Africa Rice Center (WARDA)

Curriculum for Participatory Learning and Action Research (PLAR)

for

Integrated Rice Management (IRM) in Inland Valleys of Sub-Saharan Africa

Technical Manual

Marco C.S. Wopereis, Toon Defoer, Philip Idinoba, Salif Diack and Marie-Josèphe Dugué

Africa Rice Center (WARDA)

The Africa Rice Center is an autonomous intergovernmental agricultural research association of African member states and one of the 15 international agricultural research centers supported by the Consultative Group on International Agricultural Research (CGIAR).

Its mission is "to contribute to poverty alleviation and food security in Africa, through research, development and partnership activities aimed at increasing the productivity and profitability of the rice sector in ways that ensure the sustainability of the farming environment."

The modus operandi of the Africa Rice Center is partnership at all levels. The Africa Rice Center's research and development activities are conducted in collaboration with various stakeholders—primarily the national agricultural research systems (NARS), academic institutions, advanced research institutions, farmers' organizations, non-governmental organizations (NGOs) and donors—for the benefit of African farmers, mostly small-scale producers, as well as the millions of African families for whom rice means food.

The development of the 'New Rice(s) for Africa,' or NERICA(s), for which WARDA was conferred the CGIAR King Baudouin Award, is bringing hope to millions of poor people in Africa. This scientific breakthrough of crossing African with Asian rice species has helped to shape the Center's future direction, extending its horizon beyond West and Central Africa into Eastern and Southern Africa. The creation of NERICA rice and its expected contribution to food security and income generation in Sub-Saharan Africa are in harmony with the spirit and sustainable-development aspirations of the World Summit on Sustainable Development (WSSD), the Tokyo International Conference on Africa's Development (TICAD), the Millennium Development Goals (MDGs), and the New Partnership for Africa's Development (NEPAD).

The Africa Rice Center hosts four networks and consortia—the African Rice Initiative (ARI), the Inland Valley Consortium (IVC), the International Network for Genetic Evaluation of Rice in Africa (INGER-Africa), and the West and Central Africa Rice Research and Development Network (ROCARIZ)—all charged with ensuring the widespread and rapid dissemination, adoption and diffusion of new rice cultivars across the various rice ecologies found in Africa.

The Africa Rice Center has its headquarters in Côte d'Ivoire and four regional research stations—one covering the Sahel and located near St-Louis, Senegal, one at the International Institute of Tropical Agriculture (IITA) in Ibadan, Nigeria, the third at Dar-es-Salaam, Tanzania, and in Cotonou, Benin, where the center also has its temporary headquarters.

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IFAD

IFAD, a specialized agency of the United Nations, was established as an international financial institution in 1977 as one of the major outcomes of the 1974 World Food Conference. The main objective of the Fund is to directly give funds and mobilize additional resources for programmes facilitating economic promotion of the rural poor particularly by increasing the productivity of agricultural and extra-agricultural activities.

CBF–Inland Valley Consortium

IVC / CBF
Inland Valley Consortium
Consortium bas-fonds

IVC was founded in 1993 to promote sustainable development of inland valleys in Sub-Saharan Africa. The Consortium groups national and international agricultural research institutes and development agencies. Since April 1999, the Consortium is part of WARDA and works with 10 West African countries (Benin, Burkina Faso, Cameroon, Côte d'Ivoire, Ghana, Guinea, Mali, Nigeria, Sierra Leone, Togo) and 8 international institutions (WARDA, IITA, ILRI, FAO, WECARD/CORAF, WUR, CIRAD, IWMI). Each of the member states has a National Coordination Unit (NCU) that brings together—under the direction of a national coordinator—the representatives of the institutions involved in the development of inland valleys. Donors of the IVC are mainly The Netherlands (DGIS), France (Ministry of Foreign Affairs), the Common Fund for Commodities (CFC) and the European Union.

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Foreword

The inland valleys of Sub-Saharan Africa are a major asset for the region's food security and they are particularly well adapted for rice growing. However, these land resources (an estimated 85,000,000 ha) have often not been developed because of their extreme diversity and because of the difficulties related to water management in such systems.

Nonetheless, sustainable intensification of inland valleys seems to be a very promising way to close the increasing gap between rice production and rice consumption on the continent, and also to help stabilize the use of the fragile upland soils.

