Food and Agriculture Organization of the United Nations

Background Reading Materials and Selected Session Guides on Roots

Based on experiences derived from the Dry Season Participatory Action Research on SRI & Soil Ecology

Prey Veng, Cambodia

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Foreword

The FAO Regional Programme on IPM in Vegetables and The Cambodian National IPM Program initiated a project on Participatory Farmer Action Research (PFAR) on soil ecology and system of rice intensification (SRI) which commenced during dry season 2006. The participatory action research activities will continue during 2006 wet season and beyond in Prey Veng province.

SRI was introduced to farmers in Cambodia in 2003. It promotes sound water and soil management which results in healthier plants and a vigorous root system. SRI has gained popularity among small scale farmers due to reduced inputs requirements with exceptionally high yields. There are, however, knowledge gaps that need further evaluation.

The FPAR activities in Prey Veng are aimed at providing opportunity for farmers, trainers and researchers to actively participate in experimentation to evaluate aspects of SRI specifically healthy root systems and living soils. The two-season FPAR activities include a season-long intensive training for selected farmers and district trainers on soil ecology and SRI organized during the dry season and an extension phase during the wet season. The farmer and district trainers will work with selected farmers in three districts in Prey Veng to evaluate and validate further the aspects on SRI through participatory action research.

The dry season training activities has led to the compilation and development of innovative exercises on technical reference and session guides root development that are included in this resource guide. It is hoped that the exercises in this resource guide will be useful to the farmers and trainers and will be further validated in the field. A.

This resource material is divided into three parts. **Part I** covers important technical aspects of root development in plants and in rice in particular; **Part II** provides a brief description of SRI, its principles and insights from field implementation in many rice growing countries; **Part III** features session guides and small experiments related to root of plants, its functions, and factors that are important for its development.

Part I:

Background Reading Materials on Plant Roots

1. Roots

Often roots are overlooked, probably because they are less visible than the rest of the plant. However, it's important to understand plant root systems because they have a pronounced effect on a plant's size and vigor, adaptation to soil types, and response to cultural practices and irrigation.

Roots typically originate from the lower portion of a plant or cutting. They have a root cap, but lack nodes and never bear leaves or flowers directly. Their principal functions are to absorb nutrients and water, anchor the plant in the soil, support the stem, and store food. In most of the plants, roots serve as a temporary sink (food or photosynthates stores in the roots) at vegetative stage. When plant reaches to reproductive stage stored food is translocated to the seed. The translocation of food from roots to the seed depends on soil water conditions. As for example drained field condition encourages translocation of food at later growth stage of rice particularly in hybrid and high yielding varieties.

1.1 Root Systems

The roots of a plant are connected differently in different plant species and this is known as the root system. The root system of a plant constantly provides the stems and leaves with water and dissolved minerals. There are two main types of root systems:

1.1.1 Fibrous System. This root system is characterized by having a mass of similarly sized roots. In this case the radicle from a germinating seed is short lived and is replaced by adventitious roots. Adventitious roots are roots that form on plant organs other than roots. These lateral roots branch repeatedly to form the network roots commonly known as feeding roots. Most monocots like rice have fibrous root systems.

Fibrous root system

1.1.2 Taproot System. This root system is characterized by having one main root (taproot) from which smaller branch roots emerge. When a seed germinates, the first root to emerge is the radicle or primary root. In many dicotyledonous plants this root greatly enlarges to become the most prominent root and is known as taproot. Many smaller branch roots may grow from the taproot. .

Source: http://facweb.furman.edu/~lthompson/bgy34/plantanatomy/plant_root.htm

1.2 Why Roots Grow Where They Do?

Roots grow where water, minerals and oxygen are found in the soil. Because the greatest supplies of these materials usually are located in the surface layer of the soil, the largest concentration of feeder roots exists in this zone.

Other factors that determine root growth include soil compaction (reduction in air pockets and thus starvation for oxygen resulting from soil particles being packed together) and soil temperature. In general, as the depth increases, soil compaction increases, while the availability of water, minerals, oxygen and soil temperature all decrease. In some instances, hard, compacted soil (hardpans) can occur near the surface, which restricts root growth.

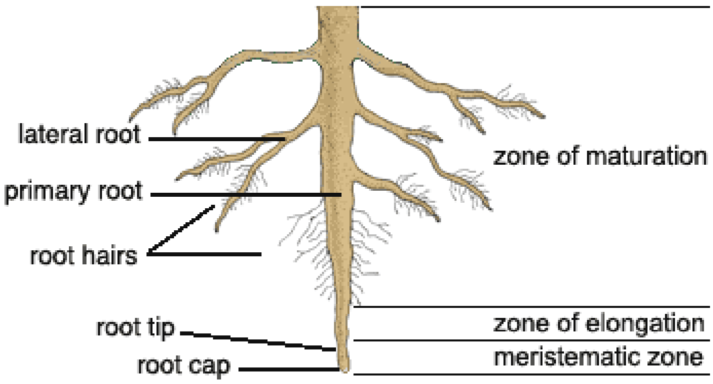


Fig. 1. A basic root structure

Source: http://extension.oregonstate.edu/mg/botany/images/fig2.gif

1.3 How roots grow?

During early development, a seedling absorbs nutrients and water from the soil around the sprouting seed. As a plant becomes well established, the quantity and distribution of its roots strongly influence its ability to absorb moisture and nutrients. For most plants, the majority of the absorbing (feeder) roots are located in the top 12 inches of soil. The soil environment in this region generally is best for root growth, with a good balance of fertility, water, and air spaces.

The following factors are important for root growth:

Roots in water-saturated soil do not grow well and ultimately may die due to lack of oxygen except aquatic plants where aerenchyma (a tissue that contains air) provides oxygen to the roots.

Roots penetrate much deeper in loose, well-drained soil than in heavy, poorly drained soil. A dense, compacted soil layer can restrict or terminate root growth.

1.4 Rhizosphere biology and roots

1.4.1 What is the rhizosphere?

The rhizosphere is the zone of soil surrounding a plant root where the biology and chemistry of the soil are influenced by the root. This zone is about 1 mm wide, but has no distinct edge. Rather, it is an area of intense biological and chemical activity influenced by compounds exuded by the root, and by microorganisms feeding on the compounds.

1.4.2 What do the roots do in the rhizosphere?

The roots exude (release/ secretes) water and compounds broadly known as exudates. Root exudates include amino acids, organic acids, carbohydrates, sugars, vitamins, mucilage and proteins. In case of rice, root also supplies oxygen to the rhizosphere. The exudates act as messengers that stimulate biological and physical interactions between roots and soil organisms. They modify the biochemical and physical properties of the rhizosphere and contribute to root growth and plant survival. The exudates have several functions.

