.016	23.1	4.34	6.5	39.34	49.82
Bo	Kakua	Tikonko	IVS	0.176	0.158	2.10	0.013	23.2	40.27	28.97	3.56	27.2
Bo	Valunia	Mandu	IVS	0.105	0.177	2.50	0.011	12.8	27.05	23.56	12.88	36.51
Kenema	Gaura	Kpuabu	Upland	0.089	0.244	4.18	0.054	25.5	24.1	29.22	8.05	38.64
Kenema	Dama	Giema	IVS	0.081	0.28	3.32	<0.005	10.1	15.44	35.7	11.54	37.32
Kenema	Gorma Mende	Nyandeyama	IVS	0.074	0.603	8.35	0.093	11.9	10.61	8.54	21.14	59.71
Port Loko	Masimera	Buline	Upland	0.239	0.316	4.76	0.066	16.0	15.41	27.21	12.08	45.3

* Associated mangrove swamp

Methods used for soil analysis

Items and methods on soil analysis

Item		Analytical method
General	Moisture content	Dry at 110 ^{O}C
	pH (H_2O)	1:2.5 = soil:water suspension;
	pH (KCl)	1:2.5 = soil:1N KCl solution;
	pH (H_2O_2)	1:10 = soil: 30% H_2O_2 solution; heat at 60 ^{O}C
	Electrical conductivity	1:5 = soil: water extract;
	Exchangeable acidity	Yuan method
	Bulk density	Dry at 105 ^{O}C; expressed as dried soil basis
	Total P	Decomposition by acid; Measured with spectrophotometer
	Available Phosphate	Truog method; Bray-2 method (1:10)
	Exchangeable-Ca Exchangeable-Mg Exchangeable-K Exchangeable-Na	Extracted with 1M ammonium acetate; Measured with atomic absorption spectrophotometer
	Water soluble Ca Water soluble Mg Water soluble K Water soluble Na	Extracted with 1:5 = soil:water; Measured with atomic absorption spectrophotometer
	Water soluble SO_4	Extracted with 1:5 = soil:water; Measured with ion chromatograph method
	Available SiO_2	pH4 acetic acid method
	Cation Exchange Capacity	Schollenberger method
	Free iron oxicides	Asada-Kumada method
Micro-nutrient	HCl-extractable Cu HCl-extractable Zn	Extract with 0.1 N HCl; Measured with atomic absorption spectrophotometer
	Easily reducible Mn	Extract with Ammonium acetate including hydroquinone; Measured with atomic absorption spectrophotometer
	Hot water soluble-B	Extract with hot water; Measured using coloring with azomethine H
	Autoclave extractable N	Extract after one hour heat at 105 ^{O}C; Measured with Kjeldahl method
Nitrogen	NH^{4+}-N	Extract with 1N potassium chloride; Indo phenol method
	NO_3^-N	Extract with 1N potassium chloride; phenol sulfate method
	Total-N	Dry combustion method
Carbon	Total-C	Dry combustion method
Sulfur	Total- S	Inverse aqua regia and per chlorate decomposition method
	SO_4^{2-}	Extract with 500 ppm Calcium phosphate
Particle size composition		Pipette method

Soil samples are air dried, crushed and sieved with 2mm mesh.

Fertility Evaluation of Soils in Sierra Leone by a Pot Culture

Sustainable Rice Development Project in Sierra Leone (SRDP-SL/JICA)

Abstract

Soils of diverse agro-ecologies in Sierra Leone were collected at 37 sites. They were subjected to nutrient depletion or addition treatments upon the standard nutrient treatment and to graded nutrient application treatments. Rice plants (*Oryza sativa*) were grown in pots with the treated soils under the submerged condition for about four weeks. Soil nutritional status was diagnosed on the basis of dry matter production during the growth. Phosphorus (P) deficiency was most severe and widely spread over the country. Sulfur (S), potassium (K) and nitrogen (N) were lacking in many locations, and zinc (Zn) in specific sites. The deficiency level in N, P, K, S, and Zn was 30, 70, 30, 40, and 10 on average nationwide, respectively. The productivity of the indigenous soils varied greatly, but the differences in productivity decreased under the fertilized condition due to the positive growth response to nutrient application. Plant response to an application rate varied among soils: the larger the deficiency level, the greater the response in general. Soil nutrient status evaluated in the pot trials should be verified in field conditions to recommend appropriate fertilizer rates.

Introduction

Rice grain yield is currently one ton ha^{-1} or even less in farmers' fields in Sierra Leone (ADPK-SL, 2007). While grain yield exceeds two ton ha^{-1} in several fields, there are many fields where the yield is 0.5 ton ha^{-1} or lower. Because such a yield is common in traditional farmers' fields in West African countries, rice cultural practices in Sierra Leone are not particularly substandard compared to those in neighboring countries. Nevertheless, such yields are far below the present level of 3–4 ton ha^{-1} in Asia (FAO, 2014).

Highly weathered soils (Oxisols and Ultisols/Ferralsols and Plithosols) are predominant in the western parts of West Africa, including Sierra Leone (EC, 2013; USDA, 2005). Because of the poor soil fertility, nutrient supplement is essential to increase crop productivity. The Agricultural Development Project in Kambia district, Sierra Leone (ADPK-SL) carried out several fertilizer trials in farmers' fields under the condition in which water supply is controlled to some extent. The fertilizer rate (N-P_2O_5-K_2O) was at 61-15-15 kg ha^{-1} in 2007 and 49-26-26 kg ha^{-1} in 2008. The fertilizer application improved productivity but not to the level expected due to factors such as low nitrogen utilization efficiency (20% or lower; ADPK-SL, 2009).

Low fertilizer efficiency is most likely derived from inadequate composition of fertilizer elements, poor water control, or fake fertilizers. In case of the wrong choice of fertilizer, imbalanced composition of nutrients lessens fertilizer efficiency due to Liebig's law of the minimum. Without some knowledge of the nutritional status in crop fields, appropriate fertilizer rates cannot be established. This study aimed at diagnosing soil fertility by a series of pot trials. The last two issues are discussed separately.

Materials and Methods

Soils of rice fields were collected from all over the country and rice plants were grown under pot culture condition with various nutrient treatments. Nutritional status of the soils was quantified by dry matter production during the growth.

1. Soils used

Soils were collected in all agro-ecologies of rice culture: upland, inland valley swamp (IVS), boliland, riverine grassland, and mangrove swamp including associated mangrove swamp (Table 1 and Fig. 1 and 2). Uplands and IVSs are widely scattered over the country. Boliland is a seasonally flooded inland depression where grasses thrive during the dry season and is mostly found in the central part of the country. Riverine grasslands are riverside flood plains during the rainy season and mostly located in the southern part. Mangrove swamps are coastal tidal wetlands with muddy sediment, which are found in the northwestern part of the country.

Collection sites were selected to include a wide range of soil fertility and geographical distribution, particularly focusing on soils in IVSs and in Kambia district. In IVS, rice production is expected to improve efficiently with fertilizer manipulation compared to the other agro-ecologies, in which water control is difficult. Kambia district is where the SRDP-SL is concentrating its activities. Thirty-seven soil samples were collected: 25 in Kambia district and 12 in other seven districts.

The soil sample was taken from the surface to 20–30 cm at several plots in each site within a radius of 50–200 m (the distance depending on the situation). When the soil was sampled, rice plants were either present or absent in the field, and the fields were under either dry or wet condition. In mangrove swamps, the soils were collected during the rice growing season in the mid-rainy season to avoid salt affection (Yamaguchi, 2009). The soils were air-dried soon after collection, ground and sieved with a 5-mm-mesh screen.

Table 1. Soils used in the pot experiments (a)

Ser. no.	Agro-ecology	Location					Soil DWa (kg pot^{-1})
		District	(c)	Chiefdom	Soil (site) (c)	abbr.	(d)
1	Upland	Kenema	28	Gaura	Kpuabu	Kp	1.9
2		Kambia	62	Masungbala	Robennah (u)	Ru	2.2
3		Port Loko	84	Masimera	Buline	Bl	1.9
4	Inland valley	Kenema	15	Gorma Mende	Nyandeyama	Ny	1.3
5	swamp (IVS)		26	Dama	Giema	Gm	1.8
6		Bombali	51	Gbanti-Kamaranka	Kamaranka II	K2	1.8
7			57	Biriwa	Kanikay	Kk	2.1
8		Kambia	58	Mambolo	Misra	Ms	1.9
9			59	Samu	Makaliso	Mk	2.4
10			60	Gbinleh Dixon	Kunthai	Kn	2.0
11			60		Masineh	Mh	1.6
12			60		Mathon	Mt	2.5
13			61	Magbema	Kamaranka	Km	1.4
14			61		Karawani	Kr	2.4
15			61		Rokon	Ro	1.4
16			61		Sinbeck	Sb	1.6
17			62	Masungbala	Pintekili	Pt	2.0
18			62		Robennah	Rn	2.1
19			63	Tonko Limba	Bassia	Bs	1.5
20			63		Kamathothor	Kt	2.0
21			64	Bramaia	Tolokuray-U	T-U	2.3
22			64		Tolokuray-L	T-L	2.0
23		Koinadugu	71	Follosaba Dembelia	Musaia	Mu	2.1
24		Bo	105	Kakua	Tikonko	Tk	2.1
25			111	Valunia	Mandu	Md	1.9
26	Boliland	Bombali	46	Makari Gbanti	Rolako	Rl	2.2
27		Kambia	63	Tonko Limba	Kalintin	Kl	2.5
28			63		Tambi	Tb	2.1
29		Tonkolili	90	Kholifa Rowalla	Mayatha	My	1.8
30	Riverine	Kambia	58	Mambolo	Robana	Rb	1.1
31	grassland		58		Robis-bana	Rm	1.4
32		Bonthe	120	Bum	Torma-Bum	Tr	1.2
33	Associated MS	Kambia	59	Samu	Kibanka	Kb	2.1
34			61	Magbema	Marwirr	Mw	1.6
35	Mangrove		58	Mambolo	Rokel	Rk	2.3
36	swamp (MS)		59	Samu	Rosinor	Rs	1.8
37			61	Magbema	Robat	Rt	1.5

a) Soils were collected from June 2011 to Feburuary 2013. b) Geo-code. c) Robennah (u): upland at Robennah, Tolokuray-U: upper IVS at Tolokuray, Tolokuray-L: lower IVS at Tolokuray.
d) Soil DWa: Soil air-dried weight at ca. 2 L pot-1 after about 4-week submergence.

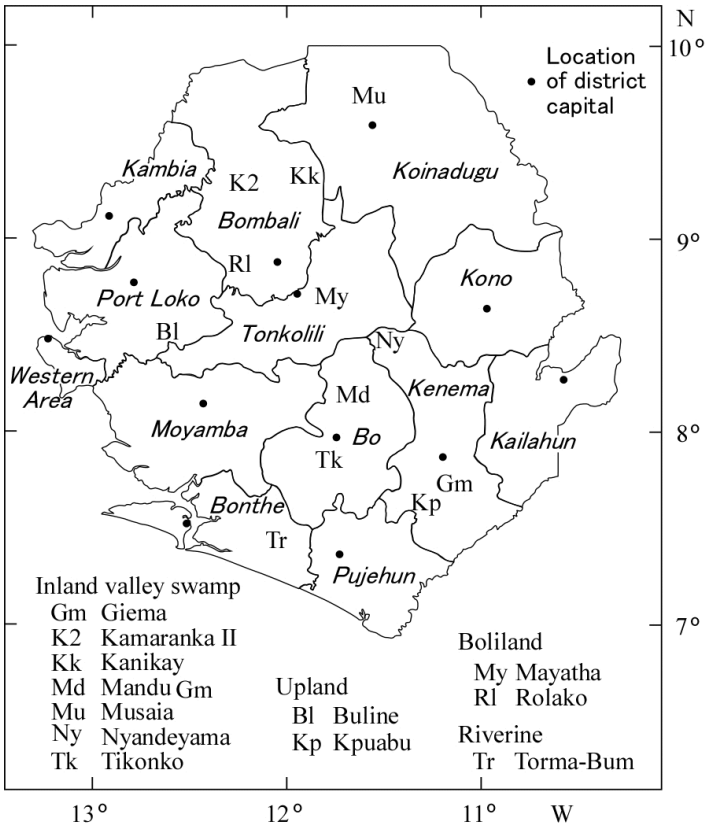


Fig. 1. Soils collected at various sites of Sierra Leone other than those in Kambia district.

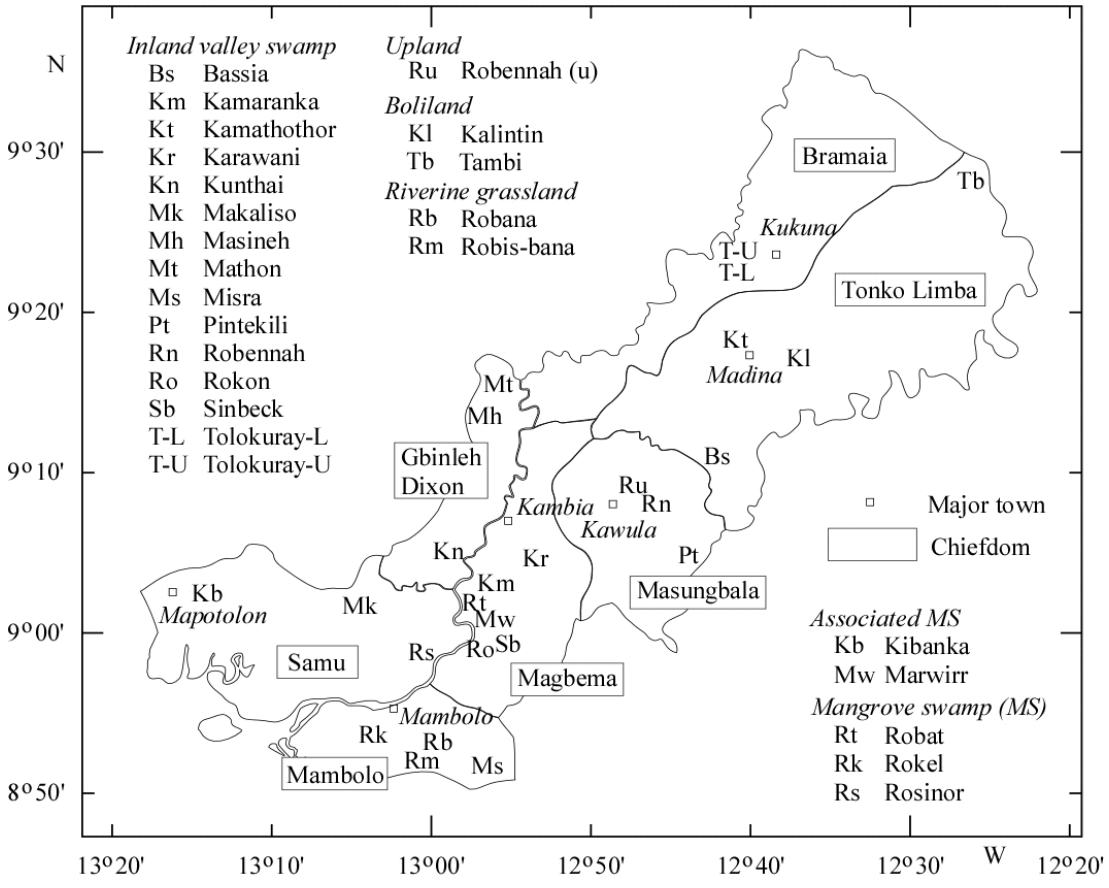


Fig. 2. Soil collection sites in Kambia district.

2. Nutrient treatment

Nitrogen (N), phosphorus (P), potassium (K), sulfur (S), and zinc (Zn) were selected as possibly deficient elements based on the preliminary chemical analyses (Yamaguchi, 2007). The standard nutrient rate (the *unity*) was 0.5 g pot^{-1} each of N, P_2O_5, and K_2O, 0.05 S g pot^{-1} and 0.02 Zn g pot^{-1}. Chemical reagents, urea, sodium di-hydrogen phosphate, potassium chloride, elemental sulfur, and zinc sulfate were used for the respective element sources.

Three categories of nutrient trials were carried out: (1) nutrient deficiency evaluation, (2) productivity comparison, and (3) plant response to graded nutrient rates. In the first trial, the standard (or reference) nutrient treatment was composed of three (N, P, and K) or four (N, P, K, and S) elements (Table 2). A single element was depleted from or added to the reference treatment. Including *None* treatment (the original soil without nutrient addition), there were seven different treatments. In the second, rice plants were grown with and without fertilizers at the same time to compare the productivity of various soils. In the third, growth response to graded rates of each of the five nutrients was examined changing the level of the unity between zero and four. The range of change was adjusted according to the level of deficiency of the nutrient in each soil, while the rates of the other nutrients were maintained at a fixed unity.

Table 2. The outlines of a series of experiments

Exp, no.	Date of transplanting (a)	Growth duration (day) (b)		Nutrient treatment			Number of measurements					
		S-T	T-H	Ref. (c)	+Zn	Rate trial	Tiller no.	Plant height	Leaf no.	pH & EC	Fe & Alga	Bub-ble
1	June 14 -July 30, 2011	11-22	17-33	NPK+S	+S		5-8	4-7	3-8	0	0-7 (d)	0
2	Jan. 6, 2012	17	26	NPK+S	+S		6	6	5-6	5	5	2
3	Feb. 6, 2012	16	25	NPK+S	+S		7	7	5-7	4	5	1
4	Mar. 8, 2012	10	26	NPK+S	+S	+Zn	7	6	4-6	4	5	1
5	June 5, 2012	15	29	NPK+S	+S		8	7	7	6	6	1
6	Jan. 6, 2013	20	25	NPK	-S		7	7	3	5	5	0
7	Mar. 13, 2013	10	29	NPK	-S		10	7	7	6	8	4
8	May 28, 2013	12	25	NPK+S	-S		11	6	6	5	8	1

a) Sequential plantings with different soils in Exp. 1: all soils at once in the other experiments. b) S-T: from sowing to transplanting. T-H: from transplanting to harvest (sampling). c) Ref.: Reference nutrient treatment. d) Only on Fe layer.

3. Experiment execution

Eight experiments, Exp. 1 through Exp. 8, were carried out in 2011-2013, in which different categories of the trials were often included in the respective experiments (Table 2 and 3). When the result of a given nutrient deficiency evaluation trial was uncertain, the treatment in question (a combination of a soil and a nutrient) was included in the succeeding experiments

for verification. Tolokuray-L soil was included in all experiments as a reference soil except in Exp. 2.

Table 3. Soil entry in each experiment

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

a) Tolokuray-L was the reference soil. b) Confirmation trial on selected treatments in nutrient deficiency evaluation trial. c) Fair comparison of soil productivity among soils used in Exps. 1 and 2. d) Included different nutrients in several soils.

4. Rice culture

Air-dried soils of 1.1–2.5 kg pot^{-1} (Table 1) were provided. The quantity was based on the apparent specific gravity (0.6–1.4 g cm^{-3}) and the rate of swelling with submergence (-2% to 34%) so that the final volume was adjusted to about 2 L pot^{-1} in each soil. They were mixed with chemical reagents and put into 2.5 L plastics pots.

Rice plants were grown under the submerged condition in the pots in a greenhouse at the RARC for 17–33 days, 26 days on average (Table 2). A single replication was adopted throughout the experiments except Exp. 6, 7, and 8, in which the reference nutrient treatment was duplicated. The greenhouse was covered with transparent plastic sheets on the roof and with insect-protection nets on the sides. The mean daily maximum and minimum temperature was 2.7 ^{o}C higher and 2.0 ^{o}C lower, respectively, indoors than outdoors (Fig. 3). Note that the low solar radiation period was avoided for most of the experiments (except part of Exp. 1).