The idea of this manual, and of the associated *Facilitator's Manual*, stems from the observation that West Africa's inland valleys are very complex and that there is a chronic lack of communication among farmers, extension services and researchers. It is a product of several years of fieldwork coordinated by WARDA in close collaboration with ANADER (*Agence nationale d'appui au développement rural*, Côte d'Ivoire), and agricultural research and development services, including NGOs, in Benin, Côte d'Ivoire, The Gambia, Ghana, Guinea, Mali, Nigeria and Togo.

This *Technical Manual* is targeted at fieldworkers of research and extension services (both government and non-governmental) to help them stimulate field-based discussions about rice cropping in inland valleys. This manual deals with all aspects of rice cropping, from land preparation up to the end-of-season evaluation after harvest, using an integrated rice management approach.

We hope that later issues will offer a more complete curriculum on the integrated management of all the natural resources in inland valleys. Some references already deal with such topics. Furthermore, we would like to encourage you to adapt these references to your own working conditions and to add further material as you see fit.

We wish to thank the staff from WARDA and all the agricultural research and development services in Benin, Côte d'Ivoire, The Gambia, Ghana, Guinea, Mali, Nigeria and Togo, who have contributed to this important work.

Dr Papa A. Seck
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Why this manual?

The inland-valley areas in Sub-Saharan Africa are very important assets for the development and intensification of agricultural production. Their surface area has been estimated at 85,000,000 ha, i.e. 7% of the total arable cropland, of which only 10–15% is actually used for agriculture. Most of the inland valleys are situated in the inter-tropical zone, where rainfall is more than 700 mm per year. The objective of the two manuals (facilitator's and technical) is to contribute to a better and wider use of this significant resource to help meet the challenge of food security in Sub-Saharan African in a sustainable way.

Although the term 'inland valley' always refers to wetlands, not all wetlands are inland valleys. In particular, the term 'inland valley' excludes coastal depressions, coastal river deltas, lagoons and mangroves; it also excludes inland depressions, such as wide alluvial lowland valleys, interior deltas, lake areas, swamps, and deep-water rice zones.

Inland valleys are characterized by their upstream position in a drainage network. The catchment area captures the water of the whole hydrologic network of an inland valley, from the hillcrest (upland) through the hydromorphic zone (with shallow groundwater table) to the inland-valley bottom.

This manual focuses on integrated rice management in inland-valley lowlands in the lower part of the watershed. Here, during the rainy season, rainfall run-off accumulates and the water table is recharged. Because of these wet conditions, inland valleys are used primarily for water supply and the maintenance of perennial pasture. Rice production makes valuable use of this water resource. The existence of shallow groundwater in some inland valleys also allows arboriculture and vegetable production.

The inland valleys of Sub-Saharan Africa are extremely diverse and complex; therefore, standard recommendations are rendered of little use to farmers. The objective of the *Facilitator's Manual* is to stimulate discussions within farmer communities, and with other actors in agriculture, such as extension agents and fieldworkers. We hope that that manual will help build bridges between local and external knowledge. This *Technical Manual*, forming a set with the *Facilitator's Manual*, offers field agents additional information and baskets of options to improve rice production and to achieve productive, profitable and sustainable rice management. This *Technical Manual* contains technical references on the options that are available to inland-valley farmers. It was developed with the collaborative work of Ivorian farmers who cultivate rice in inland valleys with full water control and partial water control.

The sustainable management of inland valleys involves many factors. It requires a holistic view of the entire watershed and hydrological network. Land use changes in the upland areas (e.g. cutting trees) will affect the inland-valley system and the water-users downstream. For this reason, these manuals represent only a first step. We hope that you who use them will adapt them to your own socio-economic and biophysical conditions. It is highly probable that we will together add modules and references on aspects that are not dealt with here, such as options of diversification, pisciculture, arboriculture and biodiversity. Eventually, our scope should broaden from integrated rice management to integrated natural-resources management, in general, for the inland valleys of Sub-Saharan Africa. We will be very grateful to those who will send their suggestions and comments for future editions.

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The authors

Marco Wopereis, Toon Defoer, Philip Idinoba, Salif Diack, Marie-Josèphe Dugué

Reference 1 Selecting PLAR-IRM sites

Summary

This reference provides guidelines for choosing inland valleys where the participatory learning and action research (PLAR) approach for integrated rice management (IRM) will be implemented. This is a very important step which will largely determine the probability of success and the ease with which results obtained can be diffused.