- Defend the rhizosphere and root against pathogenic microorganisms.
- Attract and repel particular microbe species and populations.
- Keep the soil around the roots moist.
- Obtain nutrients from the surrounding soil (supplies carbohydrates to the microbes and takes up nutrient such as nitrate, phosphate etc from the microbes.
- Change the chemical properties (including soil pH) of the soil around the roots.
- Stabilize soil aggregates around the roots.
- Inhibit the growth of competing plant species (allelopathic effect).

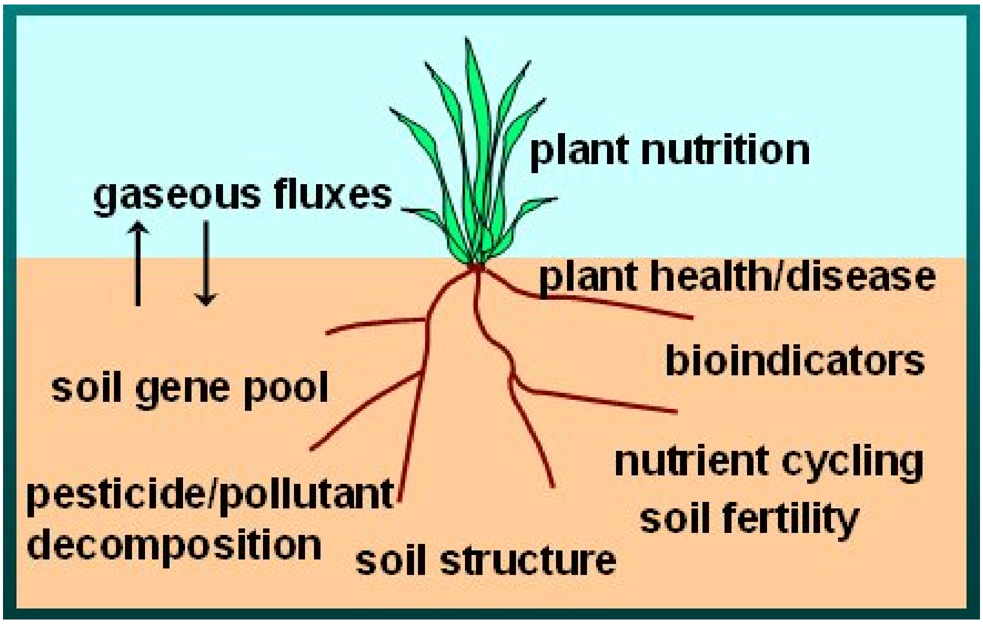


Fig.2. Rhizosphere –regulating plant and soil

Source: www.rothamsted.bbsrc.ac.uk

1.4.3 What do living organisms do in the rhizosphere?

- *Interact with plant roots.*

Sticky mucilage secreted from continuously growing root cap cells is believed to alter surrounding soil and it attracts the microorganisms.

- *Mineralize nutrients.*

Microorganisms convert organic forms of nutrients into inorganic forms that plants roots can take up. In legumes, microbial root nodulations enable plants to fix nitrogen from the air.

- *Encourage plant growth*

Rhizosphere microorganisms produce vitamins, antibiotics, plant hormones and communication molecules that all encourage plant growth. The communication molecules send signals to the plant to activate the defense gene against various soil borne diseases and so plant develops resistance against diseases.

- *Stabilize soil aggregates.*

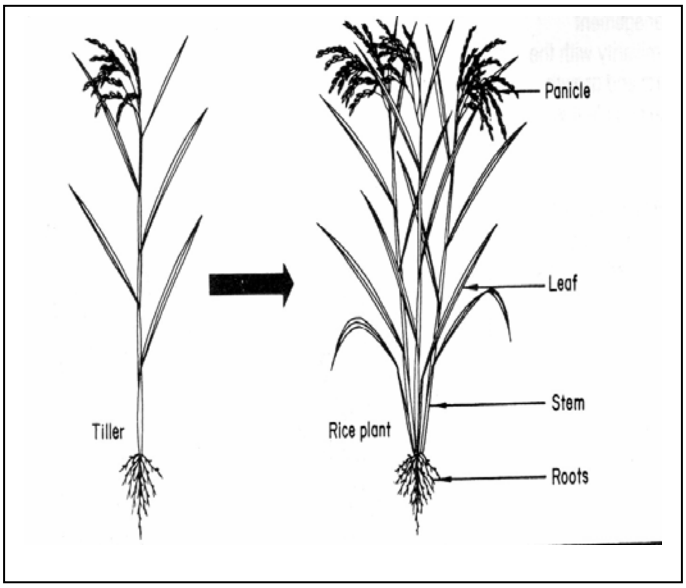
Waste products and secretions from microorganisms help combine soil particles into stable aggregates around plant roots. These aggregates hold moisture within, but allow drainage between aggregates, so that root hairs do not get waterlogged.

1.5 Rice Plant and roots

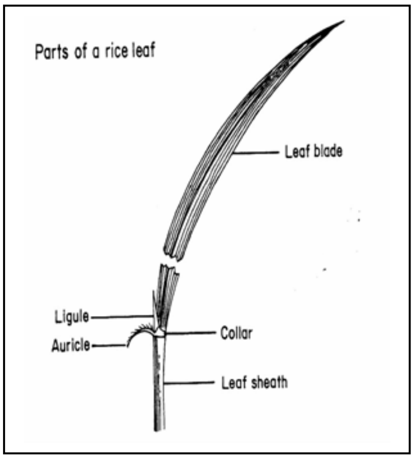
1.5.1 Structure and parts of the Rice Plant

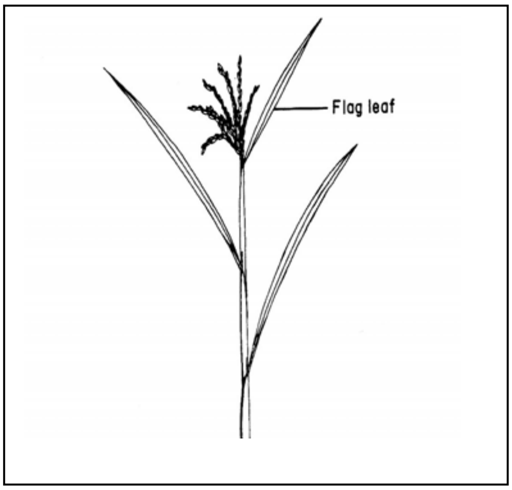
- The Tiller

The tiller is a shoot that includes the roots, stem and leaves. It may or may not have a panicle.