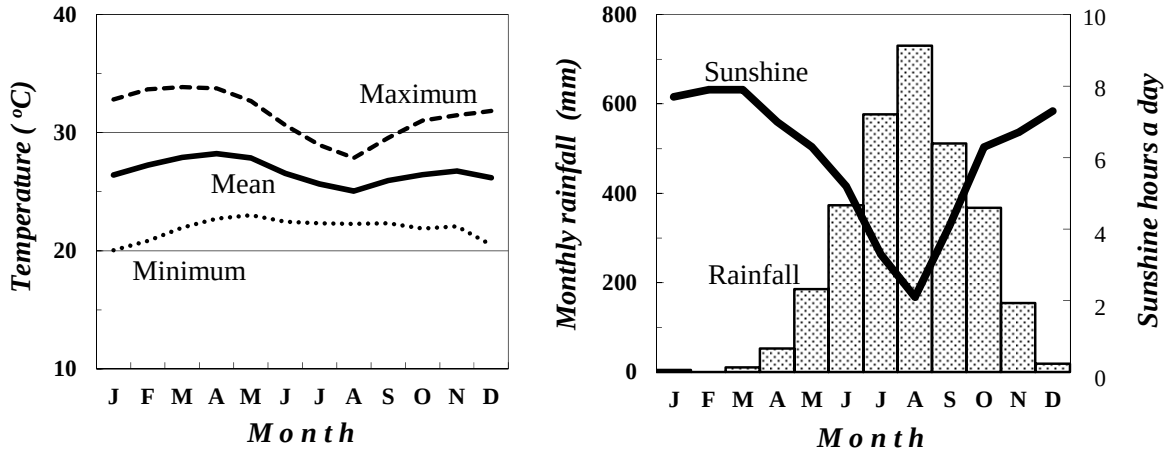


Fig. 3. Monthly changes of air temperature, rainfall and sunshine hours at Rokupr (9^{o}01' N, 12^{o}57' W) averaged over 25–36 years. Annual rainfall: 2,984 mm (RRSR, 1974).

The rice cultivar used was ROK 24, of which matured panicles were collected at two project sites, Sinbeck and Robat. Two seedlings raised in an upland nursery were transplanted in the respective pots. The plants were shaded shortly after transplanting to promote rapid root development by reducing transpiration. Irrigation water used was either rain (with an electrical conductivity of 0.2–0.6 mS m^{-1}), spring water (2.0–2.3 mS m^{-1}), or stream water (2–3 mS m^{-1}). The soils were submerged a few days before transplanting. The pots were placed far enough from each other not to be shaded and their position was randomly moved every five to seven days to minimize location effects.

5. Measurements

During the growing period, the plant height and the numbers of tillers and leaves on the main culm were measured every three to five days (Table 2). The pH and electrical conductivity

(EC) of the soil solution, algal and iron (Fe) layer development (the coverage percentage) on water surface and soil height (volume) were recorded three to eight times. Bubble and odor emissions were occasionally measured on a 5-point scale of 0 for *none* to 4 for *very vigorous*. At the end of the experiments, the upper-ground portion of the plants was sampled and dried under the sun or in an electric dryer, and its dry weight was measured. Dry matter production (DMP) during the experimental period was calculated by subtracting the seedling dry weight (0.01–0.04 g plant^{-1}) from the dry weight sampled.

Results

1. General plant growth

Plants in all experiments grew unimpeded and were free from insect and disease problems. The difference in plant growth caused by the nutrient treatments was frequently found soon after transplanting (Fig. 4). Within a few days after transplanting, tillers emerged in nutritionally favorable treatments like NPK (-S) and +S. On the other hand, in None and -P treatments, tiller development was considerably delayed, and none or only a few tillers emerged by the end of the experiments in many soils. In contrast, the number of leaves on the main culm similarly developed regardless of the nutrient treatment, provided that the nutritional condition was not so unfavorable.

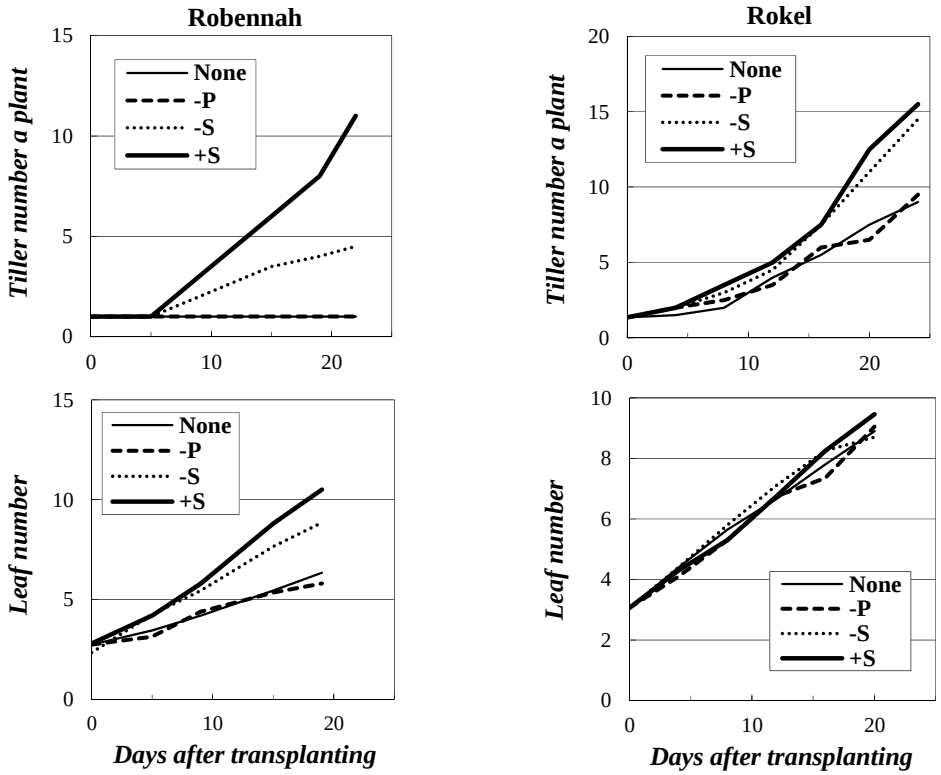


Fig. 4. Examples of tiller and leaf development after transplanting (T/P). Robennah in Exp.1 and Rokel in Exp.2. Leaf number: the number of leaves on the main culm.

Plants exhibited deficiency symptoms specific to the respective nutrients. In -P treatment, leaf blades became yellowish at the upper parts of lower leaves and later the color changed to yellowish orange, and finally the leaves died (Photo 1). The changes extended to upper leaves with advancement of growth. The leaves turned pale from lower to upper leaves in N and S deficiencies: The two were hardly distinguishable by their visual appearance. When K was lacking, the plant became stunted and its leaves turned dark green at the beginning, and then the lower leaves turned dirty yellow and died.

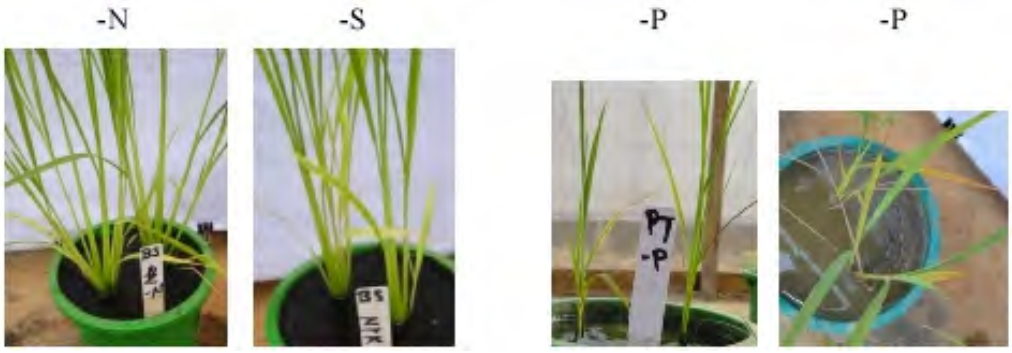


Photo 1. Examples of deficiency symptoms

Plant growth was largely subject to the nutrient and soil treatments (Photo 2). In general, the growth was poorer in None and -P treatments than in NPK (-S), +S and +Zn treatments.

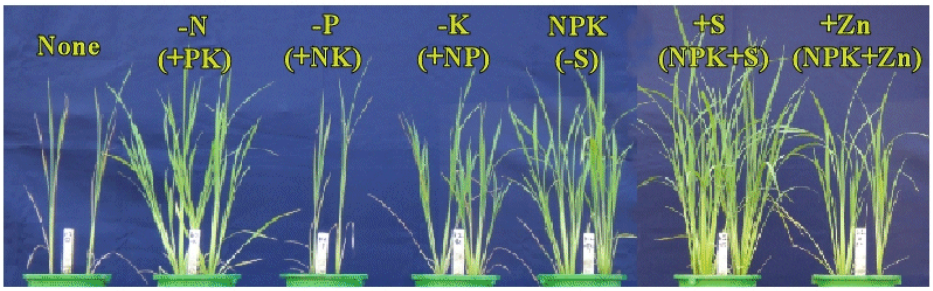
2. Plant growth in the respective experiments

Dry matter production (DMP) varied in the ranges of 0.1–3.1, 0.1–5.9, and 0.2–6.4 g plant^{-1} and the number of tillers per plant 1–13, 1–19, and 1–24 in None, NPK (-S), and +S treatments, respectively (Table 4). Both traits differed among the nutrient treatments and among the soils greatly. Plant growth in the reference soil (Tolokuray-L and partly Sinbeck soil) was nearly similar in all experiments.

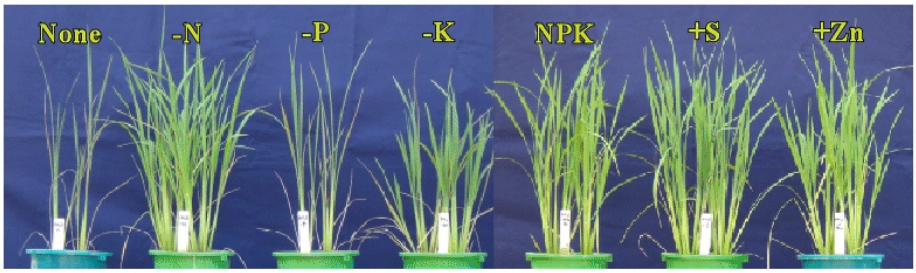
3. Dry matter production (DMP)

3-1. DMP by nutrient deficiency evaluation trials

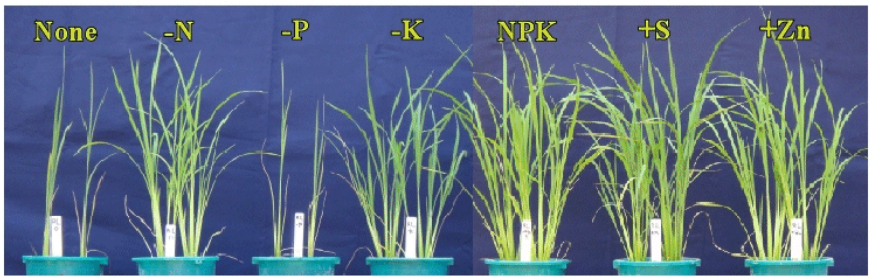
DMP was small in None and -P treatments and large in +S treatment for the majority of soils (Table 5-1 and 5-2). DMP was small in -N and -K treatments for many soils but as large as in +S treatment for several soils.



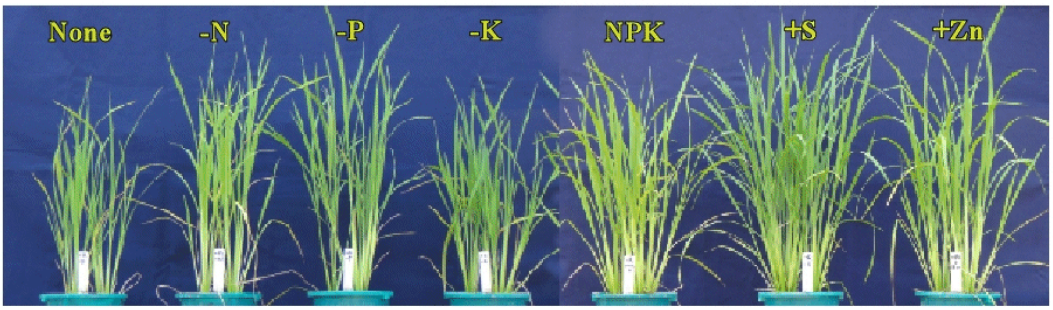
Kamaranka II (Bombali, IVS)



Musaia (Koinadugu, IVS)



Rolako (Bombali, Boliland)



Torma-Bum (Bonthe, Riverine)

Photo 2. Examples of plant growth in the nutrient deficiency evaluation trial (25 days after transplanting in Exp. 6).

Table 4. The minimum and maximum values of dry matter production (DMP) and the number of tillers among soils in selected nutrient treatments

Exp. no.	Soil	DMP (g plant^{-1})			No. of tillers a plant (a)		
		None	NPK (-S)	NPK +S	None	NPK (-S)	NPK +S
Exp.1	Min	0.1	0.2	0.8	1	3	6
(b)	Max	1.1	2.6	3.1	4	11	14
	Ref. soil	0.3	0.6	2.3	2	7	14
Exp.2	Min	0.2	0.4	0.6	2	2	4
	Max	3.1	5.6	6.3	9	18	19
	Ref. soil -2 (c)	0.7	1.1	3.7	3	5	11
Exp.3	Min	0.1	1.0	0.6	1	5	4
	Max	2.7	2.5	5.5	13	11	24
	Ref. soil	0.4	-	-	3	-	-
Exp.4	Min	-	0.1	0.2	-	1	1
	Max	-	5.9	4.8	-	19	18
	Ref. soil	-	0.5	-	-	4	-
Exp.5	Min	-	1.2	0.2	-	5	1
	Max	-	2.5	7.3	-	12	30
	Ref. soil	-	-	2.0	-	-	12
	Ref. soil -2 (c)	-	-	2.1	-	7	9
Exp.6	Min	0.3	1.2	1.6	1	5	7
	Max	2.1	3.7	6.4	6	10	14
	Ref. soil	0.3	-	3.0	2	-	11
Exp.7	Min	0.1	0.2	0.9	1	1	4
	Max	0.7	2.4	3.5	3	8	13
	Ref. soil	-	1.2	2.8	-	6	13
Exp.8	Min	-	0.1	0.3	-	1	3
	Max	-	1.9	5.4	-	10	19
	Ref. soil	-	1.0	2.5	-	7	14

Ref. soil: Tolokuray-L.

a) At harvest. b) Values not comparable to other experiments due to different growth duration and climatic condition. (c) Sinbeck soil.

Table 5-1. Dry matter production (g plant^{-1}) in the full set of nutrient deficiency evaluation trials

Experi-	Soil			Nutrient treatment						
ment	Ser. no.		abbr.	None	-N (PK+S)	-P (NK+S)	-K (NP+S)	NPK (-S)	NPK +S	NPK +S+Zn
Exp.1	12	Mathon	Mt	0.4	1.5	0.5	0.8	0.6	2.6	2.5
	13	Kamaranka	Km	0.1	0.7	0.1	0.4	0.2	0.8	1.0
	14	Karawani	Kr	0.1	2.8	0.1	0.8	1.5	2.3	3.4
	16	Sinbeck	Sb	0.2	1.0	0.2	1.6	1.9	2.9	2.5
	18	Robennah	Rn	0.2	2.1	0.2	1.3	1.1	3.0	2.7
	21	Tolokuray-U	T-U	0.3	1.4	0.2	1.2	1.3	2.5	3.1
	22	Tolokuray-L	T-L	0.3	0.8	0.1	0.5	0.6	2.3	2.1
	27	Kalintin	Kl	0.5	1.3	0.6	1.7	0.9	2.1	1.9
	30	Robana	Rb	0.2	1.2	0.1	1.4	1.7	1.8	2.3
	33	Kibanka	Kb	1.1	2.4	1.0	1.9	2.4	3.1	3.4
	34	Marwirr	Mw	0.3	1.3	1.2	1.9	2.6	2.5	2.3
Exp.2	8	Misra	Ms	1.2	2.8	0.6	2.0	1.9	3.5	4.3
	9	Makaliso	Mk	0.2	1.2	0.2	1.2	0.9	1.1	1.4
	10	Kunthai	Kn	0.5	2.6	0.6	3.1	5.3	4.7	5.4
	16	Sinbeck	Sb	0.6	4.2	0.7	1.4	1.1	3.7	3.5
	17	Pintekili	Pt	0.3	0.5	0.2	0.6	0.4	1.8	1.2
	19	Bassia	Bs	0.3	2.3	0.4	2.9	0.6	2.4	2.1
	20	Kamathothor	Kt	0.8	2.0	0.8	2.0	1.6	4.0	3.4
	35	Rokel	Rk	3.2	4.2	3.1	7.1	5.6	6.3	5.2
	36	Rosinor	Rs	0.5	0.6	0.5	0.7	0.8	0.6	0.1
	37	Robat	Rt	0.3	1.1	0.4	1.3	2.2	1.9	5.2

Table 5-2. Continued.

	Soil			Nutrient treatment						
	Ser. no.		abbr.	None	-N (PK)	-P (NK)	-K (NP)	NPK (-S)	NPK +S	NPK +Zn
Exp.6	6	Kamaranka II	K2	0.5	1.2	0.3	1.0	1.2	3.4	0.9
	15	Rokon	Ro	0.4	1.6	0.5	1.8	1.7	1.6	1.4
	23	Musaia	Mu	0.6	3.3	0.7	1.9	2.4	3.2	2.7
	24	Tikonko	Tk	1.2	1.9	1.9	1.8	2.2	3.9	2.2
	26	Rolako	Rl	0.4	1.2	0.3	1.3	2.1	3.2	2.0
	28	Tambi	Tb	0.3	1.3	0.4	1.0	1.3	2.9	1.9
	29	Mayatha	My	0.3	2.3	0.4	1.7	2.2	2.6	2.6
	31	Robis-bana	Rm	0.4	2.2	0.3	1.9	2.5	2.8	3.3
	32	Torma-Bum	Tr	2.1	3.1	2.7	2.5	3.7	6.4	3.5
Exp.7	1	Kpuabu	Kp	0.2	1.2	0.1	1.0	1.5	1.0	0.7
	2	Robennah (u)	Ru	0.1	0.5	0.1	0.8	1.2	3.0	1.4
	3	Buline	Bl	0.3	2.1	0.5	1.4	2.4	3.5	2.0
	4	Nyandeyama	Ny	0.1	0.2	0.1	0.1	0.2	1.0	0.1
	5	Giema	Gm	0.1	0.1	0.1	0.3	0.3	0.9	0.3
	7	Kanikay	Kk	0.7	1.7	0.9	1.2	1.3	1.9	1.1
	11	Masineh	Mh	0.2	0.2	0.1	0.2	0.2	1.0	0.3
	25	Mandu	Md	0.2	1.4	0.3	1.3	1.5	1.4	2.1

3-2. DMP in the nutrient rate trial

Plant response to the graded rates of nutrient application largely varied with elements and soils (Fig. 5 and Photo 3). As for the N rate, DMP increased up to the unity 2 in Kt (Kamathothor) soil, whereas, in Sb (Sinbeck) soil, it was the maximum at the unity 0.25 and decreased with a further increase of the application rate. As for P, DMP increased with an increase in the unity up to 2 for all soils except Mk (Makaliso) soil. With further increase in the P rate, the DMP increased for Kr (Karawani) soils and decreased for Tr (Torma-Bum) soil, whereas it was unaffected for T-L (Tolokuray-L) soil. As for K, DMP was the maximum when the unity was 1 for many soils. As for S, DMP increased for K2 (Kamaranka II) soil at the unity over 1, but it was the maximum at the unity 0.25–1 for the other soils. As for Zn, the maximum DMP was attained at the unity 0.5 for most soils but at the unity 1 for Mh (Masineh) soil.