Each inland valley is a complex entity in which biophysical, agricultural, human, socio-organizational and economic factors interact and influence crop management and the level of intensification and diversification. This includes:

- Size of the catchment area and land use.
- Interest, motivation and capacity of farmers.
- Social organization.
- Land tenure and population pressure.
- Production systems.
- Agronomic characteristics of the inland-valley lowlands (water management, soil type/quality, etc.).
- Accessibility of input and output markets.

The choice of sites is very important, as it determines to a large extent the probability of success and the ease with which results can be diffused. It is important to note that selected sites will become PLAR-IRM Centers in the area. Such centers have an important role to play in the diffusion of results through farmer-to-farmer training (*see* Section 3.2 of the *Facilitator's Manual*).

Major factors to consider in selecting intervention sites are:

- *Size and diversity of the target area*: the number of intervention sites will depend on how diverse the zone is and on how many staff are available to facilitate the PLAR-IRM work. Limit the number of intervention sites at the start to gain experience and to ensure that the approach is properly implemented.
- *Inland-valley typology*: the most important criteria are: degree of water control, social organization, land tenure, production system (rice, rice–rice, rice–vegetables, etc.), the size of the catchment area, its morphology, its agricultural potential, and market accessibility.
- *Representativeness*: a site has to be representative of a large proportion of the inland valleys in the target zone (as based on typology). The site also needs to be reasonably close to other inland valleys with the same or a similar typology to facilitate extension of PLAR-IRM to neighboring villages through farmer-to-farmer training.
- *Accessibility*: the site needs to be easily accessible throughout the year to avoid cancellation of PLAR-IRM sessions because of bad weather, and to facilitate diffusion of PLAR-IRM to neighboring villages.

- *Distance to the site*: it is important to choose sites that are not too far away from where the PLAR-IRM team members are based, as PLAR-IRM sessions are held once every one or two weeks.
- *Prior knowledge of the area*: it is preferable to select sites that are relatively well studied in terms of farmer community and environment.
- *Degree of water control*: water control is a determining factor for inland-valley potential. If there are striking differences in water control, intervention sites should cover such differences.
- *Intensification and diversification*: this aspect is closely linked to water control; in general, good water control increases the levels of intensification and diversification. It is also influenced by market accessibility and by farmers' interest, motivation and capacities. The technical options that will be discussed in the PLAR-IRM sessions will to a large extent depend on the levels of intensification and diversification.
- *Social cohesion*: PLAR demands a strong commitment from participating farmers as they are expected to attend all the PLAR-IRM sessions, which are held every one or two weeks. PLAR is based on collective learning and implementation of collective activities, such as the maintenance of irrigation and drainage infrastructure. Good social cohesion among farmers is, therefore, important. Such cohesion may be lacking, for example, where inland-valley lowlands are jointly exploited by more than one village.
- *Farmer organization*: strong farmer networks will facilitate the spontaneous and autonomous diffusion of PLAR-IRM from farmer to farmer.

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Reference 2 Hydrological network, inland valley catchments and lowlands

Summary

This reference addresses the principles of a hydrological network, inland-valley catchments and lowland areas, and how they are linked. This information is important for water management and inland-valley development planning.

The wetlands in Sub-Saharan Africa include coastal plains (deltas, estuaries and tidal flats), inland basins (comprising extensive drainage depressions), river floodplains (consisting of recent alluvial deposits bordering rivers) and inland valleys. Inland valleys are defined as flat-bottomed, relatively shallow valleys; they are widespread in the undulating landscape. They are known as dambos in eastern and central Africa, as fadamas in northern Nigeria and Chad, bas-fonds or marigots in francophone African countries, and as inland-valley swamps in Sierra Leone (Andriesse, 1986).

Inland valleys are characterized by their upstream position relative to a hydrological network. The edges of the valley are called fringes. The hydromorphic fringe or zone refers to the area close to the valley bottom where the groundwater table is sufficiently shallow to be within reach of crops. The catchment area captures the water of the whole hydrological network of an inland valley, from the crest (upland area, without groundwater-table influence on crop growth) through the hydromorphic zone (with shallow groundwater table) to the inland-valley bottom (usually flooded in the wet season).

To understand how an inland-valley lowland functions, one should not forget that it belongs to a catchment area and a hydrological network. This is important for several reasons.

- The position of the inland valley in a hydrological network has consequences for its sustainable development, ensuring a good integrated management of the watershed.
- The inland-valley lowland is just one part (although a very important one) of the inland valley.
- A good knowledge of the hydrological functioning of the catchment area will help in the management of the inland-valley lowland.