- <u>The Rice Leaf</u>

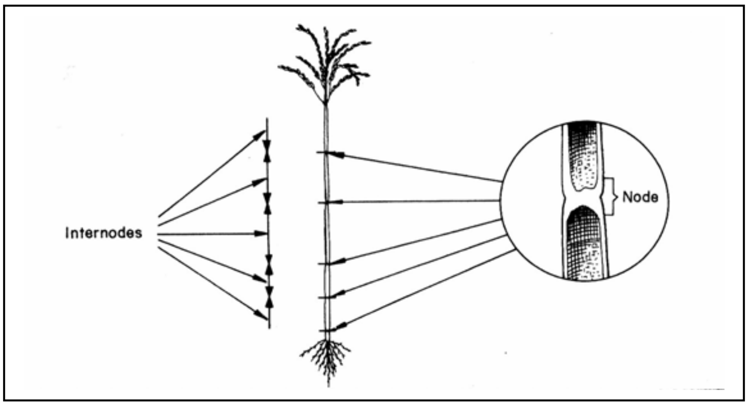




Arrangement of leaves on a stem

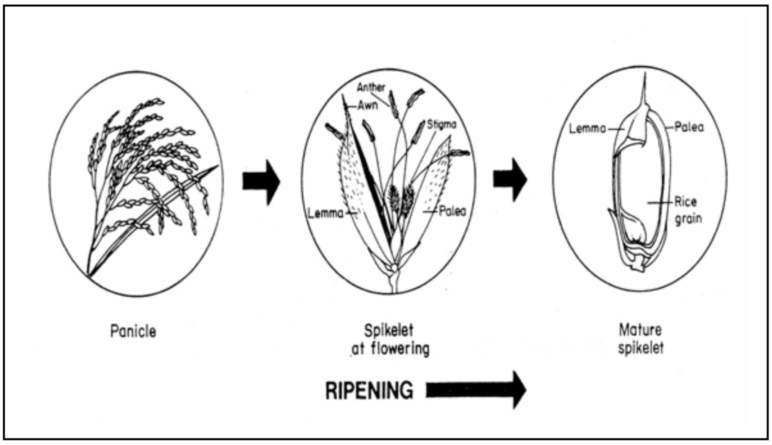
- The top leaf just below the panicle is called the flag leaf.
- The leaves grow alternately on the stem

- <u>The Rice Stem</u>



The culm, or joined stem, of rice is made up of a series of nodes and internodes. The node is the solid part of the stem. The internode is the portion of the stem between the nodes.

- <u>The panicle</u>



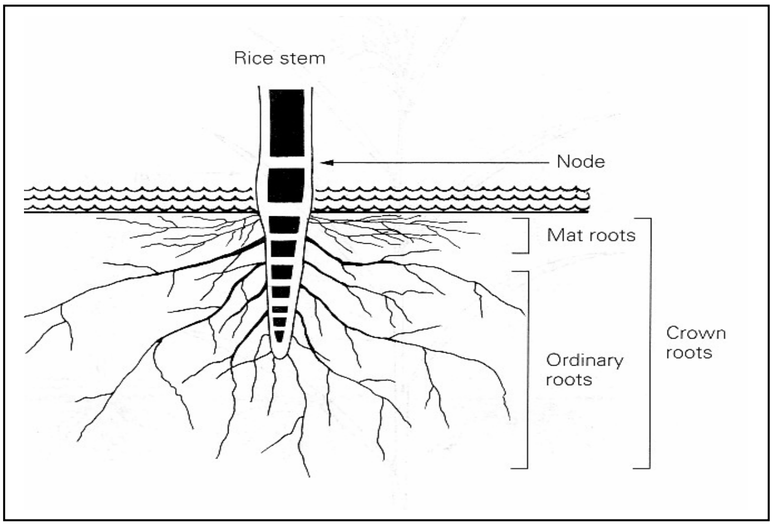
The smallest unit of the panicle is the spikelet.

At flowering, the floral parts can be seen between the lemma and palea.

The mature grained is cover by the rice hull.

- <u>The Roots</u>

There are two types of crown roots in rice: mat roots, which are shallow and ordinary roots.



1.5.2 The Growth Stages

Stage 0 – germination to emergence

The first stage covers the period from germination until the emergence of the first leaf

Stage 1 – Seedling Stage

Stage 2 – Tillering Stage

The tillering stage extends from the appearance of the first tiller until the maximum number of tillers is reached.

Stage 3 – Stem elongation

Stem elongation begins late in the tillering stage and ends just before panicle initiation.

Stage 4 – Panicle initiation

At the panicle initiation stage, the panicle develops and grows into a white feathery cone, creating a bulge at the base of the leaf sheath near the bottom of the tiller.

Stage 5 – Panicle development

The panicle grows and extends upward inside the flag leaf sheath, and the spikelets develop. At the end of this stage, the panicle causes the flag leaf sheath to swell (booting).

Stage 6 – flowering

The flowering stage begins when the panicles emerge from the leaf sheath (heading). It ends with pollination and fertilization.

Stage 7 – Milk grain stage

At the milk grin stage, the grain contains a white liquid that can be squeezed out with the fingers. The panicles are green and the flag leaves are green and erect.

Stage 8 – Dough grain stage

The milky portion of the grain turns into a soft and then a hard dough. The grain turns yellow and the whole field appears yellowish.

Stage 9 – Mature grain stage

The grain is full-size, hard, and yellow. The upper leaves are dry and the panicles bend toward the ground. .

1.5.3 The Growth Phases of the Rice Plant

The life cycle of the rice plant may be divided into three main phases. These are:

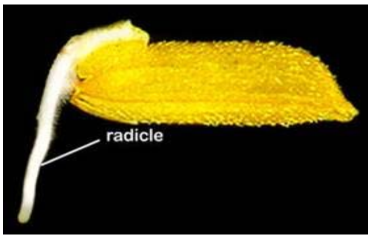
- Vegetative phase – from germination to panicle initiation
- Reproductive phase – from panicle initiation to flowering
- Ripening phase – from flowering to maturity

1.5.4 Development in Rice Plants

<u>Seed Germination</u>

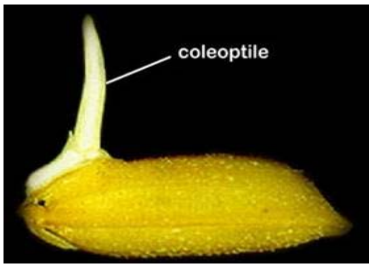
Germination is the appearance of the white tip of the coleoptile after a seed is placed in soil or water

When the seed germinates in well-drained and well-aerated soil, the coleorhiza, a covering enclosing the radicle or primary root, protrudes first.