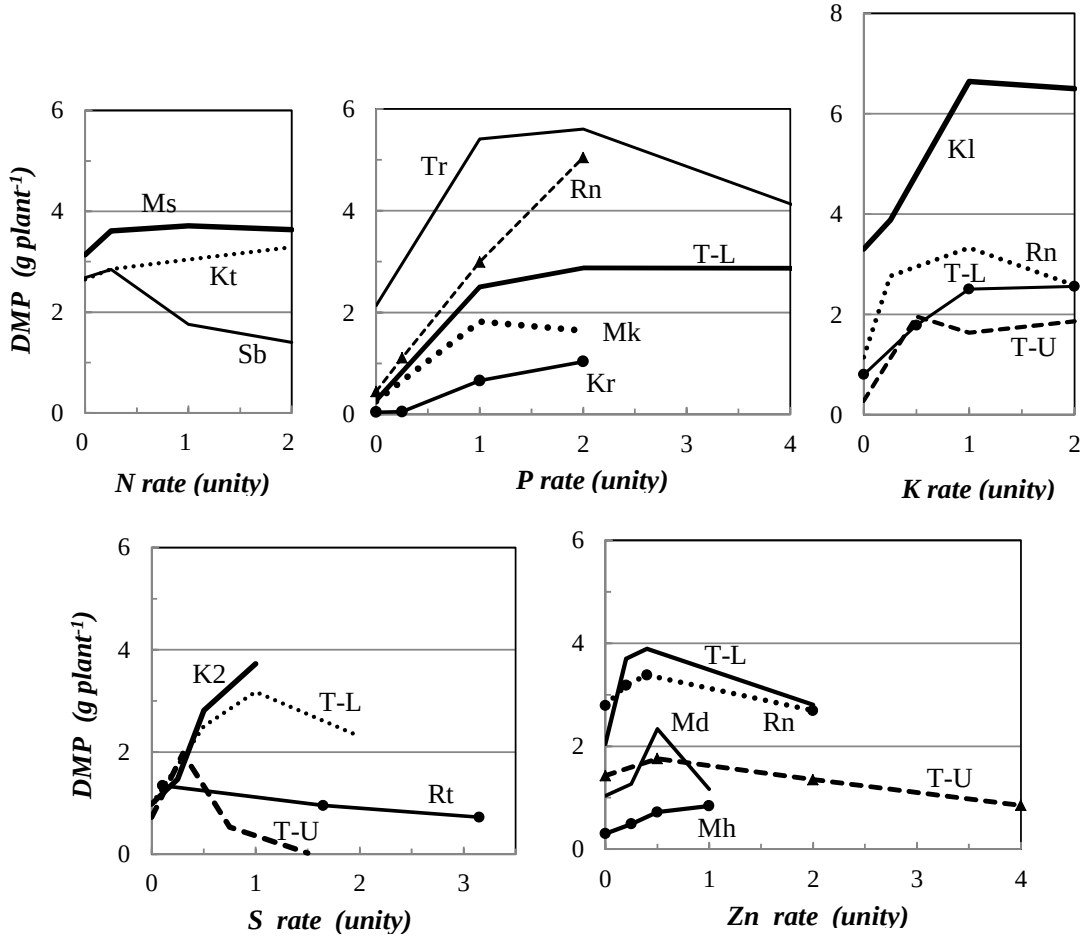


Fig. 5. Growth response of rice plants to the graded nutrient rates. DMP: dry matter production during the growth. The unity: 0.5 g pot^{-1} each of N, P_2O_5, and K_2O, 0.05 S g pot^{-1}, and 0.02 Zn g pot^{-1}.

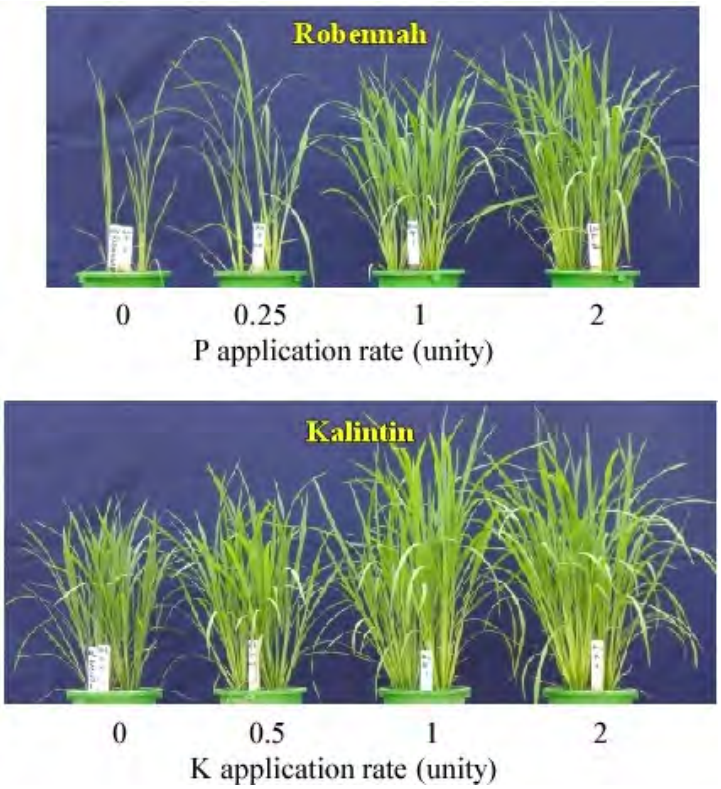


Photo 3. Examples of plant response to nutrient application rates in Exp. 4. The unity (1): 0.5 g pot^{-1} each in P_2O_5, and K_2O.

4. pH changes in the soil solution

Changes of pH at successive growth stages largely varied among the treatments, especially among the soils (Fig. 6). Shortly after submergence, pH increased and remained at the level throughout the growth stages in several soils (e.g., Robat soil), whereas it decreased at later growth stages in some others (e.g., Rokel soil). However, pH remained the same in several soils (e.g., Tambi and Robis-bana soils) throughout the whole growth stages.

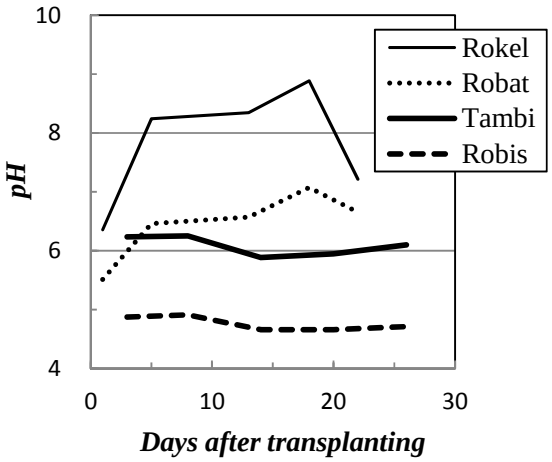


Fig. 6. Examples of pH changes during the growth in Exp. 2 and 6. The pH value was averaged over all nutrient treatments.

The average pH did not vary much across the soils (5.8–6.1) regardless of the nutrient treatment at the early growth stage (Table 6). In contrast, at the later growth stages, it was higher in -K treatment and slightly lower in -P and -S treatments than in the others.

Table 6. Mean pH and electrical conductivity (EC) averaged over soils (a)

	Growth stage		Nutrient treatment						
		(DAT)	None	-N	-P	-K	NPK	+S	+Zn
pH	Initial	(1-3)	5.9	5.9	5.8	6.1	5.9	5.9	5.9
	Final	(18-28)	6.1	6.0	5.6	6.6	5.9	5.7	5.8
	Whole	(1-28)	6.1	5.9	5.7	6.4	6.0	5.7	5.8
EC	Initial	(1-3)	10	19	17	13	22	20	26
(mS m^{-1})	Final	(18-28)	25	38	49	35	42	34	51
	Whole	(1-28)	23	34	44	31	41	33	44

a) Averaged over all nutrient deficiency trials: Exps. 2, 6 and 7. DAT: days after transplanting (submergence). Whole: averaged over whole growth stages.

5. Electrical conductivity (EC) variation

EC values in the soil solution varied greatly among the soils (Fig. 7). The EC averaged over the whole growth stages was low at 3 mS m^{-1} in Torma-Bum soil and it was as high as 520 mS m^{-1} in Rosinor soil. Also, EC variation during the growth period was large: EC gradually decreased at successive growth stages in some soils (e.g., Sinbeck soil), but it kept increasing in the others (e.g., Giema soil). The EC value tended to be low in None but high in +Zn and -P treatments during the later growth stages, although the difference was small (Table 6).

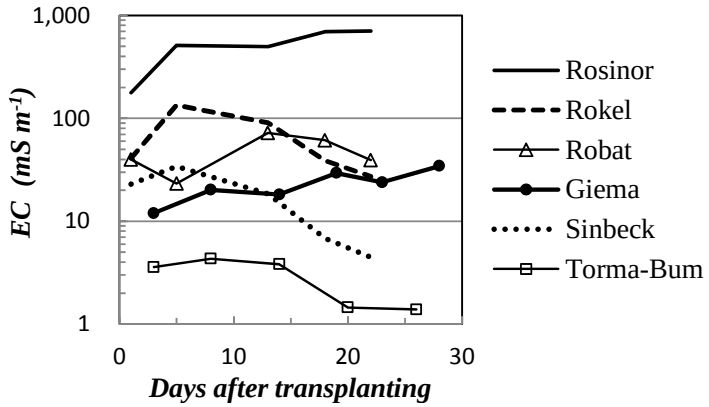


Fig. 7. Electrical conductivity (EC) of various soils at successive growth stages. Examples were selected from Exp. 2, 6, and 7, and EC was averaged over all nutrient treatments.

6. Fe layer development

Fe layer development in the soil solution differed among the treatments. The Fe layer rapidly developed soon after submergence in some treatments (e.g., None in Giema); it started to develop only at the later growth stages in several treatments (e.g., -K in Kanikay), and no Fe layer developed in many others (e.g., +S in Masineh) as shown in Fig. 8. Even if a thick layer fully covered the entire surface, no typical symptom of excess Fe like bronzing or brown spots was observed in the plants. Note that the Fe layer was likely composed of ferrous carbonate based on its crystal structure.

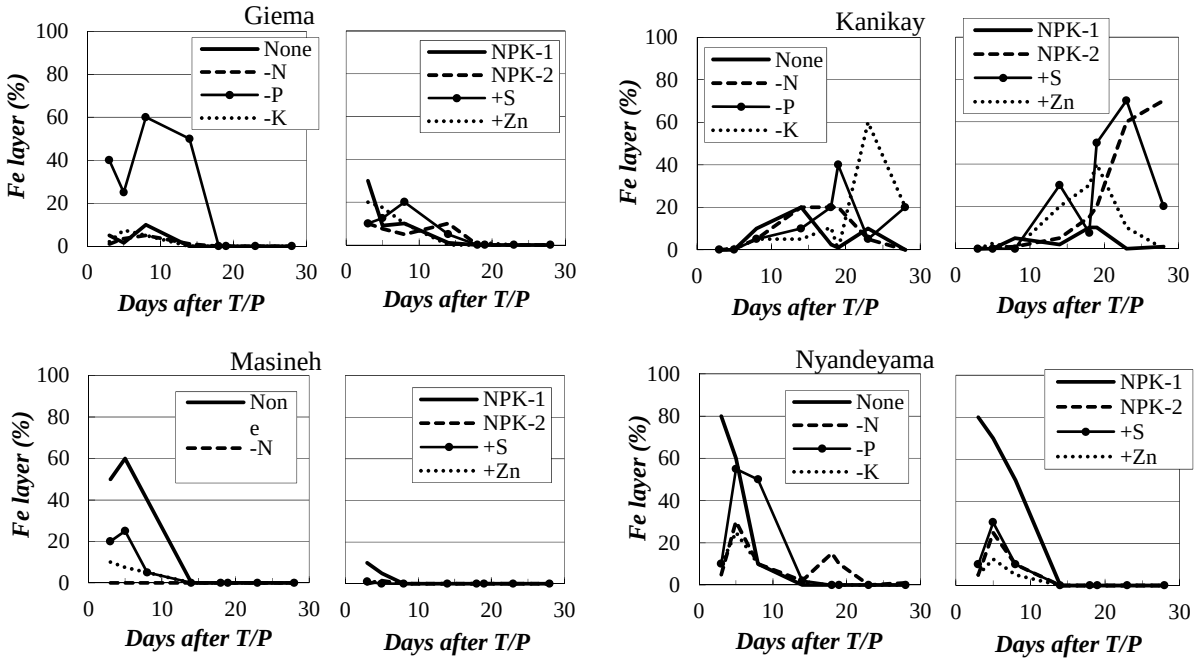


Fig. 8. Examples of Fe layer development on the water surface of pots in Exp.7.

Fe layer development averaged over the whole growth stages varied greatly among the soils but little among the nutrient treatments (Table 7). It was less in the soils of Robennah (u), Kunthai, Bassia, Tambi, Robis-bana, Buline, Musaia, Tikonko, Mandu, Rolako, Mayatha, and Torma-Bum but larger in Rokon and Robat soils.

Table 7. Development (%) of Fe layer and algae on the water surface averaged over whole growth stages in Exps. 2, 6 and 7 (a)

	Nutrient treatment							
	None	-N	-P	-K	NPK	+S	+Zn	mean
	Fe layer development (%)							
mean	7	6	6	5	4	6	4	5
min	0	0	0	0	0	0	0	0
max	52	40	46	32	31	37	25	37
CV (%)	176	182	158	162	184	165	161	154
	Algal development (%)							
mean	8	21	14	26	26	36	28	23
min	0	0	0	0	0	5	0	5
max	37	72	47	67	74	77	64	52
CV (%)	128	87	107	69	83	56	64	62

a) The number of soils was 27. The values of the two traits were based on 5-8 measurements during the growth in each experiment. CV: coefficient of variation.

7. Algal development

A few days after transplanting (submergence), algae often appeared in NPK and +S treatments

but did not in None and -P treatments (Photo 4). Algal development largely varied among the treatments (Fig. 9). In some cases (e.g., NPK in Kanikay), algae started to develop shortly after transplanting and steadily grew until the end of the experiment. In others (e.g., NPK in Mandu) they developed towards the middle of the growing period and then decreased, and in several others (e.g., None in Nyandeyama) they did not grow at all throughout the growth stages.

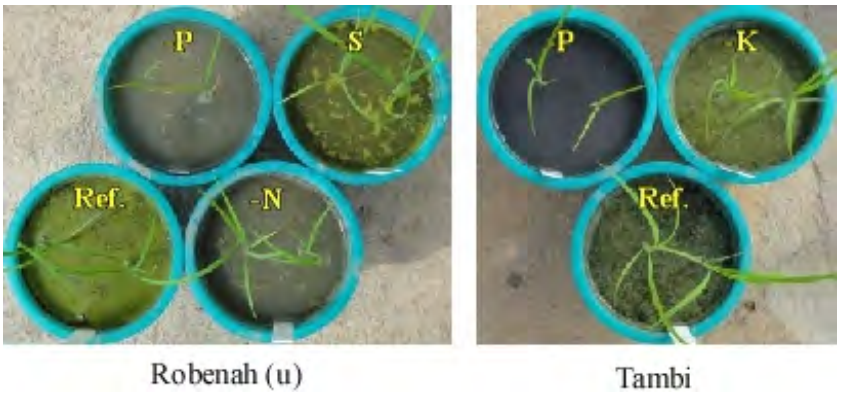


Photo 4. Examples of algal development 8 days after transplanting in Exp. 8. Ref.: reference standard applied at the rate of 0.5 g pot^{-1} each of N, P_2O_5, and K_2O and S 0.05 g pot^{-1} (the unity).

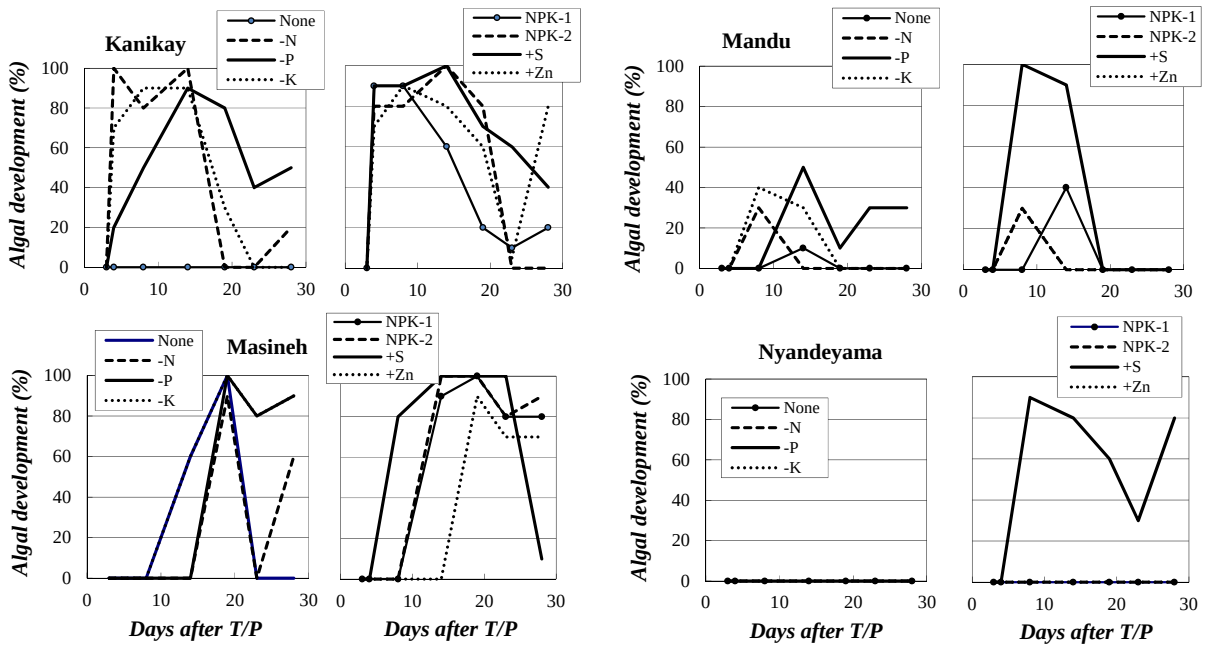


Fig. 9. Examples of algal development during the experiment period in Exp.7.

Algal development over the entire growth stages varied more among the soils than the nutrient treatments (Table 7). The variation across the soils was larger in None and -P than in the other nutrient treatments. Algae thrived in soils like Rokon, Kpuabu, Giema, and Kanikay but did not grow much in Bassia and Rolako soils. The algal development on average tended

to be large in +S treatment and small in None treatment.

8. Bubble and odor emissions

Bubble emission varied greatly among soils (Fig. 10). Bubbles began to emerge soon after transplanting (submergence) and continued to increase in some soils (e.g., Masineh) but decreased at the later growth stages in some others (e.g., Tolokuray). In several soils (e.g., Musaia), bubbling started sometime after transplanting. Little or no bubbling was observed in soils of Robennah (u), Kunthai, Rokon, Tolokuray-U, Tambi, Robana, Robis-bana, Kibanka, Rokel, Rosinor, Tikonko, Rolako, Mayatha, and Torma-Bum. There was no apparent difference among the nutrient treatments.

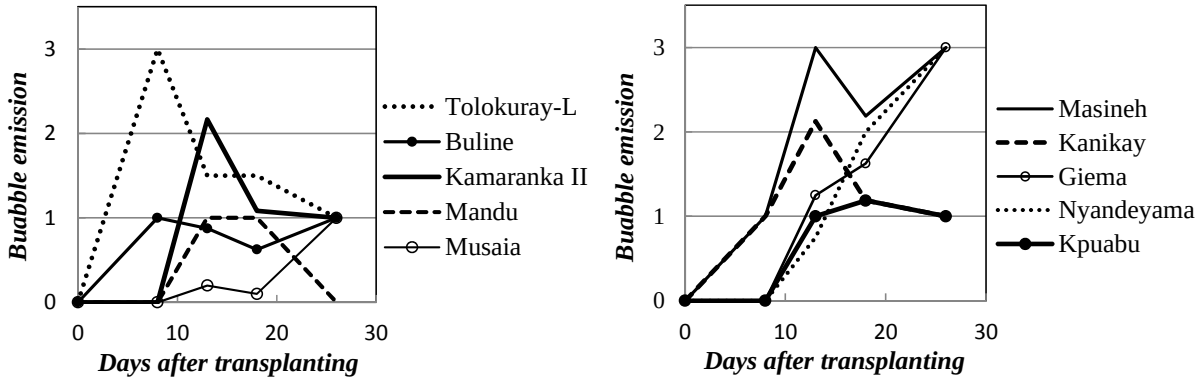


Fig. 10. Examples of bubble emission averaged over all nutrients in Exp.7.
Bubble emission scale: 0 (*none*)–3 (*vigorously*)

Soils with vigorous bubbling were usually accompanied with odor emission (Fig. 11). The magnitude of bubbling and odor emissions were related to the growth stage, and the relationship appeared to be similar between different growth stages.

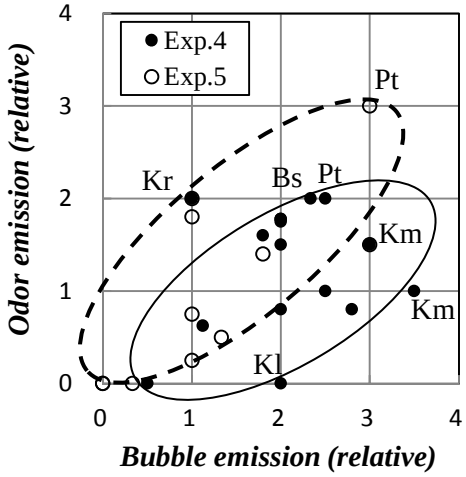


Fig. 11. Relationship between bubble and odor emissions over all nutrient treatments in Exp. 4 (17 DAT) and Exp.5 (24 DAT). Relative value: 0 (none)–4 (very vigorously).

Discussion

1. Nutrient deficiency level

The deficiency level of each element was calculated from the relative DMP between the reference treatment and the nutrient treatments for each soil. The level is an absolute value to cancel the negative or positive value derived from a nutrition depletion or addition treatment. The level of nutrient deficiency is between 0 and 100 for the depletion treatment. In contrast, the level exceeds 100 when the DMP of the addition treatment is more than double that of the reference standard. Such a case represents a substantial shortage.