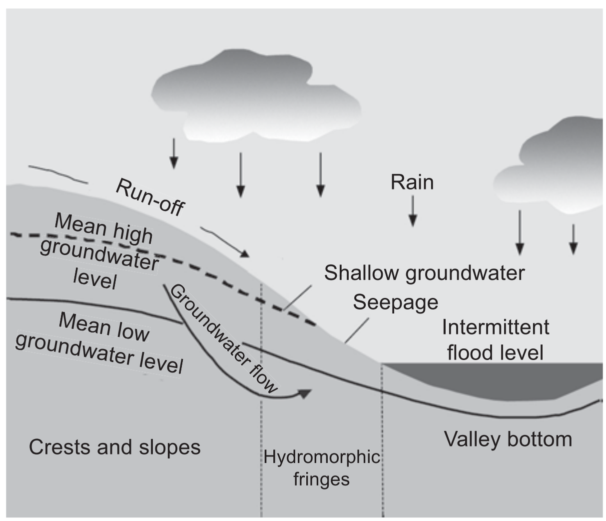


Figure 2.1. Water flows from the crest to the bottom of the inland valley

- The management of the other land units in an inland valley (upland, hydromorphic zone) has direct implications for the sustainable use of the valley bottom.

The following concepts should be defined accurately: hydrological network, catchment and inland-valley lowland.

Hydrological network

'Hydrological network' is a general term used to describe the whole area occupied by several catchments or watersheds linked to each other by a drainage network. A drainage network is composed of several small streams (perennial or seasonal) that flow into a river downstream.

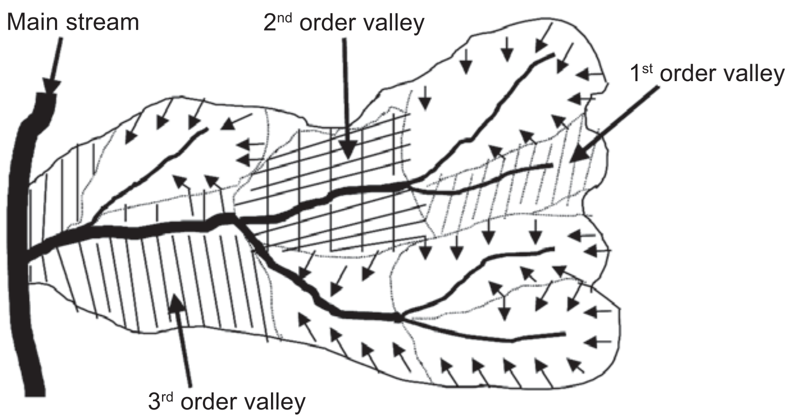


Figure 2.2. First-, second- and third-order inland valleys

A typical hydrological network has many watersheds and wetlands of different sizes, which can be classified into different 'orders'. These orders run generally from one to four, the watersheds of the first order being upstream and the watersheds of the fourth order downstream.

A **first-order inland valley** is located at the beginning of the network, which means that there are no other inland valleys draining into it. These valleys are typically located upstream in the hydrographical network, but they can also be found further downstream if their water flows into a valley of a higher order. Such valleys are generally narrow with concave lowland fringes and a drainage pathway that is not well defined. Valley-bottom soils are often sandy loams.

A **second-order valley** receives water from at least one first-order valley. Second-order valleys are generally situated further downstream than first-order valleys and they are usually somewhat wider. A seasonal stream may be visible in the center of the inland-valley bottom. The slope (or hillside, i.e. distance between the crest and the inland-valley bottom) is longer and more pronounced than those of first-order valleys.

A **third-order valley** receives water from first- and second-order inland valleys. Third-order valleys are situated further downstream and are wider, with longer slopes. The inland-valley soils are deeper and more clayey. Depending on the degree of embranchment of the stream, there may be valleys of the fourth or fifth order.