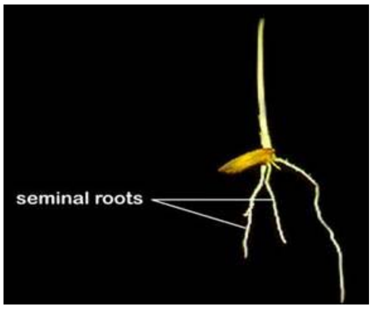
Shortly after the coleorhiza appears, the radicle or primary root breaks through the covering. The radicle elongates to a maximum length of about 15 cm. It functions until the seventh leaf stage.

If the seed germinates in water, the coleoptile, a covering enclosing the young shoot, emerges ahead of the coleorhiza. The coleoptile emerges as a tapered cylinder.

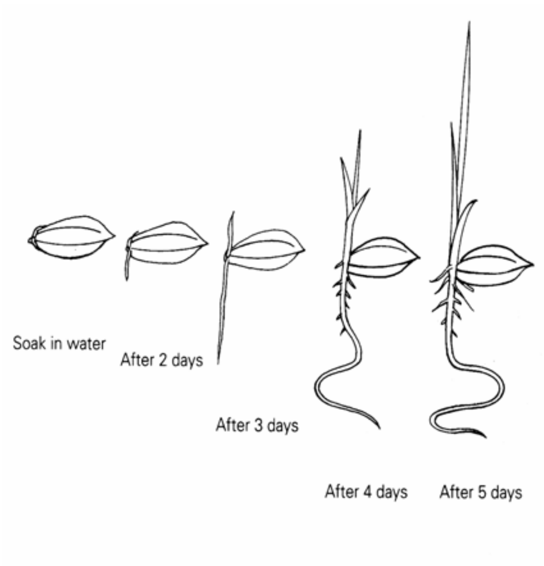


Root Development

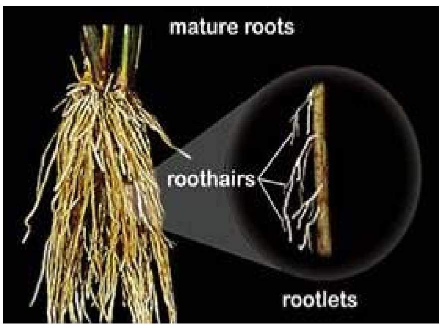
The radicle is followed by the growth of or more sparsely branched seminal roots. These roots eventually die and are replaced.



The growth of the rice plant from germination to the 5th day is shown in the figure below.



The mature root of a rice plant is shown in the opposite picture



1.5.5 How do roots help to get better yield?

Rice grows under continuously flooded conditions or under rain fed condition where it is exposed to subsequent flooding and drying that affect the soil redox potential (ability of soil to oxidize or reduce the ion present in the soil solution. In another word this gives the idea about the soil's aerobic or anaerobic condition). In general, rice root survive in hypoxic condition (poor oxygenated soil environment) that causes rice to undergo several adaptation in its root system, most notably the creation of aerenchyma (root tissue with air pockets) that provides oxygen to the roots. However, formation of increased aerenchyma tissue is linked with poor grain yield because it interferes with the nutrient uptake capacity of the roots.

For rice plants to be more productive, they need to have:

• More tillers per plant,

• More productive tillers (panicles) which develop from the tillers that a plant puts out,

• More grains per panicle,

. higher percentage of filled grains; and,

• Larger grains.

For the plant to grow successfully above ground and support above mentioned yield contributing parameters, it needs a healthy and vigorous root system below ground. If rice plants are spread out and not planted very close together, they have more room to grow. They will get more sunshine and air and can produce more tillers. More of these tillers will become productive and produce grains of rice. With more space to grow, root systems become larger with enhanced capacity to take up water, nutrients etc.

1.5.5 How can we get rice plants to grow stronger roots?

It is important for crop development to plant 1-2 seedlings/hill only, rather than to plant them together in bunches of 4 or 6 seedlings, or even more, as is often done by farmers in some localities in Cambodia and elsewhere.

When several seedlings are planted together, their roots must compete with each other. This is a similar problem for rice plants as, when they grow closer together, they must compete with weeds for nutrients, water and sunlight.

Whereas the rice plant survives when its roots are continuously submerged under water, it does not thrive in this situation. Rice does not grow optimal under permanent flooded conditions. Rice plants that grow in permanent standing water will adjust to this environment. Their roots develop small air pockets i.e. aerenchyma that permit oxygen from above ground to reach the roots. But this is not an ideal condition for plant growth. It interferes with transfer of nutrients from the soil to the plant's tillers and leaves. Therefore, ideally, a rice field should be drained once or twice during the crop growth cycle to avoid anaerobic conditions or, alternatively, a shallow water level should be maintained to provide better oxygen concentration in water-submerged soil for healthier root growth.