Eventually, the deficiency levels were divided into five classes: *severely* (the deficiency level 101–150), *highly* (76–100), *intermediately* (51–75), *fairly* (26–50), and *least* (-24–25) deficient (Table 8). Several cases remained doubtful: (a) the DMP was larger in the depletion treatment or smaller in the addition treatment than in the reference and (b) the results were inconsistent among the experiments. Those cases were respectively classified as *Likely abundance* and *Pending* (unidentified) in the present study. The treatments in question should be replicated and verified in a future study.

Table 8. Nutrient deficiency level classified in respective soils

a) in Kambia district

Ser. no.	Soil	abbr.	Element N	P	K	S	Zn
2	Robennah (u)	Ru	++	+++	+	*	-
8	Misra	Ms	-	+++	+	+	*
9	Makaliso	Mk	-	+++	-	-	+++
10	Kunthai	Kn	+	+++	+	-	-
11	Masineh	Mh	-	+	-	*	*
12	Mathon	Mt	+	+++	++	+++	-
13	Kamaranka	Km	-	+++	+	+++	*
14	Karawani	Kr	++	+++	++	+	-
15	Rokon	Ro	-	++	-	-	-
16	Sinbeck	Sb	-	+++	++	+	+
17	Pintekili	Pt	+++	+++	+++	+++	++
18	Robennah	Rn	+	+++	++	++	-
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	*

b) in other districts

Ser. no.	Soil	abbr.	Element N	P	K	S	Zn
1	Kpuabu	Kp	-	+++	+	a	a
3	Buline	Bl	-	+++	+	+	-
4	Nyandeyama	Ny	-	-	+	+++	-
5	Giema	Gm	+	+++	+	++++	-
6	Kamaranka II	K2	-	++	-	++++	-
7	Kanikay	Kk	a	+	-	+	-
23	Musaia	Mu	a	++	-	+	-
24	Tikonko	Tk	-	-	+	+++	-
25	Mandu	Md	-	+++	-	-	+
26	Rolako	Rl	+	+++	+	+	-
29	Mayatha	My	-	+++	-	-	-
32	Torma-Bum	Tr	-	+	+	++	-

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

Phosphorus shortage was most marked and prevalent across the sites (soils) except several sites (e.g., Nyandeyama). Sulfur, K, and N were lacking in many sites and Zn only in a few sites (e.g., Makaliso). Also, nutrient status differed among the soils greatly. For example, Pintekili and Tolokuray-L soils severely lacked many elements, whereas Rokon and Rokel soils were fairly or intermediately deficient only in P. Before the recommended fertilizer rate for the country is established, the general nutrient status that is applicable to a wide area must be determined. Then, the most appropriate rate for each field should be found modifying the standard rate according to the nutrient conditions of the field.

The finding of the present study that DMP was closely related between None and -P treatments (Fig. 12) supports the severe P deficiency in general. Several soils like Mw (Marwirr) were affected by deficiency not only in P but also in other nutrients, N for instance.

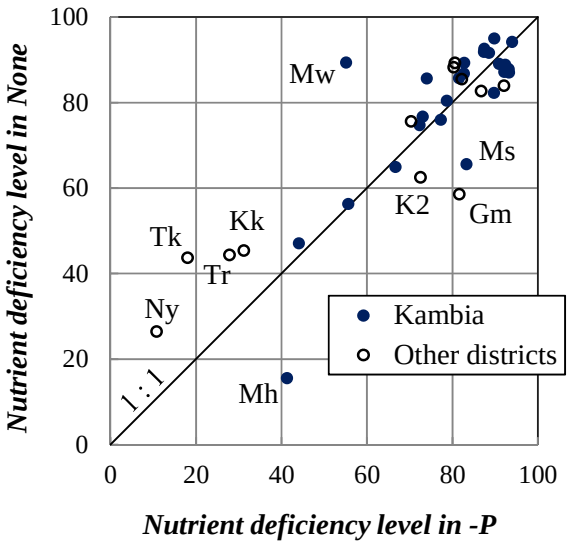


Fig. 12. Relationship in the nutrient deficiency levels between -P and None treatments.

There was no apparent difference in deficiency levels between Kambia district and other districts (Fig. 13). While the difference was marginal, S deficiency tended to be more frequent and N and Zn deficiencies to be less in other districts than in Kambia.

The deficiency levels of N, P, K, S, and Zn were 30, 70, 30, 40, and 10, respectively when it was averaged over all the soils evaluated (Table 9). Phosphorus deficiency was somewhat pronounced in uplands and bolilands, so was S deficiency in uplands and IVSs, as compared with other agro-ecologies.

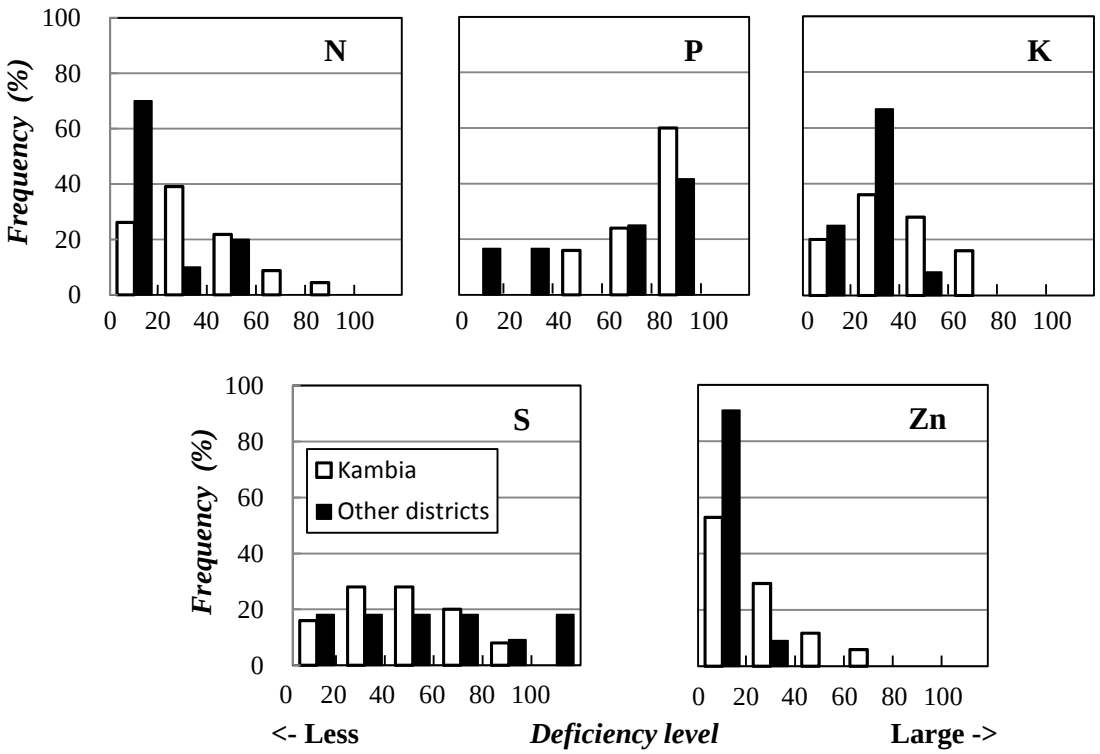


Fig. 13. Frequency of nutrient deficiency levels in Kambia and other districts.

Table 9. Rounded nutrient deficiency level in various agro-ecologies of Sierra Leone

Agro-ecology		Nutrient				
	n	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

There is a general understanding that it is difficult, if not impossible, to estimate a fertilizer rate for fields simply based on the soil fertility evaluated in pot culture experiments. The main reason is that the soil volume in pots is much less than that in fields, about one-tenth in the present study. The standard nutrient rate (the unity) of 0.5 g pot^{-1} N, P_2O_5, and K_2O each is about 100 kg ha^{-1} each in the field condition from the perspective of plant growth. However, the deduced rate is one-fifth of or less than the directly converted rate.

Two approaches need to be taken in the immediate future. First, the relationships between soils and nutrients are elucidated. In the pot trials of the present study, the nutrient status was based on single element modifications. To identify the composition of fertilizer appropriate for fields, the interactions between soils and nutrients must be examined through a set of trials combining two or more nutrients at graded rates for each nutrient. Second, chemical analyses

are essential to obtain background information on the nutrient status of soils. Eventually, the results of pot experiments must be verified by field trials to establish the standard fertilizer rate.

In the present study, several technical procedures involved in the pot culture experiments could have affected the nutrient deficiency levels. First, soils were ground and sieved after air-drying for homogenization. The drying might have enriched the soil, thereby alleviating N deficiency. Second, natural water of rain, spring, or river was used for irrigation instead of distilled water, which was not easily obtainable under the circumstance. While water with the lowest EC available was used for each experiment, K deficiency might have been mitigated (except for some trials in which rainwater was used). Third, the submerged condition contributed to solubilizing P, and thus, perhaps improving P status; on the other hand, P deficiency in the upland condition might have been accelerated by the plants that grew there. Fourth, the experiments began shortly after submergence. Because the period of submergence affects the soil's redox potential, the plant growth could be influenced, positively or negatively; the effects might be substantial if plants were transplanted after a long period of submergence like one month.

2. Comparison of soil productivity

DMP with fertilizer application consists of two components: one that depends on inherent soil fertility and the other that is determined by fertilizer application:

DMP with fertilizer = DMP without fertilizer + Fertilizer response

Note that the present study was composed of eight experiments in which the growing condition differed from each other due to such climatic factors as solar radiation and temperature (Table 2 and Fig. 3). The DMP in each experiment was standardized on the basis of the mean DMP of the reference soil (Tolokuray-L) for comparisons. Because of the exclusion of the reference soil in Exp. 2, Sinbeck soil was adopted: Based on the relationship between the two soils in Exp. 5, the DMP in Exp. 2 was standardized. The DMP with fertilizer was selected from the maximum value of NPK (2 soils), +S (17 soils), +Zn (2 soils), or +S+Zn (16 soils) treatment.

Soil productivity was analyzed based on the relationship between DMP with fertilizer, DMP without fertilizer, and fertilizer response. DMP largely varied among the soils: DMP with and without fertilizer was 0.7–6.1 and 0.1–2.9 g plant^{-1}, respectively (Fig. 14). The DMP with fertilizer was greatly dependent on fertilizer response. Fertilizer responsiveness is considered to have played a key role in determining productivity under the fertilized conditions.

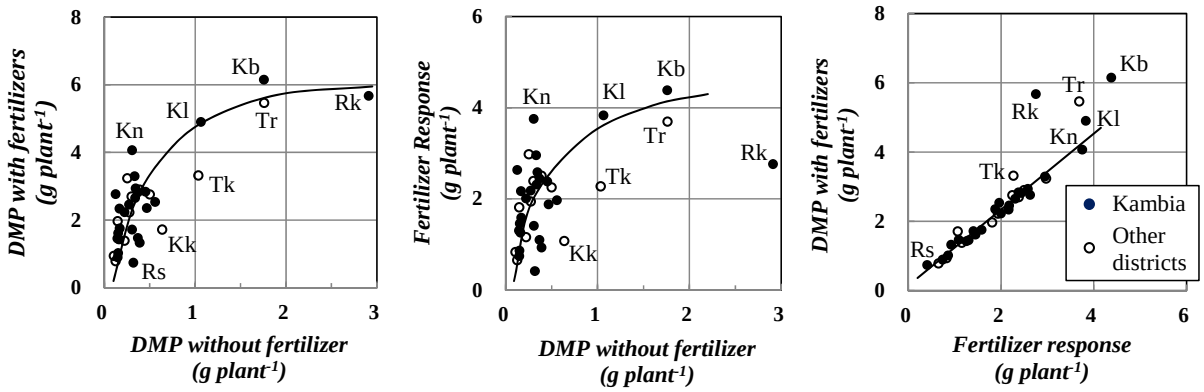


Fig. 14. Relationship between dry matter production (DMP) with and without fertilizers and fertilizer response. Refer to Table 1 for soil abbreviations.

No apparent difference between Kambia and other districts was found in these relationships. Rk (Rokel) soil behaved somewhat differently from other soils: the DMP with fertilizer was large mainly owing to the large DMP without fertilizer, although the fertilizer response was intermediate. The DMP with fertilizer for Kb (Kibanka) soil was the largest because of large fertilizer response and fairly large DMP without fertilizer. Hence, DMP with fertilizer relative to fertilizer response was large for these two soils; this was also the case in Tr (Torma-Bum) soils.

The ratio of DMP with fertilizer to DMP without fertilizer varied in the range of 2–22; the ratio tended to be large for soils of small DMP without fertilizer (Fig. 15). This suggests that fertilizer application largely improves DMP for soils with inherently low productivity.

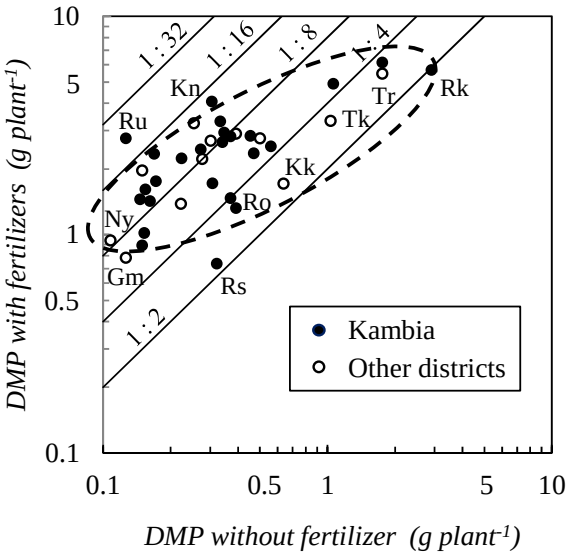


Fig. 15. Relationship between dry matter production (DMP) with and without fertilizers

Soil productivity can be grouped by the combination of DMP with/without fertilizer, nutrient responsiveness, and the ratio of DMP with fertilizer to DMP without fertilizer. Such soil grouping was not associated with particular locations or agro-ecologies, however.

3. Factors causing differences in fertilizer responsiveness among soils

Fertilizer response is presumed to be similar among soils unless there is a factor that hinders plant growth. However, it largely varied among the soils tested (Fig. 14 and 15). The present study adopted a pot culture for experiments with considerable care: plants were grown free from mutual shading and pest damage. The same cultivar was used for all the experiments and the climatic condition (e.g., solar radiation, temperature, etc.) was identical for all the soils within an experiment. The irrigation water was properly controlled so that no nutrient was lost through runoff or leaching. The variation was therefore most likely caused by factors other than genetic, climatic, or cultural.

Plausible causes of the observed difference in fertilizer response are (1) nutrient loss or ineffectiveness from soil fixation, volatilization or emission, transformation, etc., (2) excess or shortage of other nutrients like Cu and B, (3) toxic substances like organic acids derived from organic matter decomposition, (4) imbalance of the nutrients applied, and (5) growth retardants in the soils, like phenols and polycyclic aromatic hydrocarbons. Note that actual causes may differ among soils, and also, several factors may interact with each other.

Various properties of the soil solutions were measured in an attempt to identify actual causes, and in the process, some findings indicative of future approaches were obtained: the lower the EC, the larger the DMP, for example (Fig. 16). However, such findings could be the consequences of natural plant growth. When a plant grows, it avidly absorbs nutrients to support its growth leaving only a little electrolyte in the soil. Plant growth would be retarded in Rs (Rosinor) soil due to salt injury: high EC is expected to be related to low fertilizer response. This is not the case for Rk (Rokel) soil due to its large DMP relative to its EC. In such a case, factors other than EC should be considered because EC affects plant growth differently at the threshold point (lwama and Yamaguchi, 2006).

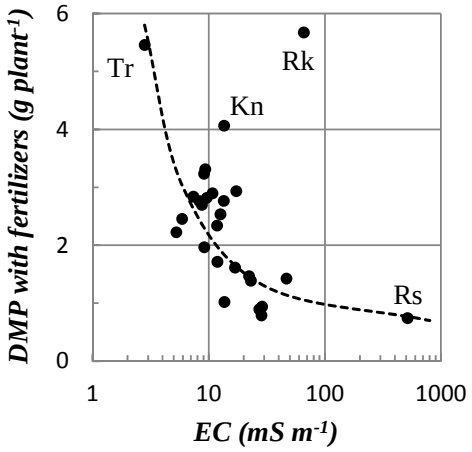


Fig. 16. Relationship between electrical conductivity (EC) and dry matter production (DMP) in various soils. EC was the mean value averaged over the whole growth stages.

Bubble emission started shortly after submergence in several soils, and its magnitude largely differed among the soils (Fig. 10). Also it often accompanied odor emission (Fig. 11). Bubbles

were most likely composed of carbon dioxide as a result of organic matter decomposition and, in part, of hydrogen sulfide because of the rotten-egg odor. Hence, the vigorous bubbling and the odor were often associated with smaller DMP (Fig. 17).

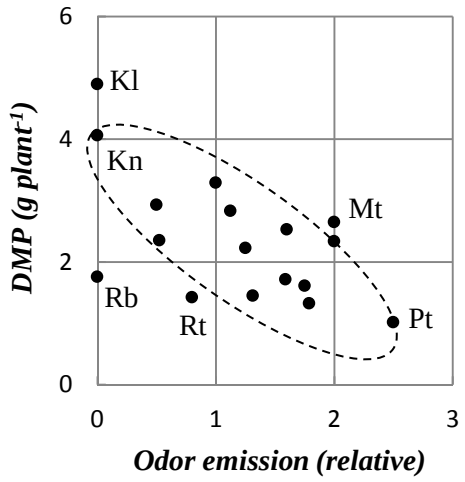


Fig. 17. Relationship between odor emission and dry matter production (DMP) with fertilizers. Mean of Exp. 4 and 5.

The most significant factor of fertilizer response likely varies among soils. To identify it, first all possible factors should be sought by soil chemical analyses. Then, supplementary experiments based on the possibilities should be run, and the results would help find real causes.

4. DMP difference among agro-ecologies

DMP without fertilizer tended to be in the order of uplands, IVSs, bolilands, riverine grasslands, and mangrove swamps, from small to large; DMP with fertilizer was larger in the last three agro-ecologies than in IVSs (Fig. 18). The differences in soil productivity among the agro-ecologies were statistically insignificant, however, because the number of entries was small except in IVSs. Nevertheless, it is more likely that soils of relatively high fertility are found in topographically lower areas where sedimentary materials are deposited. Nutrients in uplands and IVSs are easily lost through leaching and runoff, especially during the mid- rainy season; IVSs are seldom embanked in the country.

Fertilizer response was smaller in IVSs (1.7 g/plant on average) than the other agro-ecologies (2.3–2.6 g/plant). The small fertilizer response in IVSs is probably in part due to the existence of peaty soils, in which intermediate metabolites and low redox potential from the decomposition process of organic matters might have harmed plant growth.

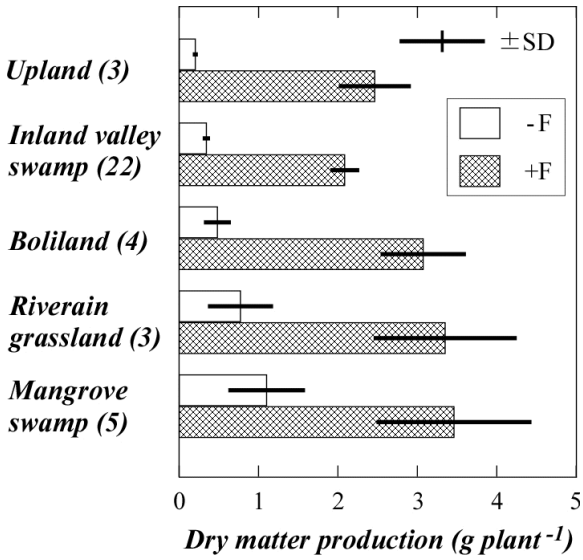


Fig. 18. Dry matter production with (+F) and without (-F) fertilizers in various agro-ecologies. The number of soil entries in respective agro-ecologies was in parentheses.

5. Growth response to graded nutrient rates

The growth of rice plants responded to the graded rates of nutrient application in the respective soils (Fig. 5). Nutrient response generally corresponded with the nutrient deficient level of the soil (Table 8). As for N, both deficiency level and DMP response were low in Sb (Sinbeck) soil, and DMP negatively responded to large N application. In Kt (Kamathothor) soil, the N deficiency level was intermediate and the DMP response to N was large. Kr (Karawani) soil was possibly an exception, however: Its DMP negatively responded to N application rates even if its N deficiency level was large. The determinants of these relationships need to be revealed through supplementary experiments.