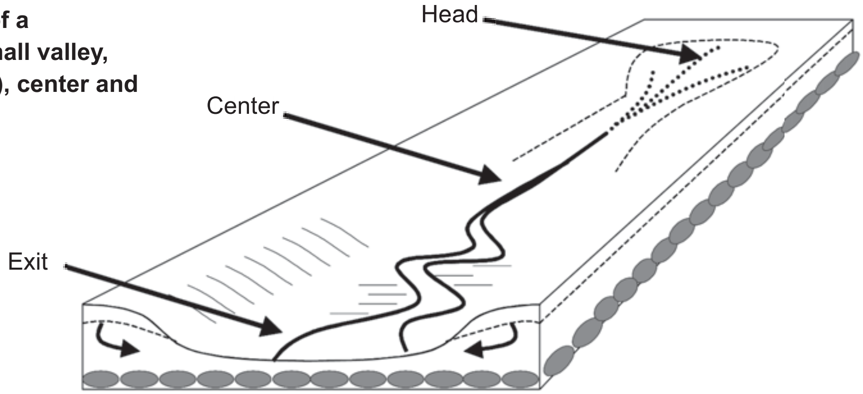
The inland-valley catchment area

The inland-valley catchment area covers the space between the crests and the inland valley, and includes the landscape drained by a smaller valley into the valley in question. Catchments range in size from 100 to 2000 ha, depending on local topography. Their draining canals are oriented transversally to the slopes and longitudinally along the valley or stream. The inland-valley catchment area is the smallest unit of the hydrological network.

The catchment is composed of several elements that are defined by their hydrology and ecology in a continuum from the hillcrest, the slope, down to the bottom of the inland valley. The most important elements of the toposequence of a small valley are the upland area, the hydromorphic fringe and the valley bottom.

- The **upland area** (strictly rainfed zone). This comprises the hillcrest and the higher parts of the inland-valley slopes. This area is characterized by the risk of lack of water. Rainfall is the only water supply for the crops, as the groundwater table does not get near enough to the root zone. Soils are relatively coarse-textured and get wet only during the rainy season. Small stones, gravel, iron concretions or stone blocks can hinder crop management practices such as plowing. Traces of water erosion due to run-off can usually be observed, e.g. sand deposits at the bottom of the slope, or gullies along the slope.
- The **hydromorphic fringe** (groundwater zone). The hydromorphic zone covers the transition between the valley bottom and the upland. Rain and capillary rise of groundwater are the major water sources for the crops grown in this zone. The groundwater table is fed by sub-surface groundwater flow from the slope and from infiltration of surface water. The hydromorphic fringe is often used to grow vegetables.
- The **valley bottom** (fluxial zone). This zone is characterized by water saturation and is often flooded in the wet season. Water is provided by rain, run-off and sub-surface flow from the uplands and fringes, and drainage from inland valleys further upstream. The period of flooding depends on several factors, e.g. frequency and intensity of rainfall, inland-valley shape, types of soil in the watershed, type and density of vegetation in the upland area and hydromorphic fringes. During flooding, one can often observe stains on the water that resemble oil spills—these are due to the presence of high concentrations of iron (Fe) in the floodwater. This may mean that Fe concentrations may be toxic to rice (Reference 4). Sandy patches can be found at the border of the inland-valley lowland because of erosion from the uplands.

Figure 2.3. Representation of a longitudinal transect in a small valley, showing its head (upstream), center and exit (downstream)



Type of inland valleys and valley bottom

Andriesse (1986) distinguishes three types of inland valley:

- Narrow valleys with relatively steep and straight to convex side-slopes, occurring in relatively hard rocks (such as granite and quartz).
- Intermediate valleys with moderately steep, concave side-slopes, in moderately hard rocks (such as schists).
- Wide valleys with gentle, concave side-slopes, in relatively soft formations (such as sedimentary rocks).

Two main types of valley can be recognized on the basis of hydrologic characteristics (Andriesse, 1986):

- Stream-flow valleys in the uppermost parts of the river catchments (low-order valleys). Apart from rainfall, run-off and seepage from the adjacent uplands are the main water sources. These valleys have a poorly defined, more or less centrally located, shallow stream channel, which does not exist in the upper parts. The flat bottoms of the valleys vary in width from about 10 m in the upper portions to about 100 m in the lower stretches. Catchment sizes vary from 2–5 km^2 on granitic formations to 20–50 km^2 on sedimentary rocks.
- River-overflow valleys, downstream of the stream-flow valleys. These valleys have a distinct stream channel that, in general, is located at one side of a small floodplain (up to 200 m wide) in the valley bottom. The main water source is overflow from the river, rather than runoff or seepage.

Soils of the valley lowlands vary widely in their characteristics, both within and between valleys, ranging from sand to clay. In general, however, textures of the soils, as well as their chemical characteristics, reflect the soils of the surrounding uplands and the parent material from which they are derived (Andriesse, 1986). Thus, broadly generalized, coarse infertile soils prevail in valley bottoms of poor and acid rocks (sandstones, granite) and medium to fine, relatively fertile soils are found in valley bottoms of areas with rich parent rocks (such as shales, siltstones, basalts).