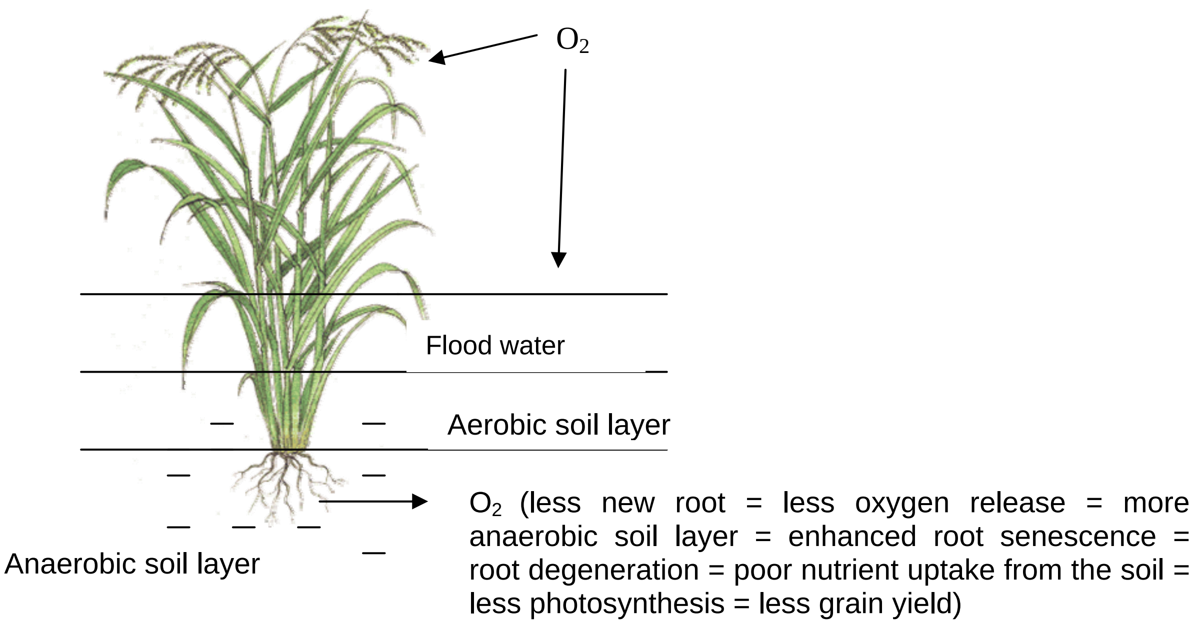


Fig.3 Rice under permanent flooded condition

For growing healthy roots, rice plants need healthy root systems at seedling stage and aerobic root growth conditions that subsequently facilitate new root formation and revitalization at tillering and grain filling stage respectively.

The healthy rice root system consists of:

- More volume of roots in the feeder zone i.e. upper soil layer;
- Continuous formation of roots from the node of the tiller;
- Light brown/ cream color of the roots;
- High root weight;
- More root hairs;
- Highly branched lateral root systems; And,
- less thickness of single root (root arises from the base of the tiller and initially it is very fine. The thickness of the root i.e. diameter increases with the time. If the ratio of thick root is high compared to thin root, it means root system are relatively older i.e. more aged.

Keeping these facts in mind, it is important that IPM farmers understand the mechanics of ‘growing healthy rice root systems’. The session guides presented in Part Two of this Guide allow farmers and trainers to explore root systems, study their functions and interactions in the rhizosphere and facilitate better understanding on how to facilitate growth of healthy root systems for better rice yields and profits.

PART II:
The System for Rice Intensification (SRI)

1. Beginnings of SRI

SRI was developed in 1983 by the late Fr. Henri de Laulanie, a Jesuit priest working with Malagasy farmers, who observed a strong increase in tillers a strong increase in tillers and yield after an accidental early transplanting of rice. He went on to combine early transplanting with other practices that provided an optimal rice plant environment. In 1990, Fr. De Laulanie helped to establish Association Tefy Saina (ATS), a NGO to promote and improved SRI in Madagascar.

2. Principles of SRI

2.1 Early transplanting

- 8 – 12 days after sowing
- When seedlings have two leaves
- Seedlings should be planted immediate within 15-30 minutes after they have been uprooted
- The tiny roots should be placed horizontally in the soil so that the tip of the root can easily resume its downward growth.
- Get insure that endosperm is attached while uprooting and transplanting seedling

2.2 Plant only 1 or 2 seedling(s) per hill

- This is done to enhance the development of roots and tillers and minimize competition between plants

2.3 Wide Spacing

- 25 x 25 cm and 50 x 50 cm (depending on the soil fertility and varietal characteristics of the plant)
- 5 to 8 kg of seed is sufficient per hectare of transplanted rice

2.4 Alternative wetting and drying of the field

- Improves soil structure
- Gets more oxygen into the root zone
- Enhances active soil life
- Maintain 1 -2 cm of water in the field at reproductive phase (panicle initiation, flowering, grain filling and drain water 10-12 days before harvesting).

Rice is not an aquatic plant. When there is no standing water and there is air in the soil, the roots can acquire oxygen much more easily through the *aerenchyma* (air pockets in the root cells). Lack of oxygen in the roots zone leads to soil acidification that causes the destruction of *aerenchyma* and hampers nutrient uptake, assimilation and plant growth.

2.5 Minimum Irrigation –

At the beginning of tillering, there is still not much vegetative growth and the plant only requires a small amount of water. When the root system has been developed, 3 or 4 days of superficial dryness should not cause alarm even if some cracks developed in the field. During growth irrigation will be needed if rainfall is inadequate and then should be applied in moderate amounts and at favourable times – preferably at night. In this way, irrigation requirements can be reduced by up to 50%.

2.6 Early and Frequent Weeding

- Use of simple push-mechanical weeders to churn up soil and promote soil aeration for at least 3 times during the season – (during vegetative stage until plant canopy closes.)

2.7 Application of Compost

3. Results Associated with SRI

3.1 Increased Tillering – with 30-50 tillers per plant, 80-100 possible, and sometimes even more from a single plant.

3.2 Greater Root Growth – with 5-6 times more force to uproot an SRI plant than to pull up one conventionally grown rice.

3.3 Increased Grain Filling – panicles are larger as well as more numerous.

3.4 Higher grain quality and greater grain weight – with SRI farmers get heavier, denser grains that withstand shattering and keep their shape better after cooking.

3.5 Water savings – water requirements with SRI are usually reduced by about half since paddies are not kept flooded during the entire crop cycle.

<u>Other Benefits with SRI</u>

- Less Lodging – with strong tillers and larger root systems, SRI plants can withstand strong winds and rain.
- Fewer pests and disease attacks
- Seed savings
- No need for chemical fertilizers
- Lower costs of production

- Increased productivity
- Profitability
- Reduced risk

4. Report on Yield of Rice under SRI

After it was proven its potential as a novel technology, SRI is now being tested in 18 countries ranging from China to Peru. Reported average yields from SRI are in the 7-8 t. hectare to over 15 ha reported from at least four countries beyond Madagascar (Uphoff, 2004). The table below summarizes yields from SRI fields across different countries.