The nutrient deficiency evaluation trials were based on the depletion/addition treatment with the fixed rate of the respective elements. The nutrient rate trials indicated that the nutrient deficiency levels were affected by the unity itself. For example, the maximum DMP was obtained at 0.25–0.5 unity of N in Sb (Sinbeck) soil, S in T-U (Tolokuray-U) soil, and Zn in many soils. The result needs to be further examined for the nutrient rate that leads to the maximum plant growth. On the other hand, the general nutrient status quantified in Table 8 was probably not greatly influenced except a few soils because it was broadly classified into five groups.

The nutrient rate trials showed that the optimum nutrient rate for DMP varied across the soils. Although the unity (the standard nutrient rate) would be valid in most soils, it should be modified to double the P rate and halve the Zn rate in the future study. Note that the phosphate adsorption coefficient or phosphate retention will help analyze the variation among soils in the P rate trials

6. Pertinence of nutrients applied

The quantity of nutrients applied should be sufficient to support active and healthy plant growth throughout an experimental period. On the other hand, excess application should be avoided because most chemical fertilizers are salt-based.

There are two key factors that determine the optimum nutrient rate for plants in a pot culture: soil volume and growth duration (and their combination). For the former, prompt and sharp response is expected when the quantity of soil is small. Notwithstanding, if the soil volume is too small, deficiencies in other nutrients will occur. Given the above, the volume of about 2 L pot^{-1} was selected from the viewpoint of nutrients contained and experimental efficiency. For the latter, the active vegetative (tillering) stage is the most appropriate because the growing period is long enough for plants to respond to nutritional manipulation and for the experimenter to estimate the final productivity, and also the shorter the growing period, the greater the efficiency of an experiment. In the experiments of the present study under the tropical lowland condition, the active tillering stage attained at about four weeks after transplanting.

Whether the nutrient rate in the present study was appropriate or not needs to be examined in terms of excess and shortage. Excess is not the case because no salt injury due to nutrient treatments appeared in plants. Moreover, actively growing plants developed 15–20 tillers per plant within one month in many experiments (Table 4). Therefore, nutrient shortage could have been responsible. Unless the status of those nutrients in the present study is examined, the results obtained with nutrient treatments may not be justified.

Nutrients that were absorbed by plants and that remained in pots are estimated from two examples, which produced nearly the maximum DMP of all experiments: the P rate trial for Robennah soil and the K rate trial for Kalintin soil in Exp. 4. The nutrient concentration of rice plants grown under the graded rates at the active vegetative growth stage was deduced from existing data: 30 N, 3 P, 30 K, 3 S, and 0.03 Zn g kg^{-1} under a favorable nutrient condition (Tanaka and Yoshida, 1970). The net nutrient absorption at the graded application rates is calculated multiplying DMP by nutrient concentration and by subtracting the amount of nutrient absorbed by plants grown without fertilizer. The proportion of net nutrient absorption for the fertilizer applied, often called as nutrient absorption ratio (NAR) or fertilizer utilization efficiency, is calculated.

The NAR was 40–70% for N and K, 6–14% for P, 11–20% for S, and about 1% for Zn (Table 10). The NAR in the other treatments is smaller because the ratios obtained were based on the nearly maximum DMP of all treatments. This indicates that the amount of fertilizer applied was sufficient to produce the maximum DMP and that an adequate amount of nutrients remained in the soil even at the end of the experiments.

Table 10. Nutrient absorption ratio (NAR, %) in Exp. 4

Soil	Nutrient rate (unity)	Nutrient absorption ratio (%)				
		N	P	K	S	Zn
Robennah	P (0.25)	42	6	51	14	1.0
	P (1)	33	8	40	11	0.8
	P (2)	41	9	49	14	0.7
Kalintin	K (0.25)	44	10	53	15	0.4
	K (1)	60	14	72	20	1.3
	K (2)	42	10	51	14	0.6

1) NAR = (Nf - No) * 100 / Np, where Nf and No was the quantity of nutrient absorbed by plants grown with and without fertilizers, respectively, and Np was that of nutrient added.
2) Nutrient absorption was the dry matter production (DMP) multiplied by nutrient concentration in plants.
3) Refer to Fig. 5 for DMP.
4) Nutrient concentration of N, P, K, S and Zn in plants was assumed to be respectively 15, 1.5, 15, 1.5 and 0.02 g kg^{-1} (dry matter) at None and 30, 3, 30, 3 and 0.03 g kg^{-1} at P (1) and K (1), and that at graded rates was appropriately estimated on the basis of those values.

After all, the lack of nutrients that were not included in the depletion treatment did not affect plant growth. As described in the previous section, Zn application rate can be decreased to about one half of the unity because of small NAR. The NAR was small for P, but the amount of the remaining P in the soils was unknown. Most of P remained was probably adsorbed in the soils and became unavailable to the plants because the NAR of P applied in crop fields is normally in the range of 5–15% (Sumner, 2000), which was similar in the present study. Hence, the standard P rate should be doubled as suggested in the previous section.

7. Tiller development and plant growth

The number of tillers is closely associated with DMP (Fig. 19). Therefore, by monitoring tiller development, plant growth at successive growth stages may be predicted fairly well.

Nutrient conditions affected both tiller development and leaf development but the latter less (Fig. 4). This indicates that phenological development is not as prone to unfavorable nutrient conditions as DMP and the growth process like tiller development, both of which are hindered under such conditions. On the other hand, once leaf development is delayed under certain nutritional conditions, the nutritional status affects plant growth greatly.

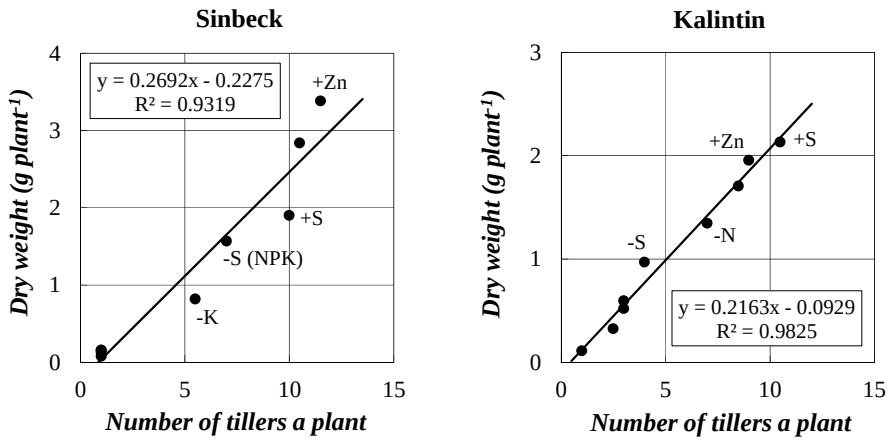


Fig. 19. Relationship between the number of tillers a plant and DMP 33 DAT with Sinbeck soil and 22 DAT with Kalintin soil in Exp.1.

8. Soil acidity caused by S addition

Sulfur application induces soil acidity, but the extent of acidification entirely depends on the amount of S application, soil properties, and plant growth. It is well known that soil pH is neutralized with submergence (Ponnamperuma, 1965). In the present experiments, similar pH neutralization occurred (Fig. 20). Also, soil pH was largely dependent on soil properties (Fig. 6) but hardly affected by S application (Fig. 21). Note that pH of Rk (Rokel) soil decreased with S application as a result of the neutralization because pH was initially as high as 7.7.

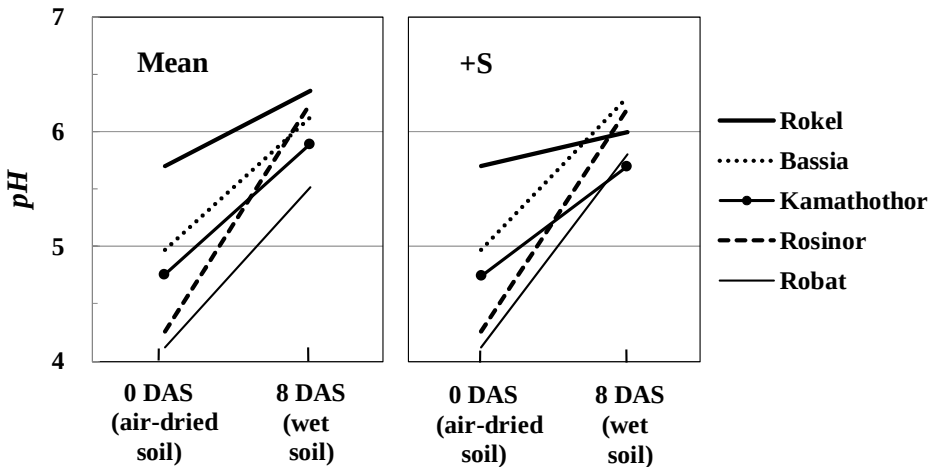


Fig. 20. Examples of pH changes shortly after submergence in various soils (Exp. 2). DAS: days after submergence. Mean was based on all the results of the nutrient depletion and addition treatments. The pH value of air-dried soils was measured at 1:2.5 soil-water ratio.

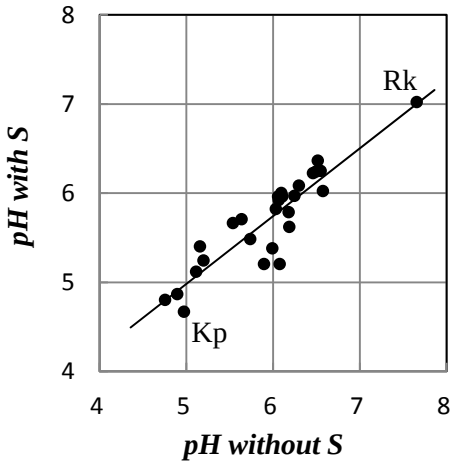


Fig. 21. Relationship between soil pH with and without S application. The values are averages over the entire growth stages and experiments.

Sulfur is one of the essential nutrients for plants: Without it, they are unable to thrive. Sulfur-deficient soils spread over several countries in West Africa (Yamaguchi, 1997 and 2007) including Sierra Lone (Table 8). Sulfur application will undoubtedly contribute to increasing crop production in the country. If S application rate is kept at rational levels, 20–30% of N requirement (Yamaguchi, 1999), soil acidification can be prevented.

9. Conclusion

At present, rice grain yield in Sierra Leone is about 1 ton ha^{-1} or even lower. It can be raised to 2 ton ha^{-1} or so by improving agronomic practices like careful water control, use of healthy seedlings, proper planting depth, timely weeding, adequate harvesting, etc. (ADPK-SL, 2009; SRDP-SL, 2013). The only way to realize further increase in grain yield is to supply anthropogenic nutrients to the soils of inherently poor fertility. The SRDP attained 3–4 ton ha^{-1} yields in farmers' fields through rational fertilizer application (SRDP, 2013).

Grain yield exceeding 5–6 ton ha^{-1} in the main cropping season may be unattainable in Sierra Leone, however, due to the net solar radiation as low as 10 MJ m^{-2} d^{-1} during the mid-rainy season (Ojo, 1977). This speculation is supported by the fact that the maximum grain yield in a series of intensive fertilizer trials was barely beyond 4 ton/ha (UNDP/FAO/IITA, 1984). Even if improved high-yielding varieties are introduced, their full potential will not be realized in terms of DMP; solar radiation is the sole energy source for photosynthate production (Tanaka, Kawano, and Yamaguchi, 1966; Yoshida, 1981).

The nutrient deficiency level averaged over all soils was 30, 70, 30, 40, and 10 for N, P, K, S, and Zn, respectively (Table 9). The current recommended fertilizer rate for lowland rice (i.e., N-P_2O_5-K_2O = 60-40-40 kg ha^{-1}; Rhodes, 2012) is hardly appropriate given the deficiency level. The fertilizer composition should be properly modified to meet the nutrient shortage of indigenous soils. The results of the present study suggest that P should be increased from the current rate and S be added. Zinc may be excluded from regular fertilizer application because its shortage is uncommon (Table 8). Inappropriate fertilizer application results in not only

lowering the fertilizer's efficiency but also leading to profit loss.

Breeding of varieties tolerant to low-nutrient conditions is widespread in the world to deal with nutrient shortage in soils. There are two concerns on the use of such varieties. First, genetic variations in tolerance are less among varieties within a species than between different species. The farmers prefer tolerant species rather than tolerant varieties in deteriorated soils. The food production capacity is incomparable between the most tolerant cultivar of rice plant and the ordinary cassava (*Manihot esculenta*) cultivars in low-fertility soils, for instance. Second, the fields would become barren if the farmers kept growing tolerant varieties or species. 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 varieties should be avoided in coping with soils of low fertility. The strategy to efficiently replenish the nutrients that are lacking in the indigenous soils should be established immediately through careful and systematic examination for sustainable agriculture.

Acknowledgement:

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Abbreviations:

ADPK-SL:	Agricultural Development Project in Kambia district, Sierra Leone
DAS:	days after submergence
DAT:	days after transplanting
DMP:	dry matter production
EC:	electrical conductivity
EC:	European Commission
FAO:	Food and Agriculture Organization
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
NAR:	nutrient absorption ratio
RARC:	Rokupr Agricultural Research Centre
RRSR:	Rice Research Station, Rokupr (presently RARC)
SLARI:	Sierra Leone Agricultural Research Institute
SRDP-SL:	Sustainable Rice Development Project in Sierra Leone

T/P:	transplanting
USDA:	US Department of Agriculture
UNDP:	United Nations Development Programme

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Project implementation and its achievement

SRDP Forum
17th July,2014

Umaru M. Sankoh
DAO, MAFFS-Kambia
Project Manager

Framework of SRDP…

Project Purpose

To establish rice production techniques and its extension method which are applicable throughout Sierra Leone

Output 1	***Output 2***	***Output 3***
To revise the Technical Package on Rice Production (TP-R), which can realize higher yield and profit, through on-farm verification	To extend TP-R to small-scale farmers through Farmer Based Organizations (FBOs) in Kambia district	To extend the contents of TP-R and an extension method to officials of MAFFS's district agricultural offices other than MAFFS-Kambia

***Project Period*: 4 years (October 2010 – September 2014)**

Major activities conducted…

- ☑ **Revision of TP-R**
- ☑ **Creation of Extension materials**
- ☑ **Training for FBO farmers**
- ☑ **Compilation of Extension guideline**
- ☑ **Training for MAFFS officials**

<All the activities implemented are in line with SCP>

Documents prepared…

TP-R
- Technical package on rice cultivation techniques at IVS
- To realize the target yield of 3 ton/ha with profit
- For MAFFS/RARC, country as a whole

Extension guidelines

Guide to FFS sessions
- Guide of FFS implementation
- To conduct FFS on rice cultivation techniques
- For extension workers

Technical manual
- Technical interpretation of TP-R
- To explain the essence of TP-R
- For extension workers

Dissemination of TP-R

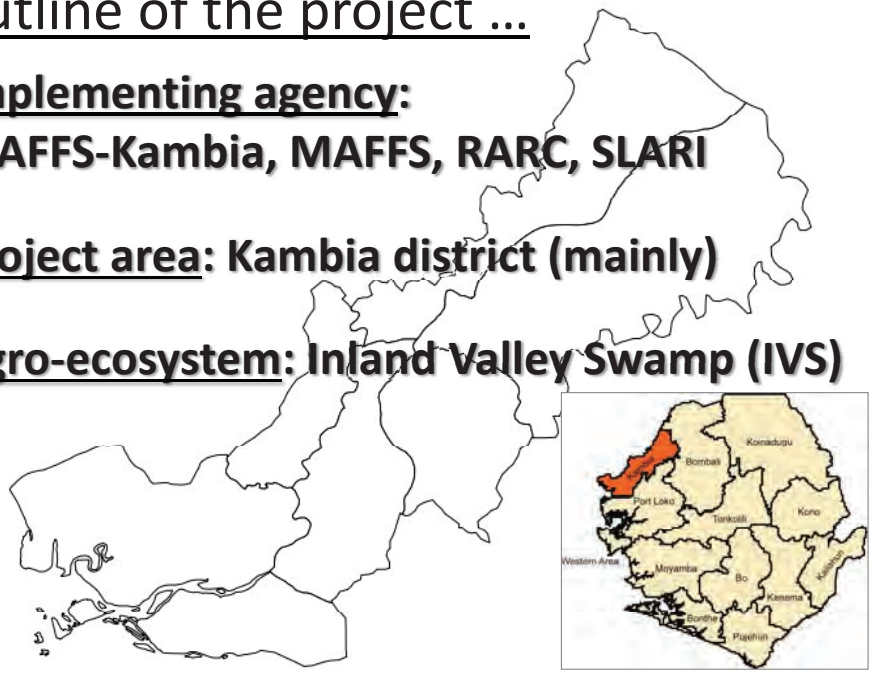
Extension materials
- Visual learning tool of TP-R
- To explain the essence of TP-R at FFS
- For rice farmers

Outline of the project …

Implementing agency:
MAFFS-Kambia, MAFFS, RARC, SLARI

Project area: Kambia district (mainly)

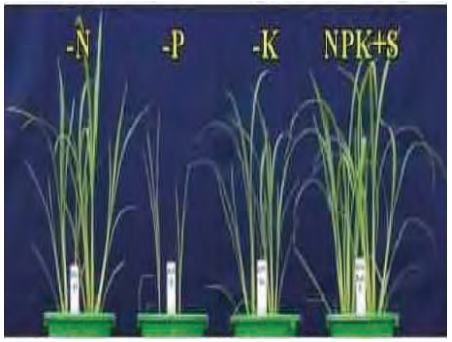
Agro-ecosystem: Inland Valley Swamp (IVS)



Collaboration with JICA…

<<Revision of TP-R [1]>>

For appropriate fertilizer application rate



Pot trial/Soil fertility evaluation

Collaboration with JICA…

<<Revision of TP-R [2]>>

For appropriate fertilizer application rate

On-farm verification

Collaboration with JICA…

<<Creation of Extension materials>>

For dissemination of TP-R through FFS

On-farm evaluation by beneficiaries

Collaboration with JICA…

<<Training for FBO farmers>>

For dissemination of TP-R through FFS

Classroom lecture

Collaboration with JICA…

<<Compilation of Extension Guideline>>

For dissemination of TP-R throughout country

Field practice and feedback

Collaboration with JICA…

<<Training for MAFFS officers>>

For dissemination of TP-R throughout country

Classroom lecture and field visit

Collaboration with NGOs under SRDP…

For further elaboration of documents

<<ASREP>>

TP-R introduction under developed swamp

Collaboration with NGOs under SRDP…

For further elaboration of documents

<<BRAC>>

Training on TP-R and exchange visit

Collaboration with NGOs under SRDP…

For further elaboration of documents

<<WAAPP>>

Training on TP-R

Collaboration with NGOs under SRDP…

For further elaboration of documents

<<WFP>>

Training on TP-R and exchange visit

Results…

<<TP-R>>

More rice production

<<Extension Method>>

FFS on rice cultivation

To be endorsed as standard extension method in Sierra Leone

… Detailed information to be explained later …

Today's topics

1. The Essence of TP-R
2. Improvement of cultural practices
3. Fertilizer application
4. Perspectives

TP-R: Technical Package on Rice Production

Sub titles

Objectives

1) To increase grain yield with cultural improvement and fertilizer use.

2) To make rice production more efficient and cost-effective.

Background

1) Agro-ecology is focused on inland valley swamp (IVS).

2) SRDP activities have been concentrated in Kambia district.