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Reference 3 Different types of soil

Summary

Soil is often the most important asset of smallholder farmers in Sub-Saharan Africa. This technical reference presents the different types of soil, their characteristics and the simple indicators for recognizing them.

Soil is crucial for plants and life in general. It supports plant roots and provides essential nutrients for plant growth. The characteristics of the soil often determine the nature of the natural vegetation and the crops that can be cultivated because they will be adapted to the soil and will provide good crop performance. The soil also determines to a large extent what happens with the water in a watershed—water losses, water availability and water quality are determined by the characteristics of the soil. The soil is also at the basis of recycling: as the micro-organisms living in the soil decompose crop residues into organic material. All soils contain four major elements:

- Air (20–30% of volume).
- Soil solution (20–30% of volume).
- Mineral fractions (45% of volume).
- Organic matter (5% of volume).

The porosity (volume of air and of soil solution) allows roots and micro-organisms to breathe and it also stores water. In a very dry soil, all the pores (the small holes and channels between grains and soil particles) are filled with air. In a flooded soil, these pores are saturated with water. In water-saturated soil, the roots of many crops cannot breathe which may lead to plant death. Rice is exceptional, as its roots can breathe within standing water.

The mineral fraction in the soil supports the roots and slowly releases mineral dissolved salts into the soil solution. These salts are the crop nutrients. The mineral fraction matter can be composed of elements of different sizes. We can distinguish:

- Coarse sand and pebbles.
- Fine sand.
- Loam.
- Clay.

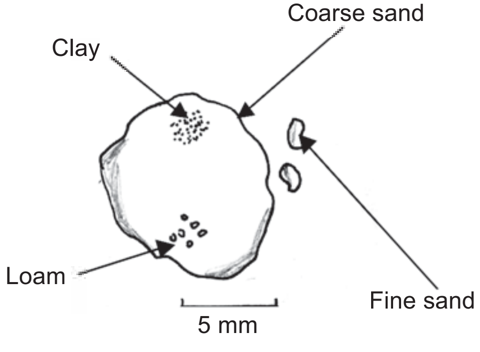

Figure 3.1. Soil texture

Soil contains only a small quantity of organic matter, but that quantity is very important. The organic matter decomposed by micro-organisms releases mineral salts (nutrients) into the soil solution, and also increases the availability of water in the soil. This organic matter, coming from the decomposition of leaves, dead roots and crop residues, accumulates in the upper part of the soil and is dark colored. This is the reason why, when observing the profile of a soil, we can often see different layers: from a black topsoil to lighter colors in the lower layers.

Soil color

The first thing noticed when observing a soil is its color. The soil color is often determined by the color of iron oxides or by the organic matter that covers the surface of the soil particles. The color of organic matter is darker (brown to black) than the color of iron oxides (yellow, red, brown). These colors predominate in topsoil layers, while in the lower layers the colors of iron oxide or manganese oxide (very dark) predominate. Dark topsoil indicates fertile soil. Black soils are generally more fertile than lighter soils because they tend to have a higher organic matter content.

Color changes can provide some indications about the moisture status of the soil, because in dry and aerated conditions the iron oxides have a different color than they do under flooded conditions. The red and brown color of iron in a well-drained and aerated upland soil (high oxygen level) changes to gray, gray-green or blue in a flooded valley-bottom soil (low oxygen level). An intermediate layer (zone) can often be observed, showing variegated colors, including the red and gray of the iron oxides and the black from the manganese oxide. The depth of this layer in the soil indicates the level of the groundwater during the rainy season. These soils are located in the hydromorphic zone of the inland valley. Even in the inland valleys that are flooded throughout the whole year, red coloration can be observed along the roots of aquatic plants such as rice. This is due to the oxygen liberated by the roots when the oxygen content in the soil is low.

Soil texture

The sand, loam and clay contents determine the texture of the soil, which indicates the percentage of coarse and fine particles. A sandy soil contains much sand, a loamy-clayey soil mainly loam and clay.

Soil texture is very important as it determines to a large extent the dynamics of water flow in the soil (Table 3.1). In general, water percolation rates (vertical flow) in sandy soils are much faster than in clayey soils. Together with this percolated water, nutrients flow into lower layers, sometimes out of reach of the plant roots. A sandy soil cannot store much water, but can easily absorb water which is quickly evacuated to the lower parts of the soil. This can be a problem as nutrients can be lost. Sand does not contain a lot of nutrients. A clayey soil can store more water than a sandy soil because the spaces between particles are finer (smaller). Clay is in general fertile, as it easily retains nutrients.