Country	No. of Data Sets (no. of farmers)	Average Comparison Yield (t/ha)	Average SRI Yield (t/ha)	Average Max. SRI Yield
Bangladesh	4 on-farm (261) 6 on-station	4.9	6.3	7.1
Cambodia	3 on farm (427)	2.7	4.8	12.9
China	7 on-station with hybrid varieties	10.9	12.4	13.5
Cuba	17 on farm trials	4.3	7.4	13.3
Gambia	1 on-farm (10) 1 on station	2.3	7.1	8.8
India	On farm trials (134)	4.0	8.0	15.3
Indonesia	2 on-farm 5 on station	2.3	7.1	8.8
Madagascar	11 on farm (3,025) 3 on station	2.6	7.2	13.9
Myanmar	121 farmer field school trials	2.0	5.38	15.3
Nepal	13 FFS	4.2	8.5	11.0
Philippines	4 on farm (47) 1 on station	3.0	6.0	7.4
Sierra Leone	8 on-farm (160)	2.5	5.3	7.4
Sir Lanka	6 on-farm (275) 2 on station	3.6	7.8	14.3

5. Biological Support for Rice Production

Although SRI appears “too good to be true” to some skeptics, there is a growing body of knowledge to boost its merits. According to Uphoff (2004) fewer external inputs can produce more output, as using less water (avoiding soil hypoxia) and chemical fertilizer (affecting microorganisms) enhances soil biological activity. Fewer chemical sprays leave more beneficial organisms in the canopy and soil to control pests. With reduced external inputs, there is more input to crop production processes of beneficial gases as well as biological mineralization of nutrients in the soil. The beneficial and even necessary contribution of roots exudates to supporting larger and more diverse microbial populations is well established. However, the implications of this for agricultural production have been little considered.

Uphoff (2004) further opined that there are number of biological processes well documented in the literature that could be boosting rice yields with SRI management of plants, soil, water and nutrients. He enumerated the following:

- When soils are alternately flooded and drained, this gives both aerobic and anaerobic bacteria as well as mycorrhizal fungi an opportunity to contribute to plant growth. Under these conditions, there is increased biological N fixation and P solubilization.
- Plants with larger root systems and canopies are able, indirectly, to produce more N in their root zone by exuding photosynthates made from atmospheric CO_2 into the rhizosphere. These photosynthates support larger bacterial populations on the roots that in turn are 'grazed' by protozoa which then excrete excess N onto the plant roots which utilize this biological waste product.
- Many species of bacteria and fungi produce phytohormones in the rhizosphere – auxins, cytokinins, ethylene, etc. – that regulate and promote root growth. Unpublished research from the University of Natal has found that certain bacteria are able to double the size of plant root systems by their activity.
- Uphoff (2004) concluded that there is much to know about the soil system dynamics. He is certain that plants and soil function symbiotically, even though biology texts emphasize the differences between the plant and microbial kingdoms instead of their interdependence. SRI gives evidence of the productive potentials that can be capitalized upon by understanding and supporting these relationships.

6. Constraints and Limitations of SRI

6.1 Good Water Control

Water savings can only be made – and soil can only be kept aerated enough to support the growth and functioning of aerobes in the soil – if farmers can apply limited amounts of water rather than keep their paddies continuously flooded. Many farmers do not have such water control as they operate in field-to-field (cascade) systems of distribution.

6.2 Labor Intensive

Initially, SRI methods require more labor, as they need to be learned and mastered. The first-season increase in the labor required is usually 25-50%. Even when SRI is more labor-intensive, however, the returns to labor are increased.

6.3 Farmers motivation and skill

Farmers need to become more conscientious and knowledgeable managers of their plants, soil, water and nutrients.

6.4 Suitable only for small-scale production

One constraint that has been alleged with SRI, because of its labor intensity, is only suitable for small-scale production.

7. SRI Is a Work in Progress

SRI is something new and that evaluation of its potentials is now being given serious attention by institutions. Farmers are encouraged to try and made improvements in the methods rather than just accept and apply them. SRI extension should give more attention to the principles and ideas behind SRI than to the techniques themselves. SRI raises many interesting issues for researchers to tackle, in soil microbiology and ecology, in plant-soil-water relations; in mechanisms for phenotype expression of genetic potential; in selection and creation of the best cultivars for SRI conditions.

PART III:

Session Guides for Exploring Roots And SRI

Session 1: Plant Structure and Function

Introduction

The cultivated rice plant is an annual grass. The stems consist of round, hollow internodes connected by nodes. The leaf blades are rather flat and attached to the culm by leaf sheaths. The inflorescence is a panicle.

Rice is a semi-aquatic plant. It can adapt to a wide range of ecological diversity, from rainfed-dryland to deep-water flooded conditions (UPLB, 1983).

This exercise will lead participants to an in-depth understanding of the parts, structure and functions of parts of a rice plant.

Objective Discuss the structure, composition and function of each principal part of the plant.

Materials Sharp knife or single-edged razor blade, hand lens, newsprint, colored pens

Time required 1.5 hours

Procedure

1. Ask each group to take a mature plant and decide on what constitutes the principal sections or components of the plant (roots, stems, leaves, panicle, fruit, etc.); then cut them separately.
2. Discuss what the function of each plant part.
3. Try and dissect or gently break apart the plant parts to see as best as possible how the plant part is formed (use hand lenses if available).
4. Rub the plant parts between your fingers and try to describe the texture and any other characteristics (soft, moist, woody, slippery, etc.).
5. Draw a representative plant to show the function of each plant part in the table give below. Fill in the other columns with corresponding information.
6. Discuss the following questions and report back to the large group.

Plant Part	***Texture***	***Function***

Discussion Questions:

1. What is the relative size for each plant part (if the entire plant is 100%, then what percent is each section)?
2. What do the textures associated with each section tell you about what the parts are made of?
3. What do the textures tell you about how rapidly the plant parts might compost or degrade when turned back into the soil?
4. How will you describe the parts of the rice plant, its growth stages and phases of development?

Session 2: Fundamental functions of roots and their interaction in rhizosphere.

This particular session will set the tone for the training module on the roots. This will provide theoretical base and understanding to better deal with the subsequent session. In addition, common understanding of terminologies will be achieved to better prepare for the subsequent session on 'growing healthy root system'.

Objective To familiarize the participants with the basic functions of roots and their interactions with the soil system.

Materials needed

News print, marker, pen, chart paper

Time needed (100 minutes total):

For introduction:10 minutes
Brainstorming: 30 minutes
Preparation of summary: 20 minutes
Presentations, summary and compilation of output: 40 minutes

Procedure

The facilitators will divide participants in small groups of 4-6 farmers. Each group will be tasked to brainstorm and find answers on the following questions:

1. What is a root? Draw the root and describe the parts of the root?
2. What are the functions of the root system?
3. Where in the soil do you find more roots? Why?
4. Is there any effect of continuous flooding on roots? How does the rice root survive in flooded soil?
5. Which type of soil do you think supports better root growth?
6. How do root systems support soil and plant?
7. Why is it important to uproot seedlings carefully? Explain how best to do this.