Present condition

Current grain yield (ton/ha) of rice culture in Sierra Leone

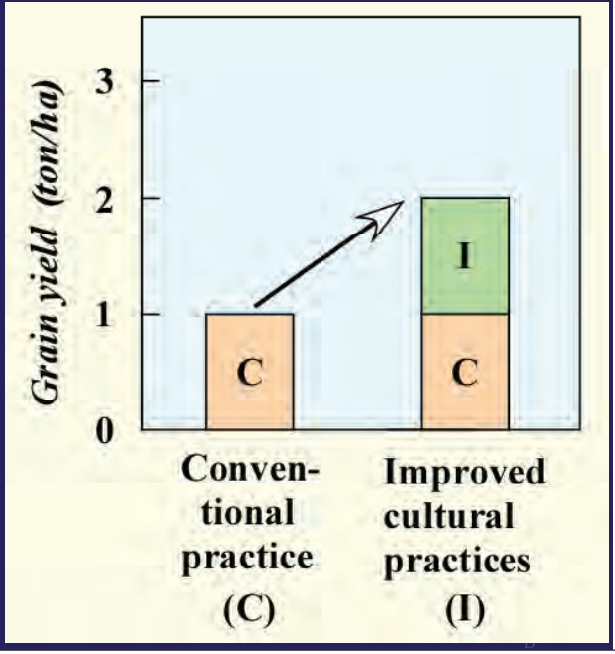
PEMSD (2013)	1.2-1.96
FAO (2013)	1.8
AHTS	0.47
Peters (GIZ, 2014)	0.5-1.5
SRDP	0.5-1.0

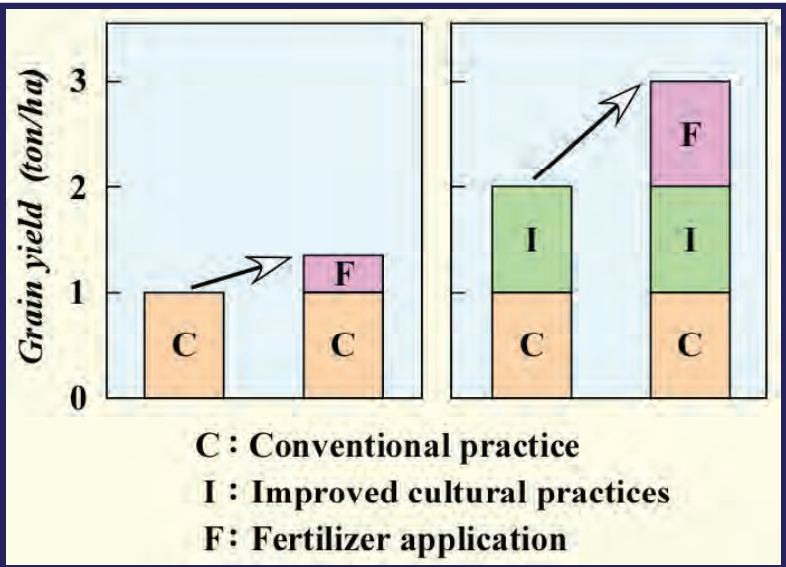
1. The essence (concept) of TP-R

Grain yield increase:

1st step by the cultural improvement.

Note that C makes an allowance of ± 1 ton/ha.





Fertilizer application enhances grain yield only together with improved cultural practices.

2. Improvement of cultural management

2-1. Some recommended farming practices

2-2. Their verification at FBO sites

Some key points of farming activities in conventional and improved (recommended) cultural methods (a)

* Some details follow.

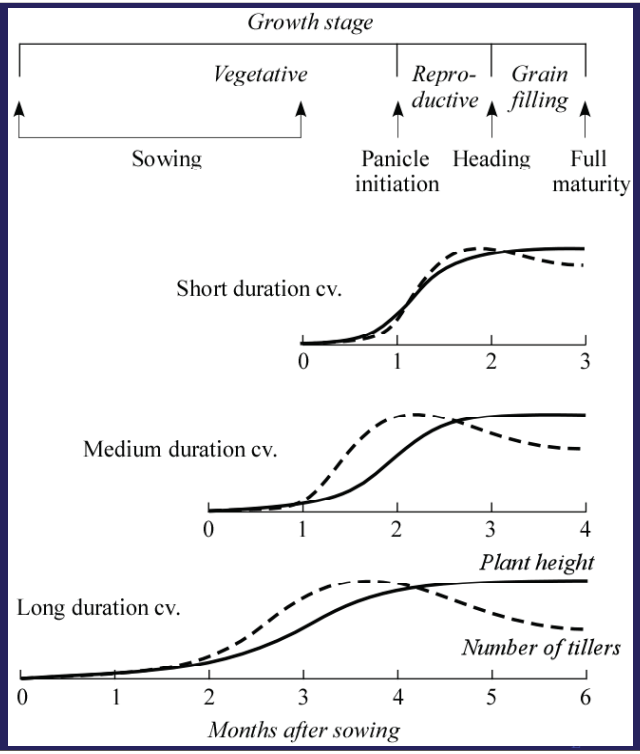
Item	Conven-tional	Improv-ed	(unit)	Contribution to yield
Seedling age *	4-10	3	weeks	Large
Planting depth *	5-15	2 - 5	cm	Large
Hill density	15-50	20 - 25	hill m^{-2}	Fairly
Weeding	none	3	weeks after T/P	Large
No. of plants per hill	5-10	2 - 3		Marginal (b)
Water management	none	Properly		Large

T/P: transplanting.

a) Improved practices are most effective to cultivars of 100-120 days.

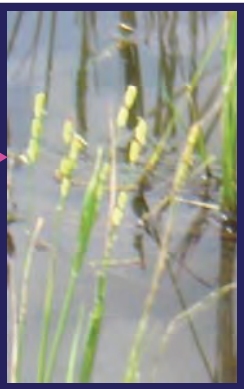
b) Greatly contribute to the seed saving.

Growth stages of rice plants



Little difference in reproductive and ripening periods.

Unexpected flowering



4-10 spikelets/ panicle.

2 weeks after transplanting of short duration cultivar (Eitori: 3 months) with 1-month-old seedlings.

(Mapilla/Port Loko. Oct. 30, 2010)

Examples of deep planting

ca. 15 cm

Unnecessary elongation of mesocotyl.

Folded stem

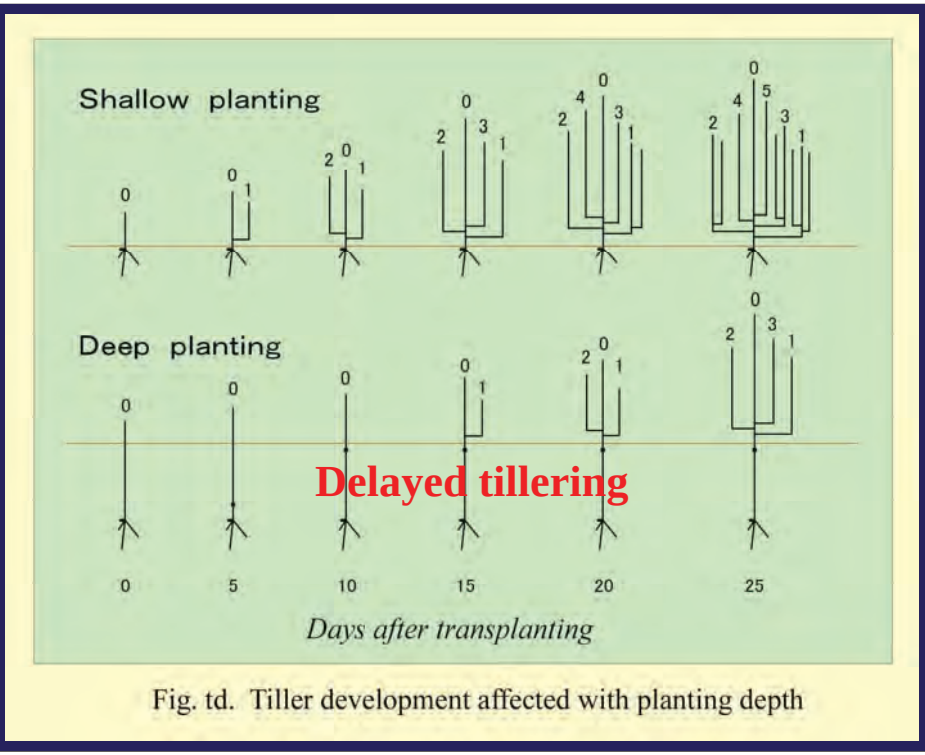


Fig. td. Tiller development affected with planting depth

Some other important means in TP-R

Cropping calendar

Land preparation

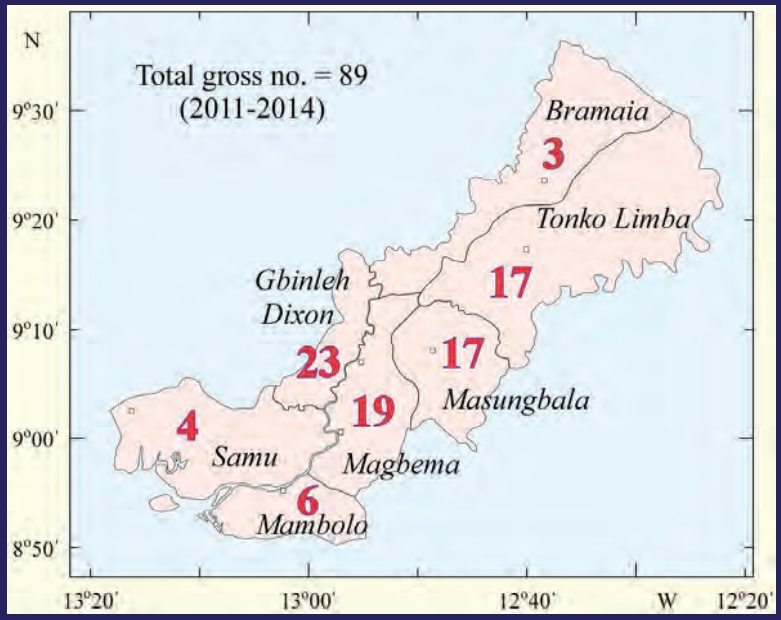
Nursery

- Plow before sowing
- Well puddling
- Proper leveling

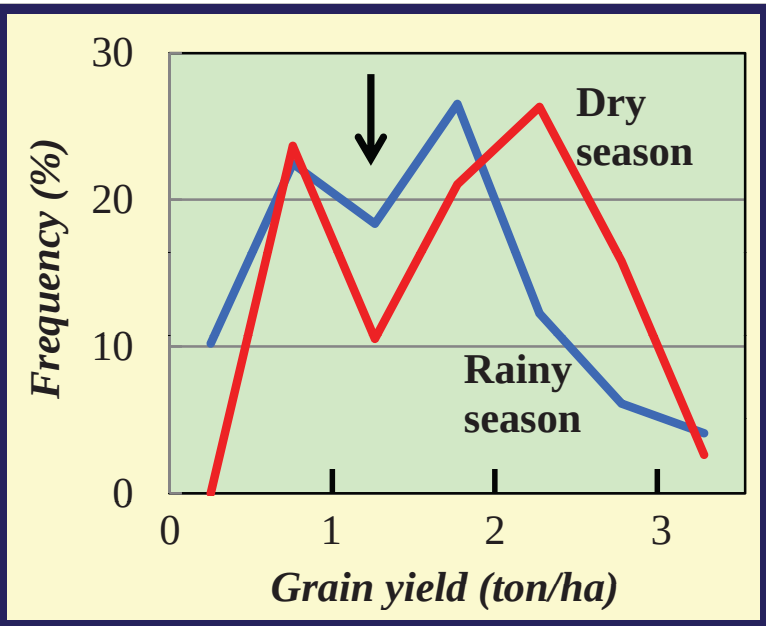
- Germination test
- Proper seed rate

Self seed production

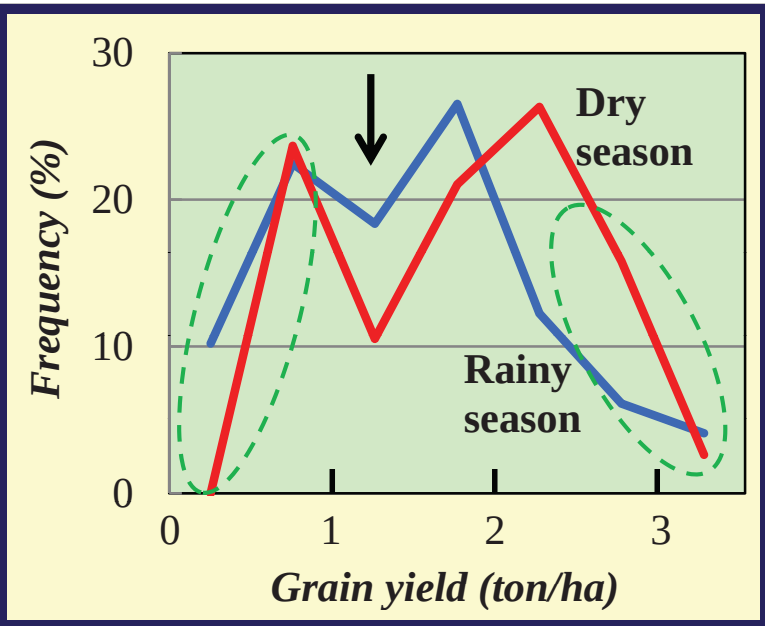
Results at FBO communal sites



Gross number of FBOs in each chiefdom



Frequency of grain yields in rainy and dry season cropping



Let's analyze the reasons on low- and high-yielding FBOs.

Grain yield (GY) of high- and low-yielding FBOs (a).

	High yielder (≧2.5 ton/ha)	Low yielder (1.0≧ ton/ha)
Number of FBOs	16	25
Mean grain yield (ton/ha)	2.8	0.8

a) Combined data of rainy and wet season plantings. Gross number of FBOs was 89 from rainy season in 2011 to dry season in 2013-2014.

Proportion (%) of recommended farming activities practiced by high- and low-yielding FBOs.

Farming activity	High yielders (≧ 2.5 ton/ha)	Low yielders (1.0 ≧ ton/ha)
Cropping calendar preparation	44	0
Germination test	50	5
Use of 3 weeks-old seedlings	100	56
2-3 seedlings/hill	94	45
Shallow planting	100	20
Bund and drainage maintenance	81	36
Land preparation before sowing	88	24
Field leveling	88	10

3. Fertilizer application *

3-1. The principles of fertilizer application

3-2. Approach to find the best choice

3-3. Cost-benefit analysis

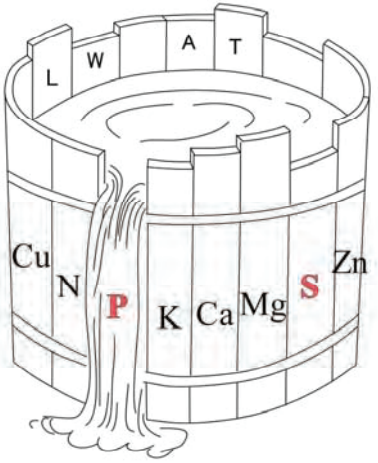
* Critical on the rate and nutrient combination.

3-1. The principles of fertilizer application

a) Liebig's law of the minimum

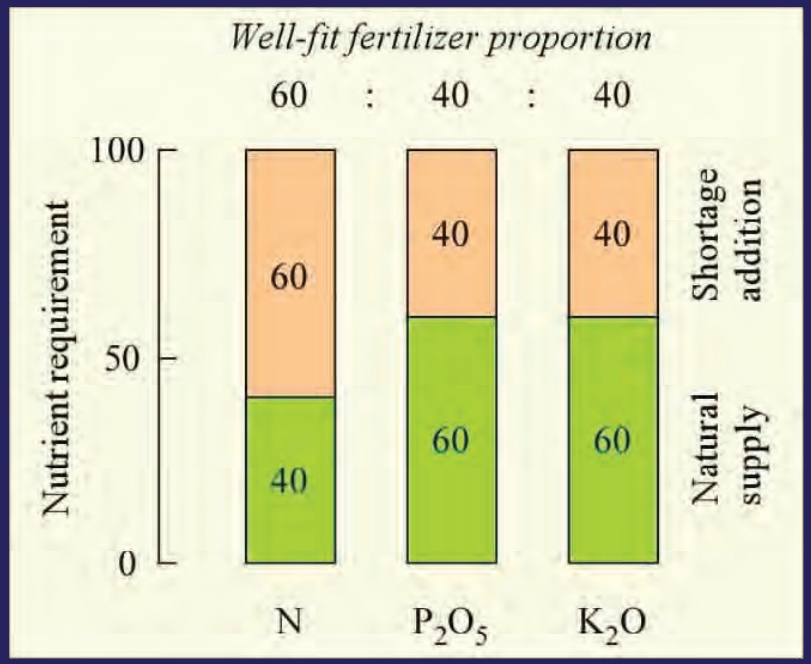
The capacity of a barrel with staves of unequal length is limited by the shortest stave.

➔ Plant's growth is limited by the nutrient in shortest supply.

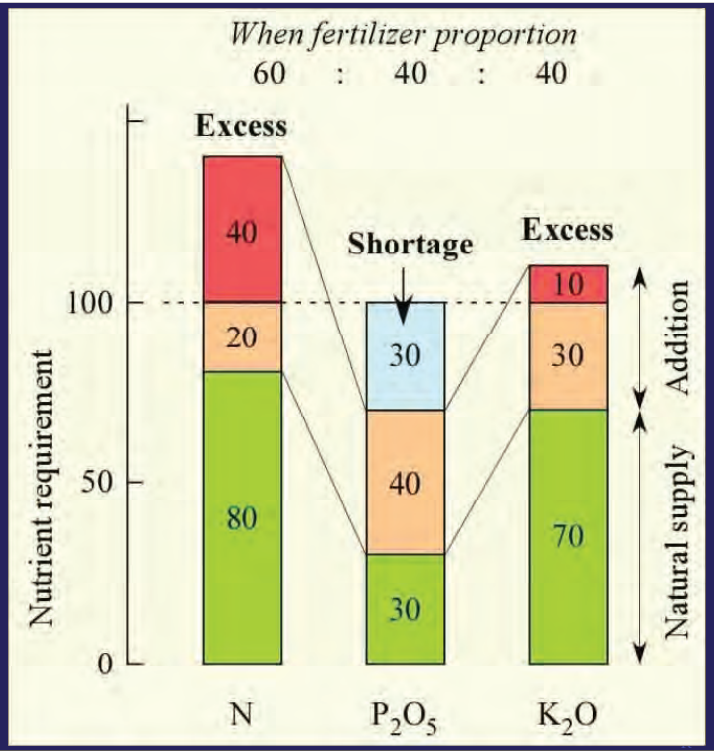


Donebek's element barrel (The minimum law)

L: light, W: water, A: air, and T: temperature



An example of a soil



c) Fertilizer response and cost

Basic data on the cost-benefit analysis:

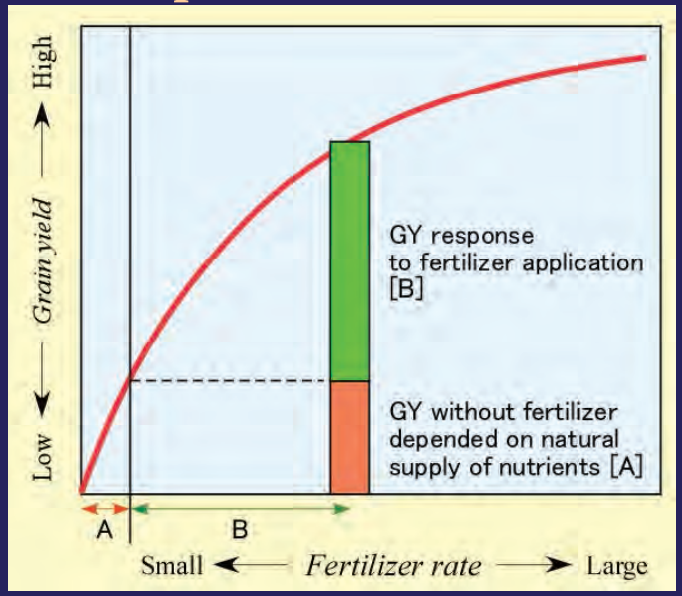
1. **Fertilizer cost = 200,000 Le/50 kg**
   (15-15-15 NPK compound) = 4,000 Le/kg
2. **Rough rice (paddy) price = 1,200 Le/kg (a)**
   = 1,200,000 Le/ton

e.g.: Marginal paddy production for compensating a fertilizer cost at 40-40-40 kg/ha of N-P_2O_5-K_2O

= (4,000*40/0.15) / 1,200,000 = 0.9 ton/ha ≒ 1 ton/ha

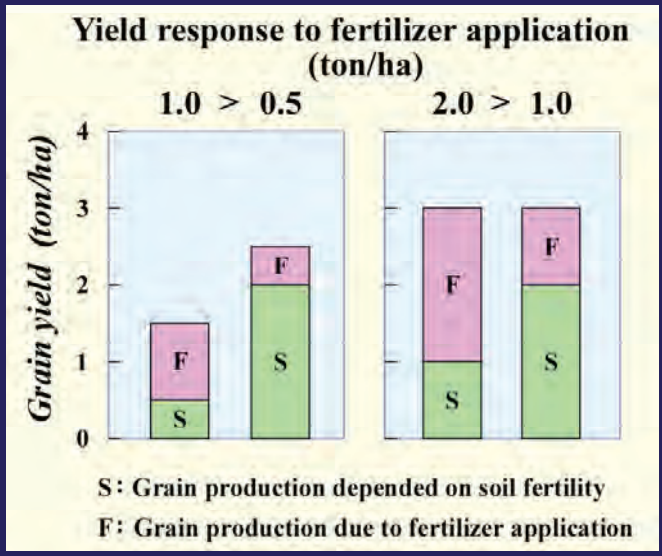
a) Farm gate price in November, 2013.