Reference 3

Different types of soil

Table 3.1 Important soil characteristics and their relation to soil texture

Characteristics	Sand	Loam	Clay
Drainage	Fast	Average	Slow
Retention capacity	Low	Average	High
Capacity to stock nutrients	Low	Average	High
Organic matter content	Low	Average	High
Easiness to plow soil in wet conditions	Easy	Average	Difficult
Erosion by run-off	Low (high for fine sand)	High	Low
Wind erosion	Low (high for fine sand)	High	Low

How to observe and determine soil texture

- Take a sample of soil large enough to fill about a quarter of a handful.
- Remove extraneous pieces (roots, seeds, insects, etc.) and any material larger than 2 mm (gravel).
- Add some water to the sample and mix it to form a paste. The soil must be evenly moist without any aggregates.
- First, rub the paste between the thumb and the index and then form a ball or a cylinder, by moving the paste forward from the palm to the fingers and backward to the wrist and vice-versa; this will enable you to determine whether the soil is mostly:
  – *Sandy*: grits can be felt between the fingers and the soil does not stick to the fingers; there is no cohesiveness: the ball breaks easily when it is squeezed between the fingers; a cylinder cannot be formed easily;
  – *Loamy*: the paste partly sticks to the fingers; a ball can be made and it does not break easily when squeezed between the fingers; a cylinder can be formed but cracks appear when it is bent into a U-shape;
  – *Clayey*: the paste is very elastic and sticks to the fingers; it is very easy to roll make it into a ball, to make a hole in it or mold the paste; it is easy to shape a cylinder that does not show cracks when it is bent into a U-shape.

Figure 3.2. Method to determine soil the texture

Soil structure

Soil structure is linked to the organization of primary particles, such as grains of sand, loam and clay in the soil. A good soil structure allows the roots to breathe. In flooded and plowed inland-valley lowlands, the soil often loses its structure and turns into mud. Rice can put up with such a structure because it has channels bringing air from the leaves through the stems down to the roots. In dry conditions, clayey soils show fissures, become compact and form rectangular or hard prismatic blocks. This process hinders root growth as the soil becomes more difficult to penetrate.

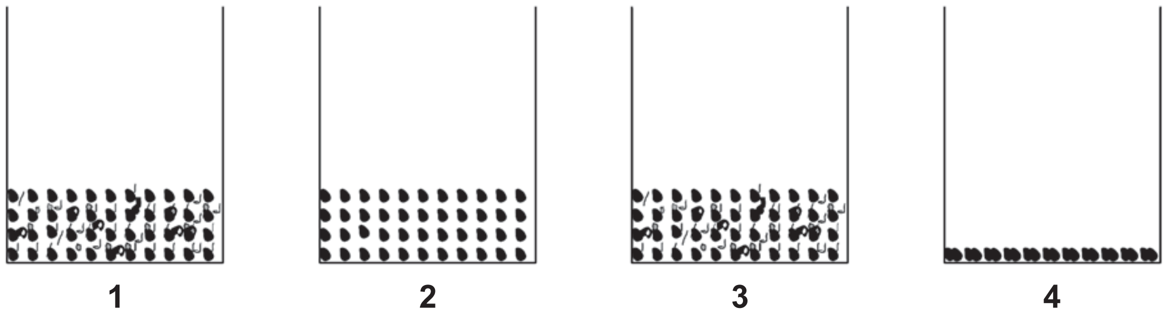

Figure 3.3. Soil aggregates lumps with high organic matter content (1 in dry condition and 3 in moist condition) are more stable than soil aggregates lumps with a low organic matter content (2 in dry condition and 4 in moist condition)

In lighter soils (sandy-loamy), the primary particles are present as in a 'powder,' or in soil aggregates lumps depending on the organic matter content. Organic matter stabilizes soil structure, which is good for the plant. By adding a small quantity of water to a soil with a low organic-matter content, soil aggregates lumps disaggregate into powder. On the contrary, the lumps will not disaggregate in a soil with high organic matter content.

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Reference 4 Iron toxicity

Summary

This reference addresses iron toxicity, a serious problem affecting rice growth in inland-valley lowlands, especially in the moist savanna zone. It is a nutrient disorder associated with high iron concentrations in the soil solution. All types of inland valleys, with or without water control, may be affected by iron toxicity. This reference focuses on recognition and causes of iron toxicity and ways to control it.