Question number 1, 2, 3, 5 and 7 are pre-requisite for better understanding of subsequent sessions.

In a plenary session, small groups will then be tasked to answer a question, one by one until all of the above questions have been discussed. Facilitators can add useful content information as to deepen participant's understanding about the topic under discussion.

Additional questions for discussion:

1. Why is the tap root (or main root) longer than other roots? What is the main function of the tap root?
2. Why are feeder roots primarily distributed in the upper layer of the soil?
3. How is root growth affected by poor drainage?
4. Why do rice seedlings recover fast from transplanting stress when roots injuries are less? Why is a speedy transplant recovery important?
5. Why is root growth better in composted soil?

Session 3: Seedling vigor and its association with root growth

Seedling vigor is critical when competition for light, nutrients, air, and water becomes strong. Seedlings with a vigorous growth pattern can compete successfully under stress, influencing stand establishment and ultimately grain yield. The seedling vigor-and that of root systems in particular- depends much on soil and water conditions. The exercise below aims to explore differences in seedling & root system vigor when grown under different water management conditions in the seedbed.

Objective

To compare rice seedling's root and shoot development under *drained* and *wet* soil bed conditions.
(Both seed bed should be prepared and sown in advance. The observation should start from the second day of sowing until one week of sowing)
Materials needed – polythene bags, transparent glass or bottle, clean water, bamboo stick, hand hoe, marker, pen, chart paper, measuring scale etc.

Time required 30 minutes for data gathering at 2 DAS, 90 minutes for data gathering at 7 DAS

Procedure and Preparation

1. A seedbed should be prepared in advance, seeds should be sown and the beds should be maintained with one section fully drained (maintained like a vegetable nursery with frequent irrigation – morning and evening time) and one section kept flooded (the puddled and flooded seed bed – the farmer's practice)
2. At 2 DAS, go to seedling nursery in groups of three to five and ask each group to take a reading on germination%. in each seedling bed.

3. At 7 DAS, return to the seedbeds in groups and uproot randomly 5 seedlings from drained and wet seedbed. This should be done carefully with a bamboo stick or hand hoe. Ensure minimal injury to the seedling roots and that seeds are still attached. Observe how much soil sticks to the roots upon uprooting.
4. Soak the plant in water for 10-15 minutes and carefully remove the soil.
5. Ask each group to collect the following data and have this recorded in the table provided below. Use estimates if difficult/too many to count and/or indicate with 'More' or Less' when comparing treatments..
    - Measure the vertical length of the roots and count the # of lateral roots
    - Observe the color of the root.
    - Observe density of root hairs.
    - Float the seedling in a clear/ transparent plastic jar with clear water and measure the diameter of the surface area the roots covers.
    - Count the number of leaves
    - Measure the plant length
    - Observe the color of leaves

.. …

S.N	Parameters	Drained seed bed	Wet seed bed
1	Germination%		
2	Amount of soil sticking to the roots		
3	Length of vertical roots		
4	Number (#) of lateral roots		
5	Color of root (white/ brown)		
6	Number (#) of leaves		
7	Length of shoot/ Plant height		
8	Surface area of root cover when floated in water		
9.	Seedling vigour (use IRRI scale)		

Use the scale (IRRI, 1996) below:

1 – Seedling very green with thick stem
3 – Seedling light green?
5 – Seedling yellow
7 – Seedling brown
9 – Seedling dead

Questions for discussion

1. What are the main differences in root and shoot development under *drained* and *wet* seed bed growth conditions? Explain!
2. What are the main differences observed in root systems?
3. Is there any difference in germination %, number of leaves and plant height?
4. Which seed bed has higher seedling growth rate and why?
5. What will be the effect on rice plant when you select vigorous seedlings?
6. Which seed bed shows better establishment? Explain why!

Session 4: Rice root health under *flooded* and *drained* soil conditions

Whereas root elongation is induced under flooded soil conditions, root formation is severely restricted under anaerobe soil conditions. This results into early senescence of the root systems at the crucial yield-determinant grain filling stage. Intermittent drainage of the soil induces new root formation and this, in turn, can facilitate better plant health. The exercise below aims to explore differences in root growth after transplanting under flooded and drained soil conditions.

Objective

To compare the root growth under flooded and drained soil after transplanting

Time required 90 minutes

Materials required

4 plastic pots/buckets (each group will have two pots- one for flooded soil and another for drained soil), Field soil, cow manure, watering cane, rice seedlings (15-20 days old).

Procedure

1. Divide the farmer participants into small groups of 4-6 farmer and provide each group with 2 buckets/pots.
2. Make a drainage hole at the bottom in one of the pots/buckets for the *drained* soil treatment. Fill both the pots with soil leaving 10 cm space above the soil surface.
3. Compress the soil in the pot having no hole (pot/ bucket for the *flooded* soil condition) by pressing it heavily.

4. Top up the soil layer with small amount of compost by spreading it in both pots/ buckets
5. Transplant the seedling (1-2 seedlings/pot)
6. Irrigate the pots with no hole to maintain 8-10 cm of water level above the soil surface and maintain it by checking water level every 24 hours.

7. Irrigate the other pot (with drainage hole) until water starts draining out from the bottom and maintain similar wet soil conditions by applying water every 24 hours.

At 50 DAT, carefully take out the rice plant from the pot, observe the root growth and record observations in table provided below:

- Observe the root color (white, brown)
- Measure vertical root length
- Observe volume of roots
- Observe lateral root formation and distribution
- Observe root hairs
- Observe relative thickness of single root having higher ratio in entire root system
- Observe the number of tillers
- Measure plant weight (root and shoot)
- Measure root weight

1	Parameters for study	Drained soil	Flooded soil
2	Vertical root length		
3.	Root color (brown or white)		
4.	Lateral root formation (more or less)		
5.	Root hair formation (more or less)		
6.	Root volume (more or less)		
7.	Thickness of single root (more or less)		
8	Number of tillers		
9.	Plant weight		
10.	Root weight		

Questions for discussion

- Why root growth is poor in permanent flooded soil?
- Which part of root is more injured by permanent flooding?
- Why root hair formation is less under flooding condition?
- Why lateral root formation is more in drained soil?
- Why feeder root number is more in drained soil?
- Did you find any correlation between shoot growth and root growth? If yes then why?