Fertilizer response



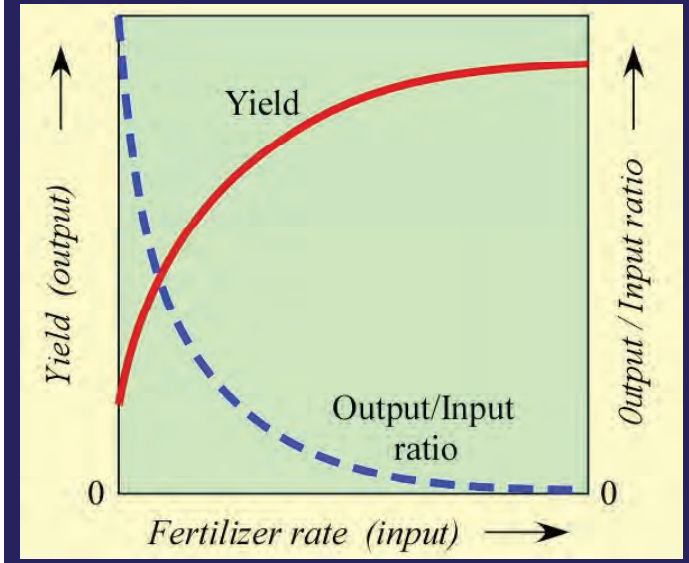
Grain yield (GY) with fertilizer = A + B

Soil fertility and fertilizer response



Fertilizer responsiveness affords the key to the profitability.

b) The law of diminishing return



The smaller the application rate, the larger the profitability.

(Mitscherlich, 1900)

3-2. Approach to find the best choice

a) Chemical analyses

b) Pot trials

c) Fertilizer trials in fields

d) Literature review

a) Chemical analyses

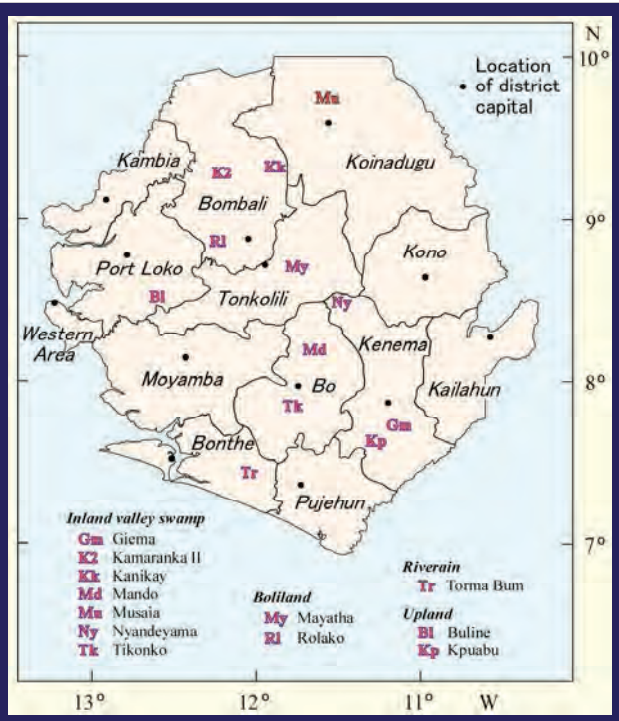
Table 1. Frequency (%) of soils with possible nutritional problems (deficiency and excess of nutrients, and acidity) diagnosed with chemical analyses (a) in various rice agro-ecologies.

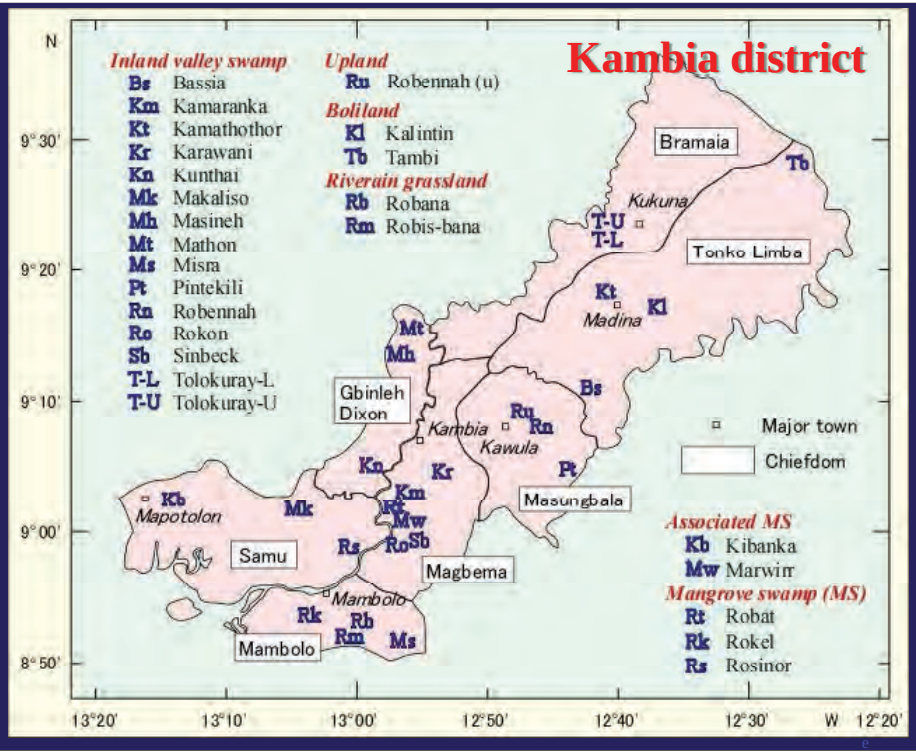
Agro-ecology	n		Deficiency							B excess	High salt	Low pH
			N	P	K	S	Zn	Cu	Si			
Upland	12	(0)	8	17	17	50	42	17	58	0	0	8
Inland valley swamp	14	(1)	7	36	57	71	29	0	71	0	0	86
Boliland	15	(3)	20	20	27	73	47	0	53	0	0	33
Riverain grassland	2	(0)	50	50	0	50	0	0	0	0	0	50
Associated MS	6	(1)	17	50	0	33	17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

n: the number of soil entries, including plural samples at the same site (the number is in parentheses) on different dates.
a) Below or above the most frequently observed critical level .

b) Pot trials

Soils collected





Nutrient treatments

Nutrient depletion and addition treatment

	Treatment		Nutrient (Element)					
			N	P	K	S	Zn	
1	None	(0)	-	-	-	-	-	
2	-N	(PK+S)	-	+	+	+	-	
3	-P	(NK+S)	+	-	+	+	-	
4	-K	(NP+S)	+	+	-	+	-	
5	-S	(NPK)	+	+	+	-	-	
6	+S	(NPK+S)	+	+	+	+	-	a
7	+Zn	(NPK+S+Zn)	+	+	+	+	+	b

a) NPK+S (+S): Reference standard.

b) +Zn is an addition treatment.

SRDP/JICA house at RARC

Growing period: ca. 1 month (measured dry weight)

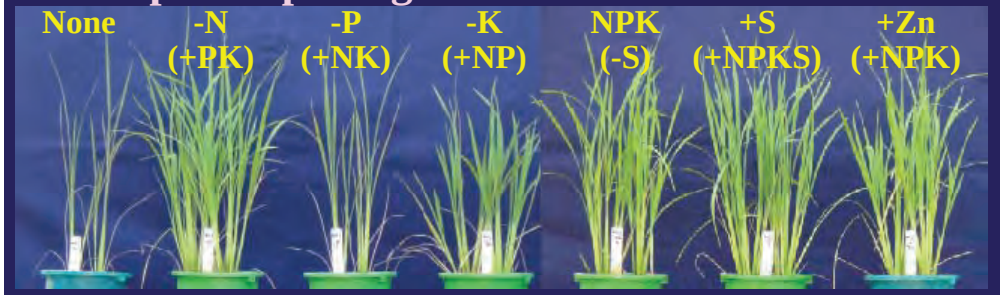
Replication: one (duplicated in the reference standard)

ROK 24 at 2 plants a pot

Submerged (irrigation water EC: 1–3 mS/m)

Soil: ca. 2 L/pot

Examples of plant growth



Musaia (Koinadugu, IVS)

Rolako (Bombali, Boliland)

Table 8c. Deficiency levels of nutrients

a) Kambia district

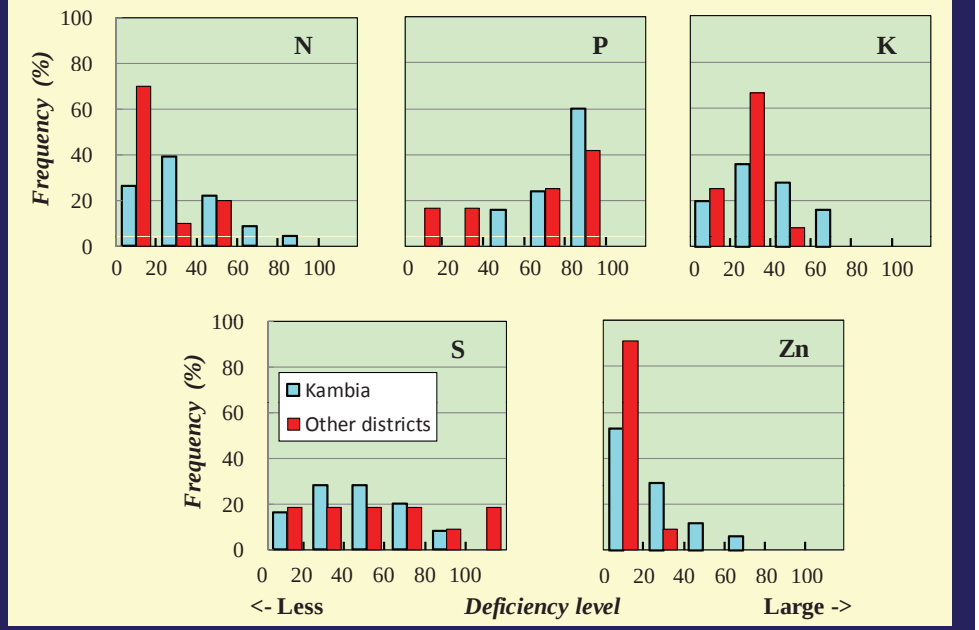
	Soil	abbr.	Element N	P	K	S	Zn
1	Robennah-U	Ru				*	
2	Misra	Ms					*
3	Makaliso	Mk					
4	Kunthai	Kn					
5	Masineh	Mh				*	*
6	Mathon	Mt					
7	Kamaranka	Km					*
8	Karawani	Kr					
9	Rokon	Ro					
10	Sinbeck	Sb					
11	Pintekili	Pt					
12	Robennah	Rn					
13	Bassia	Bs					
14	Kamathothor	Kt					
15	Tolokuray-U	T-U					*
16	Tolokuray-L	T-L					
17	Tambi	Tb				*	
18	Kalintin	Kl					
19	Robana	Rb					
20	Robis-bana	Rm					
21	Kibanka	Kb					
22	Marwirr	Mw					*
23	Rokel	Rk					
24	Rosinor	Rs					a
25	Robat	Rt				a	*

b) Other districts

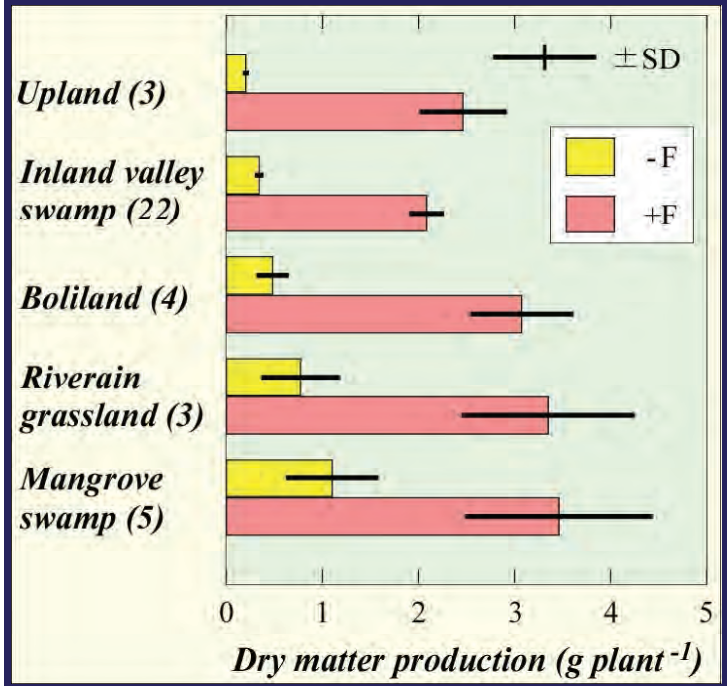
	Soil	abbr.	Element N	P	K	S	Zn
1	Kpuabu	Kp				a	a
2	Buline	Bl					
3	Nyandeyama	Ny					
4	Giema	Gm					
5	Kamaranka II	K2					
6	Kanikay	Kk	a				
7	Musaia	Mu	a				
8	Tikonko	Tk					
9	Mandu	Md					
10	Rolako	Rl					
11	Mayatha	My					
12	Torma Bum	Tr					

Nutrient deficiecny	Le-gend	Deficiency level from	to
Severely		101	150
Highly		76	100
Midiumly		51	75
Fairly		26	50
Least		-24	25

Likely abundanc	a
Pending	*



Frequency of nutrient deficiency levels in Kambia and other districts.



Dry matter production in varius agro-ecologies with (+F) and without (-F) fertilizer.

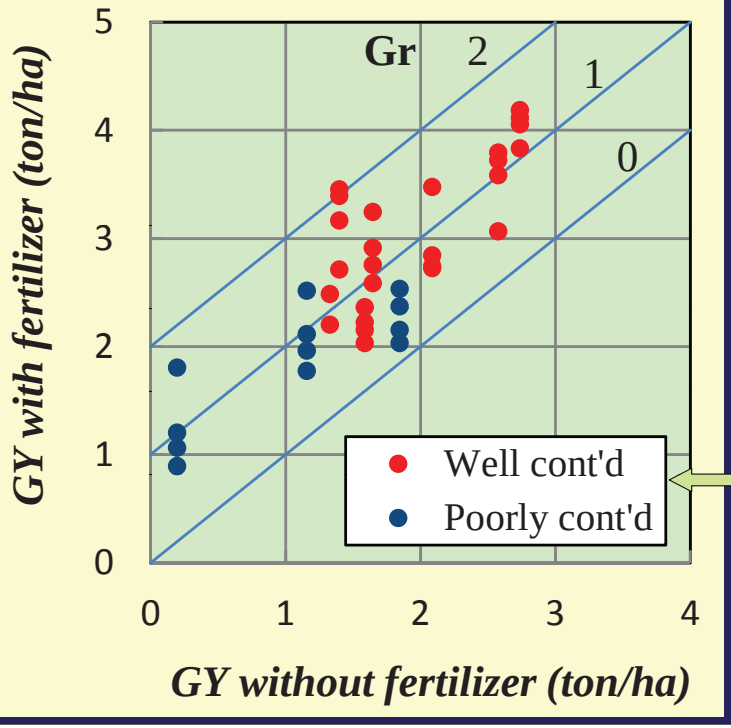
Table 9. Rounded nutrient deficiency level in various agro-ecologies of Sierra Leone

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 grassland	3	20	70	30	30	10
Mangrove swamp	5	30	60	20	10	-10
Mean (weighted)	37	30	70	30	40	10

c) Fertilizer trials in fields

Fertilizer trials in 5 IVSs of Kambia district by SRDP-SL

	Treatment (N-P_2O_5-K_2O-S kg/ha)	Cropping season
1	0- 0- 0- 0	2013 rainy
2	60- 40-40- 0	2014 dry
3	20- 40-40- 0	
4	20- 40-40-10	
5	20-100-40-10	



Gr: grain yield response to fertilizer application (ton/ha).

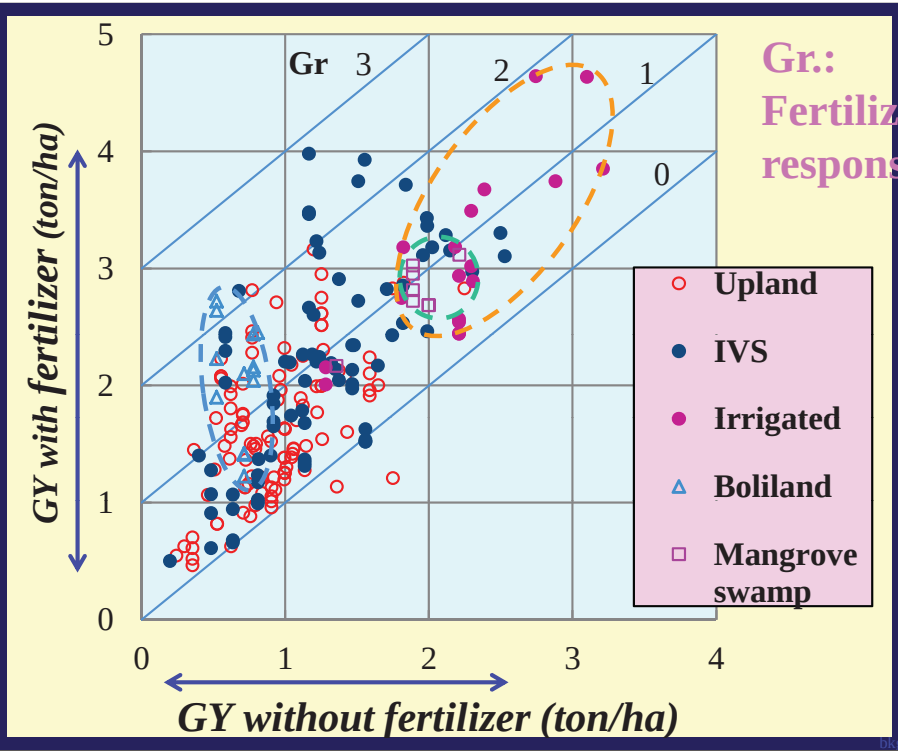
Water control

d) Literature review on fertilizer trials (Past records in Sierra Leone)

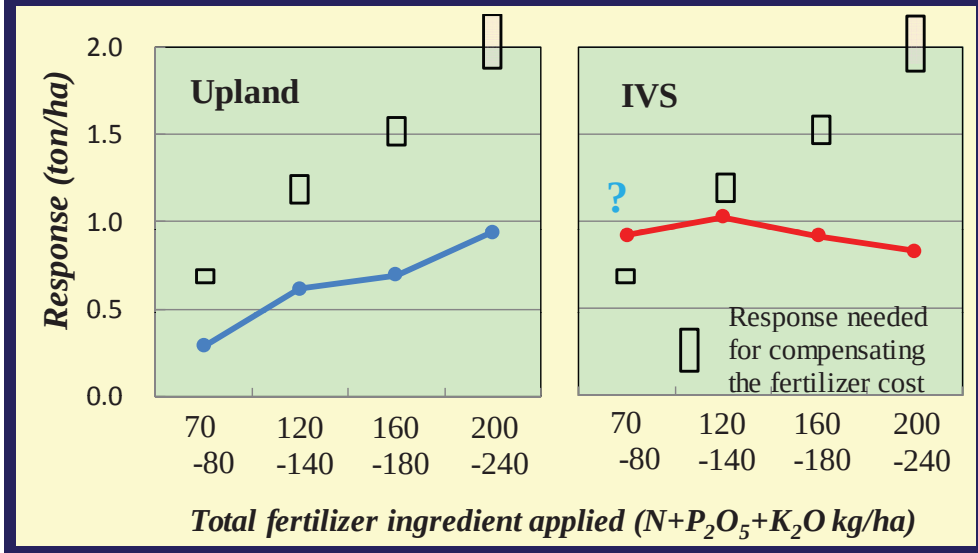
References for summarizing the fertilizer response in Sierra Leone

RRSR Annual Report		RRSR, 1975 (workshop)
1972	1989	
1978	1990	UNDP/FAO/IITA, 1974-1980
1980	1991	IITA, April 1976 (5)
1983-1984	1992	IITA, October 1976 (6)
1984-1985	1993	
1985	1994	IITA Ann. Rep., 1976
1986	1996-1999	
1988	2009-2010	EEC/RRSR, 1994

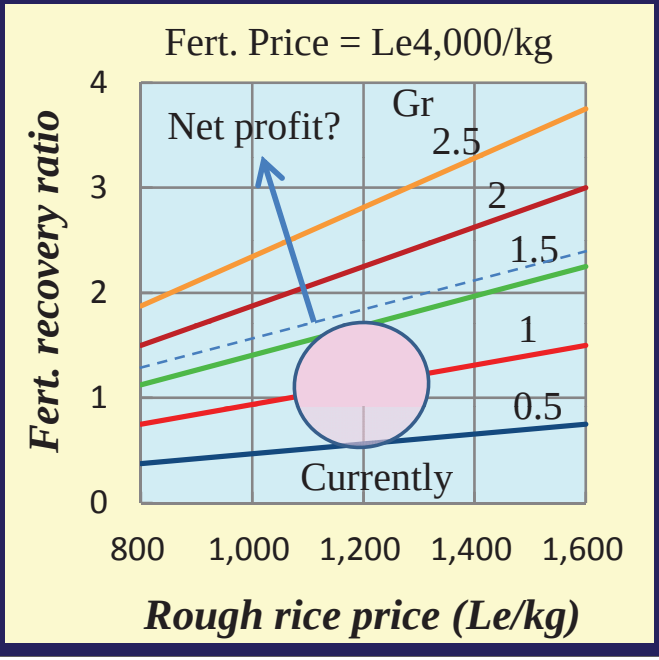
Fertilized rate: 30-20-20 to 120-80-80 kg/ha.



Gr.: Fertilizer response.



3-3. Cost-benefit analysis (sensibility test)



4. Perspectives

1) Grain yield at 3 ton/ha is very likely with applying improved cultural practices and fertilizers.

2) Fertilizer rate (N-P_2O_5-K_2O) is tentatively recommended at 40-40-40 kg/ha.

3) Further experiment is a must for making fertilizer application efficient and profitable.

4) TP-R can be applicable to all rice fields countrywide, because there is no difference in general soil fertility among districts.

5) TP-R is also applied to rice culture in fringes of bolilands and riverine grassland.

bkg

Thank you for your attention

SRDP Forum: Dissemination of TP-R to rice farmers using SRDP Extension Method

July 17, 2014

Bintumani Hotel, Freetown

Sustainable Rice Development Project (SRDP)

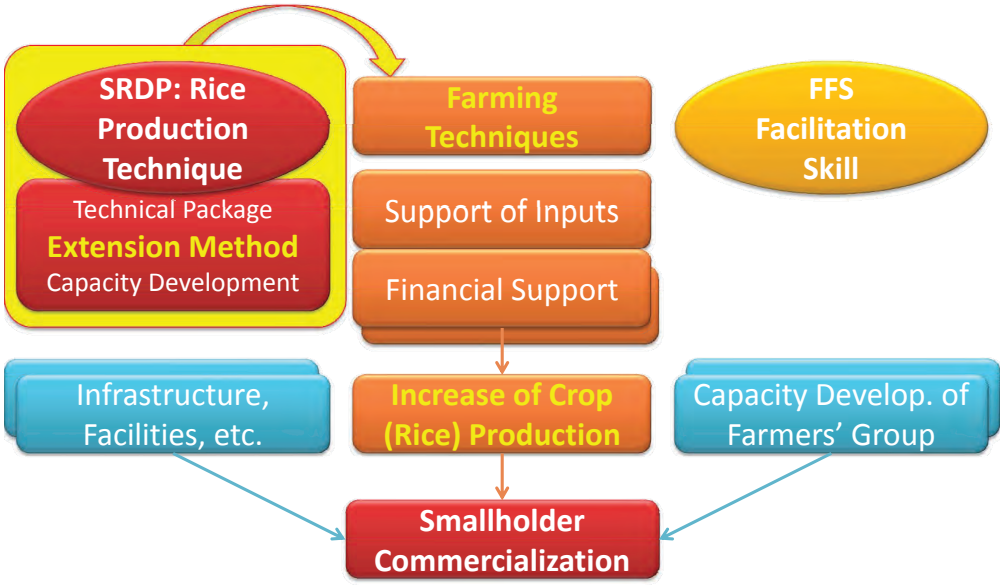
JICA-MAFFS

Policy – SCP related projects

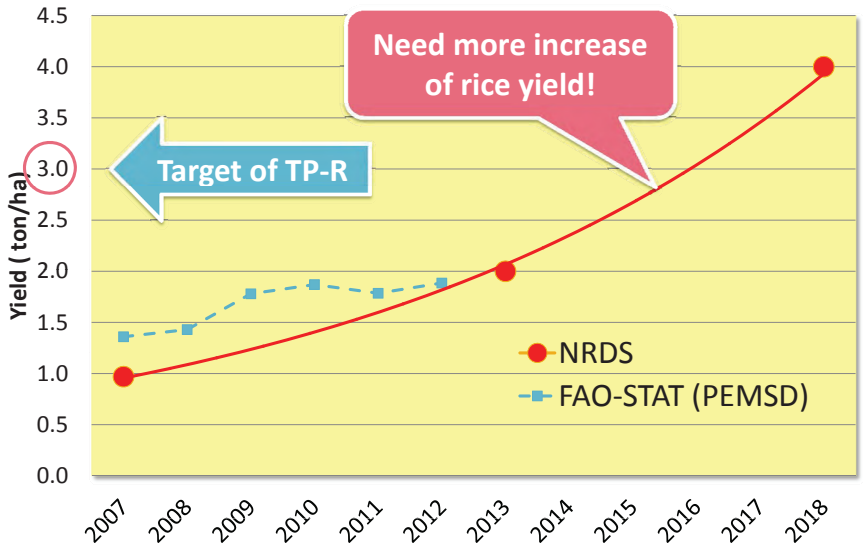
- **AfP**: Agenda for Prosperity; 2013-2018
- **CAADP**: Comprehensive Africa Agriculture Development Programme
- **NSADP**: National Sustainable Agriculture Development Programme; 2010-2030
- **SCP**: Smallholder Commercialisation Programme; 2010-2014

- Donor funded SCP support projects by components
  - Component 1: **JICA (SRDP)**, FAO, WB, BRAC, GIZ, EU
  - Component 2: ADB, IFAD, GIZ, WFP, BRAC.
  - Component 3: WB, ADB, JICA (CDCD), IFAD
  - Component 4: FAO
  - Component 5: WFP
  - Component 6: AusAID, EU

Contribution of SRDP to SCP Component 1



Target Yield of Rice in Sierra Leone



Training on FFS for Coordinators and Facilitators

Year	Training	Duration
2003	Training of Trainers (TOT)	4 months
2004	Training of Community Facilitators	3 months
2005	Training of Farmer Facilitators	10 days
2008	Training of Coordinators and Community Facilitators	4 months
2010	Training of Trainers (TOT)	2 months
2013	Refresher Training	2 days

Number of FFS and FBO Members

Year	No. of FFS	No. of FBO members	Organization
2003	83	2,324	FAO
2004	712	21,360	GCP
2005	350	10,500	GCP
2006	295	7,965	UNDP
2007	192	4,800	UNDP
2008	89	2,136	MAFFS
2009	169	3,887	ASREP
2010	376	10,150	EUFF
2011	120	3,120	FSCA & Irish Aid
2012	148	3,447	ASREP & Concern Worldwide
2013	40	1,382	DFPP
Total	**2,574**	**71,071**	

Principles of FFS under SCP

- Learning by doing
- Discovery-based learning
- Farmer-led learning activities
- Learning from mistakes
- The farmer's field is the learning ground
- Leading farmers are facilitators
- Group formation
- Systematic training process

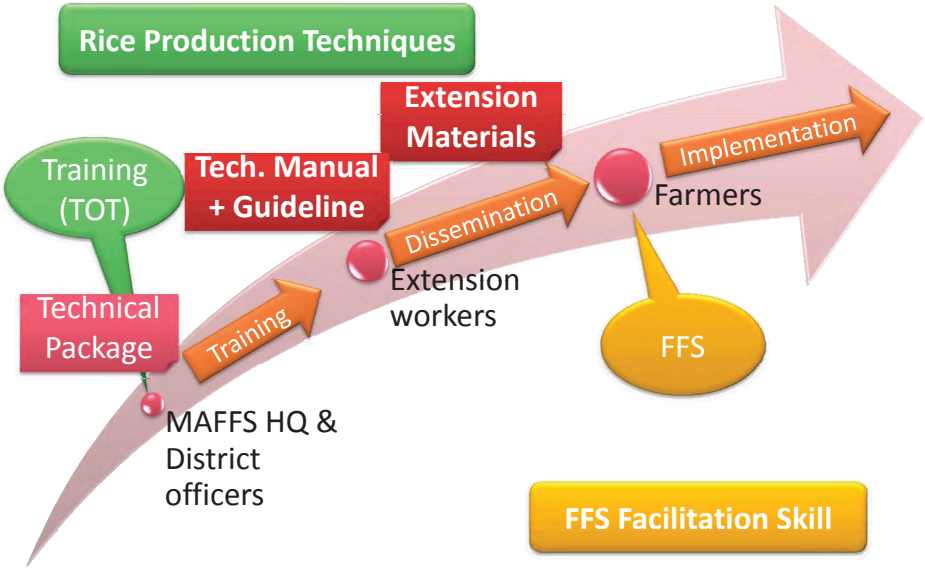
Set-back in FFS under SCP for disseminating rice cultivation technique

- No proper facilitation by extension workers due to lack of basic knowledge on rice cultivation
- No facilitation guide to the dissemination of proper rice cultivation techniques in FFS
- Belated or no provision of support (input and logistics)

Further Improvement of FFS

- **Provision of technical knowledge:**
  - Provision of thorough training for facilitators on rice cultivation techniques
  - Provision of the training materials/equipments
  - Enhancement of the calculation capacity of facilitators
  - Encouragement of facilitators and farmers to keep records
- **Enhancement of facilitation skills:**
  - Provision of periodic refresher courses
  - Change of the attitude of facilitators in working closely with the farmers
  - Provision of adequate and timely support to the facilitators

SCP-SRDP: Diagram of Extension



Extension Guideline of TP-R
Part A. Technical Manual

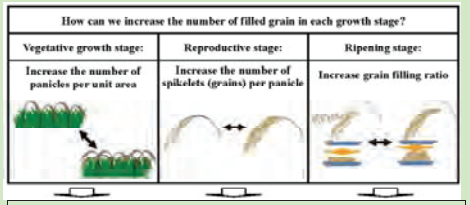
- Extension Guideline consists of Technical Manual and Guide
- **Technical Manual** to facilitate understandings of Technical Package on Rice Production (TP-R)
  - 18 technical subjects dealt with in TP-R

Sample

A.3 Important farming practices to increase yield

In A-1, we learned that efforts should be directed to the increase in the number of filled grains per unit field area to increase yield, and that the number of filled grains could be increased by increasing the three elements: (i) the number of panicles per unit area, (ii) the number of spikelets (or grains) per panicle, and (iii) the grain filling rate.

In A-2, we also learned that each of three elements for yield increase is determined in different growth stages: (i) the number of panicles per unit area is in vegetative growth stage; (ii) the number of spikelets per panicle is in reproductive stage; and (iii) the grain filling rate is in ripening stage.



Farming practices to achieve the target		
a) Use quality seed b) Prepare main field well c) Prepare nursery properly d) Grow healthy seedlings e) Uproot seedlings with care f) Transplant seedlings properly g) Manage water well h) Weed timely i) Apply adequate dose of fertilizer timely	a) Manage water well b) Apply adequate dose of fertilizer timely c) Expose to sunlight	a) Manage water well b) Expose to sunlight

As seen from the above, more efforts should be made in the vegetative growth stage to increase the number of panicles per unit area. In fact, careful management of young rice plants is very important

Extension Guideline of TP-R
Part B. Guide

- **Guide** to disseminate TP-R to rice farmers through FFS (under SCP)
  - 21 sessions each of which deal with different farming practices
  - Each session contains: (a) objectives, (b) important messages, and (c) how to facilitate the session

Sample

B.11. Fertilizer application

Objective: Objectives

1) To learn the function and characteristics of fertilizer.
2) To learn the appropriate time for fertilizer application.
3) To learn the dosage of fertilizer.
4) To learn how to apply fertilizer.

Important messages: Important messages

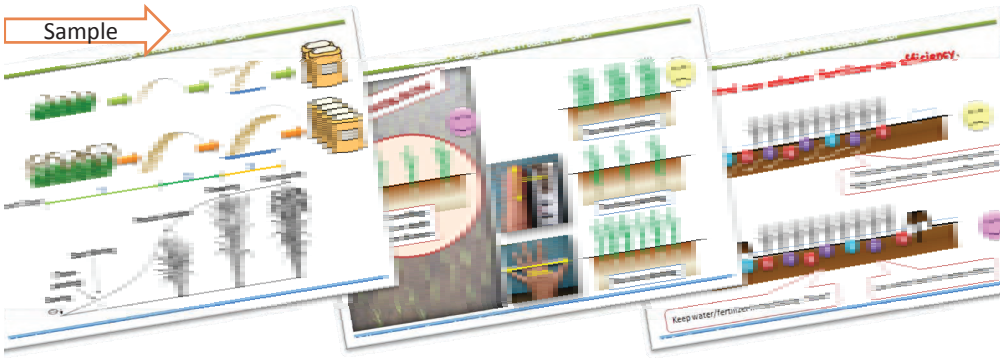
1) Chemical fertilizer is supplemental nutrition contributing to better growth of plant. dissolved into water and absorbed by plant. Nitrogen, Phosphorous and Potassiu major elements of fertilizer.
2) Fertilizer is applied timely when rice plants require more nutrients. Fertilizer is ba applied two times: (i) when tillers are produced (at the time of transplanting) and (panicles are formed (about two months before harvesting).
3) For lowland rice in IVS in Sierra Leone, the recommended fertilizer application rate N:P_2O_5:K_2O = 40:40:40 kg/ha. It is equivalent to 270 kg of compound fertilizer NP 15-15-15 per 1 ha.
4) Fertilizer is spread equally in a plot, walking in 2 directions.

How to facilitate the session: How to facilitate the session

1) Review of the previous sessions
   - Ask the farmers the technical points for nursery preparation and sowing. Ther them evaluate their own nursery in this season.

Extension Materials

- Illustrations and photos explain important messages to farmers
- 1 to 3 materials for each FFS sessions



Training of Trainers Nationwide

- March - April 2014
- Training on TP-R
- Extension Guide as a textbook
- All DAOs, Crop Officers, Extension Officers, BESs of 13 districts (more than 100 persons)
- Field visit (1 day) & Lecture/Practice (3 days)

Training of Trainers Nationwide

Conclusion

- SRDP has disseminated improved rice production techniques to extension workers and FBO farmers mainly in Kambia.
- SRDP has developed the **Extension Method** of Technical Package on Rice Production.
- SRDP has trained all MAFFS district officers responsible for extension on the contents of TP-R.
- **AESD shall fully utilize the outputs of SRDP to disseminate improved rice production techniques in all over the country.**

Voice from the frontline of extension

SRDP Forum
17th July,2014

Edward E. Bangura
Senior Technician
JICA-SRDP

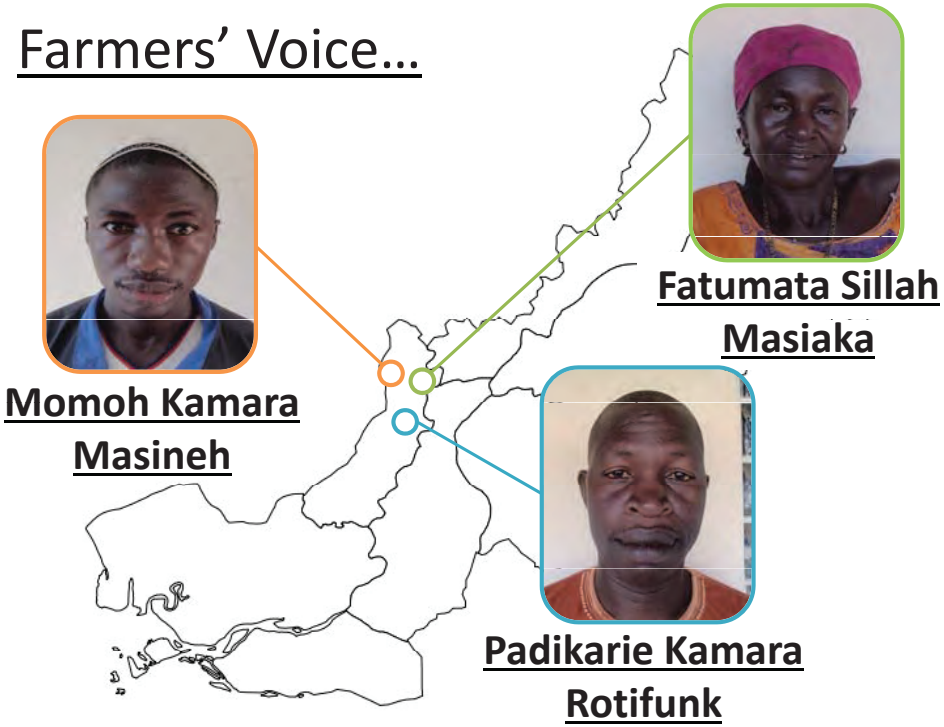
Before intervention…

0.5 – 1.0 ton/ha

After intervention…

How come…?

Farmers' Voice…



Momoh Kamara Masineh

Fatumata Sillah Masiaka

Padikarie Kamara Rotifunk

Voice from extension worker…

Survey/Planning
- Present status
- Basic needs

Implementation
- Proper training/input
- Timeliness

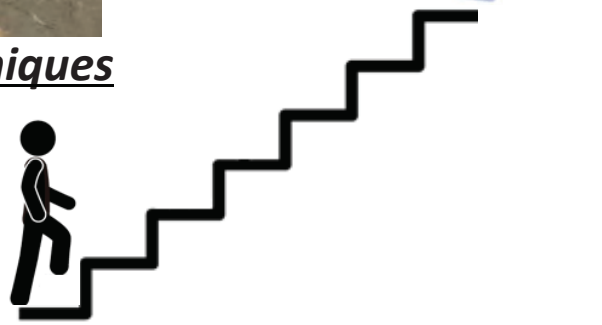
Monitoring
- Management tips
- Frequency

Evaluation
- Yield/Profit
- Farmers' perception

Daniel M. Kamara
BES, MAFFS-K

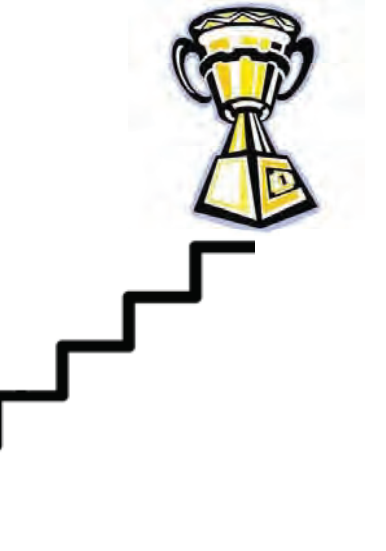
Road to 3 ton/ha…

Learning of techniques



Road to 3 ton/ha…

Proper planning



Road to 3 ton/ha…

Unity of group

Road to 3 ton/ha…

Practice & Practice

Road to 3 ton/ha…

Frequent monitoring

Road to 3 ton/ha…

Mutual understanding

Future perspective…

Question

- ☑ Is 3 ton/ha achievable “ONLY” in Kambia district?
- ☑ Are we really satisfied with 3 ton/ha for self-sufficiency and business?

If “NO”,
what should we do
after completion of the project?

Further dissemination and elaboration of TP-R

SRDP Forum:
Remained issues and recommendations

July 17, 2014

Bintumani Hotel, Freetown

Sustainable Rice Development Project (SRDP)

JICA-MAFFS

Issue -1

Limit of the application of TP-R

(1) Status of the swamp (water control, levelling)

(2) Access to fertilizer (availability, price)

(3) Farmers' capacity in rice cultivation (cropping calendar, familiarize with recommended practice)

(4) Climatic conditions (rainfall in the rainy season)

Issue -2

Further dissemination of TP-R

(1) Delayed implementation of SCP

(2) Absence of supervision and monitoring

(3) Insufficient time for building capacity of rice farmers for cultivation technique

(4) Inadequate capacity of extension workers

Recommendation -1

Creating enable environment for TP-R to be effective

(1) Improvement of the quality of IVS development

(2) Securing access to fertilizer

(3) Scaling up of capacity development of rice farmers for cultivation technique

(4) Continued research and development works

Recommendation -2

Further dissemination of TP-R

(1) Sound implementation of SCP including timely supply of fertilizer

(2) Establish mechanism of supervision and monitoring of dissemination of TP-R

(3) Repeated training of extension workers and rice farmers to develop capacity for rice cultivation techniques and related knowledge

(4) Further collaboration with other donors and NGOs in rice development