Session 5: Effects of plant density on root & tiller growth under flooded conditions

Roots growth is healthy when there is sufficient space and sun light and with root access to adequate water and nutrients. When rice seedlings are transplanted singly and widely rather than in clumps of four or six, the root systems have more room to spread and to send down roots into the soil. Grown under less cramped conditions, rice plants do not compete as much with other rice plants for space, for light, nor for nutrients in the soil and this result into stronger and healthier root systems. Further, when rice is grown in permanently flooded conditions, root degeneration starts earlier. Such early senescence can severely affect the nutrient uptake function of roots, resulting into poor grain filling. This exercise aims to explore root growth at different crop densities throughout a crop cycle and under different water regiments.

Objective

To observe the root growth at different growth stages under different water management and with different planting density.

Materials and methods for setting up experiment

Rice field, insured irrigation system, drainage facility in case if there is water logging due to heavy rainfall, fertilizer, 15 days old seedlings.

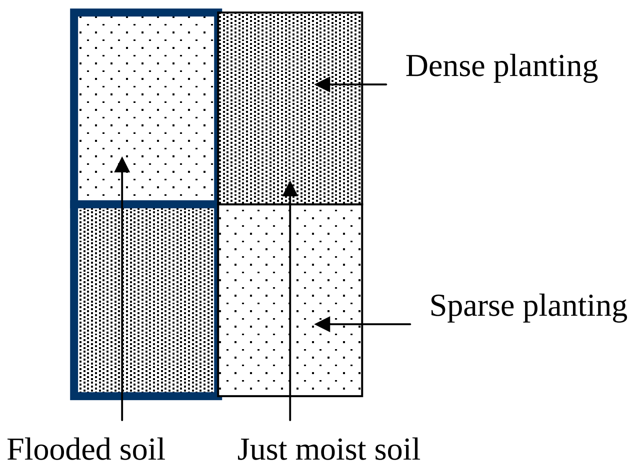
Preparation and experiment design

This session can be followed only when participants set up a season-long experiment on planting density and water management in rice so that they can compare the root growth at critical growth stages of rice and can see the root formation and root degeneration under different water management and planting density.

Treatments to be compared

Planting density – six seedlings per hill with 15 x15 cm and single seedling per hill with 20 x 20 cm or 25 x 25.
Water management - Permanently flooded and just moist condition.

Experiment lay out



Time requirements (2.hours/session)

- Tillering stage (20-35 DAT depending on the variety)
- Flowering stage (60-70 DAT depending on variety)
- Grain filling stage (90-95 DAT depending on variety)
- Harvesting stage (120-125 DAT depending on variety – the DAT (days after transplanting) provided here is for the variety which matures in 120-125 days)

Data gathering can be done anytime of the day but preferably in combination with the regular Agro-Ecosystem Analysis session.

Materials required (for each session at each growth stage)

Hand spade, polythene bags, rubber band, weighing balance, chart paper, markers, ruler, sketch pens etc.

Procedure

1. Divide participants in groups. One group will be allotted one plot.
2. Ask participants to select and tag plants randomly (two for each session)
3. Select one tagged plant and count the number of tillers, plant height, number of leaf/tiller and observe leaf color. Record data in table provided below.
4. Ask participant to experience the pulling force required to uproot the plant. Do not uproot the plants entirely but hold and try to uproot the plant by one hand. This will allow you to experience the force required to actually up root the plant.
5. Use hand spade to uproot the same plant.and observe the amount of soil that stick to the roots (volume of soil)
6. Immerse roots in to water, wash off the soil from the roots and put the plant in poly bag for further examination at the training site
7. Weigh the plant and observe the color of the roots
8. Measure the vertical length of the roots (originated from the tiller node to the tip of the longest root i.e primary root)
9. Measure the vertical length of the primary root occupied by vigorous growth of lateral roots
10. Observe the root hairs and old root and new root formation (old roots are brown in color with more thickness where as new roots are white in color with less thickness and originated from the tiller node).
11. Draw a picture of the whole plant including root system and name the plant and root parts
12. Analyse data and discuss results in a plenary group session.
13. Repeat the same procedure at Flowering, Grain Filling and at Harvesting stage. For the reading at Harvesting time, discuss the root development or degeneration in different treatments in relation to grain yield.

Tables for data analysis….

S.N	Parameters	Single seedling with wider spacing in Flooded condition	Single seedling with wider spacing in just moist condition	Six seedlings with narrow spacing in flooded soil	Six seedling with narrow spacing in just moist sol
1	Number of tillers				
2	Number of leaf/tiller				
3.	Leaf color				
4.	Plant height				
5.	Pulling force required to uproot the plant (more or less)				
6	Volume of soil stick to the roots (more or less)				
7.	Weight of plant				
8.	Color of the roots				
9.	Vertical length of the root				
10.	Vertical length of the roots occupied by vigorous growth of lateral root				
11.	Root hair (more or less)				
12.	New root formation (more or less)				

<u>Questions for discussion:</u>

- Which treatment has more root volume?
- Which treatment has browner colored root?
- Which treatment has more white color root and more root hair?
- Which treatment has more feeder root?
- Why more feeder roots are required?
- Did you find effect of better root growth on tiller number? If yes, then what are the effects and why?

NOTE: This exercise explains specifically the effect of water and planting density on root growth. Any other set up with different treatment will not yield the same results.

Session 6: Nutrient uptake: root and plant vessels

Introduction

As discussed in the previous exercise, the roots of rice plants chiefly function among others, as the absorber of water and nutrients from the soil. Water and nutrients absorbed by the plants are transported to stems and leaves of the plant.

The ability of the roots to absorb nutrients is influenced by several factors such as soil humus, organisms, pH and others.

The activity will show how nutrients move through the plant

Objective Describe how nutrient nutrients are absorbed by the roots and move through plant vessels.

Time Required 30 minutes to set-up the study and 48 hours to get full results

Materials water, red dye, 2 cups or plastic jars per group, plants, marker pen, AESA paper, plastic drinking straw

Procedure

1. In groups, find many kinds of plants including rice seedling, aquatic potato, celery, grasses, and other plants.
2. Put water in 2 cups and add several drops of the red food dye. The water should be dark red.
3. Place a sample plant in each cup. Place one cup with plants in a bright place and the other in the shade. Put in each cup a drinking straw.
4. After 48 hours, observe the plants.
5. Report your findings to the big group.

Discussion Questions

1. What has happened to the colour of the leaves?
2. How does the red colouring move in the plants?
3. How will you relate the results of the exercise to the importance of roots in absorption of nutrients?
4. What are the factors that may inhibit the roots of plants from taking up nutrients?

Follow-up Activity Conduct a brainstorming exercise with the group to come up with other methods of setting-up the exercise.

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