Observations

The rice plant

The first symptoms of iron toxicity are small reddish to brownish spots on the older leaves of the rice plant. These spots begin to appear at the leaf tips and spread onto the whole leaf, which becomes bronze–brown and dries out (*see* Photo pages: Photo 4.1). Iron toxicity also results in reduced rice growth (height, tillering) and in increased spikelet sterility. Productivity can drop by between 10 and 100% depending on the iron concentration in the solution and the tolerance of the cultivar. The effects of iron toxicity are more visible during the dry season than during the rainy season.

The soil

Substances that looks like oil spills in the flood water and reddish stains in the soil (*see* Photo pages: Photo 4.2) indicate high concentrations of iron in the soil. Under prolonged flooded conditions, without drainage, this can lead to iron-toxicity symptoms in rice.

Causes of iron toxicity

Most inland valleys in West Africa lack adequate drainage facilities. Stagnant water (resulting from poor water management) creates conditions favorable to iron toxicity. High iron concentrations in the inland-valley bottom are often related to high iron concentrations in the soil itself. Levels may be further increased by iron coming down the slopes, either by surface or sub-surface flow. In the waterlogged soils of the inland-valley bottom, visible red oxidized iron (*see* Photo pages: Photo 4.3) is transformed into an invisible soluble reduced iron, which is toxic to rice.

Iron toxicity control

Several iron-toxicity control options can be proposed. At the watershed level, iron accumulation in the inland-valley lowlands can be reduced by blocking or interrupting the sub-surface flows (through construction of roads, canalization). At the water-management level, improved water circulation helps evacuate excess iron in the irrigation water and brings oxygen into the soil solution. The best way to control iron toxicity at the plot level is to use tolerant rice varieties, such as CK4, Suakoko 8, WITA 1 and WITA 3. In general, fertilizer application decreases the iron absorption of the plant and will help to rectify the nutrient disorder. Adding a small amount of zinc (5–10 kg/ha) can, to a certain extent, be an additional option to mitigate iron-toxicity problems.

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Reference 5 Water control structures for inland-valley lowlands

Summary

The design of a water control system in inland-valley lowlands requires a good understanding of the movement of water in space and time, and requires engineering skills, which are beyond the scope of this manual. However, it is useful to have some basic knowledge of the structures that exist so as to better understand their functioning, development needs and costs, and maintenance requirements. This reference provides an overview of water control systems commonly in use in West Africa and discusses some of the most basic maintenance requirements, such as bund repairs, cleaning of canals and land-leveling.

Installation of water control structures in inland-valley lowlands should allow better water management; depending on the region and the inland valley this means:

- Storing more water on the inland-valley lowland fields (for relatively dry areas).
- Distributing the water over a larger surface.
- Evacuating/draining excess water (in very wet areas).
- Being able to drain excess water, but also to preserve water to extend the growing season (a frequent requirement).

Five water control systems will be presented here: contour bunds, water-retention dikes, diversion barriers, interception canal systems, and small dams. Contour bunds and water-retention dikes store water on the fields upstream of the bunds or dikes. Diversion barriers divert water from the lower parts in the center of the valley towards the borders, in order to allow irrigation of fields downstream of the barrier. Building a dam is an expensive solution (several million FCFA/ha, or about 3000 to 5000 euros/ha), and is, therefore, only an option for relatively large inland valleys, but it is the only system that allows full water control.

Contour bunds

Contour bunds are the simplest and cheapest form of water control. These bunds are small dikes made of soil material, built in the valley bottom and following its contour lines. As valley bottoms are often slightly concave, the bunds will have a parabolic shape. Such a shape allows redistribution from the central part of the valley bottom to the sides. The objective of this water control system is to store water on the rice fields and allow excess water to pass over the bunds. The contour-bund water control system can be divided into two sub-systems: simple contour bunds and contour bunds with a spillway.

The simple contour bund system is shown in Figure 5.1. The 30-cm high earthen bunds store and divide the water over the fields. The slope of the valley bottom defines the distance between bunds. If the slope of the valley bottom is relatively steep, the bunds have to be rather close to each other. Earthen bunds are susceptible to erosion. This means that the amount of water that is allowed to flow through the system, i.e. over the bunds, is limited. This system retains rainfall that falls on the field or comes in from upstream fields, and can store water up to the height of the bund. This very simple system can extend the growing season in some situations by up to 20 or even 50 days. However, it will only perform well if lowland soils have relatively high clay content, i.e. percolation losses are negligible, if the valley bottom has a relatively gentle slope and if water flow is not too strong (otherwise bunds will not resist it).

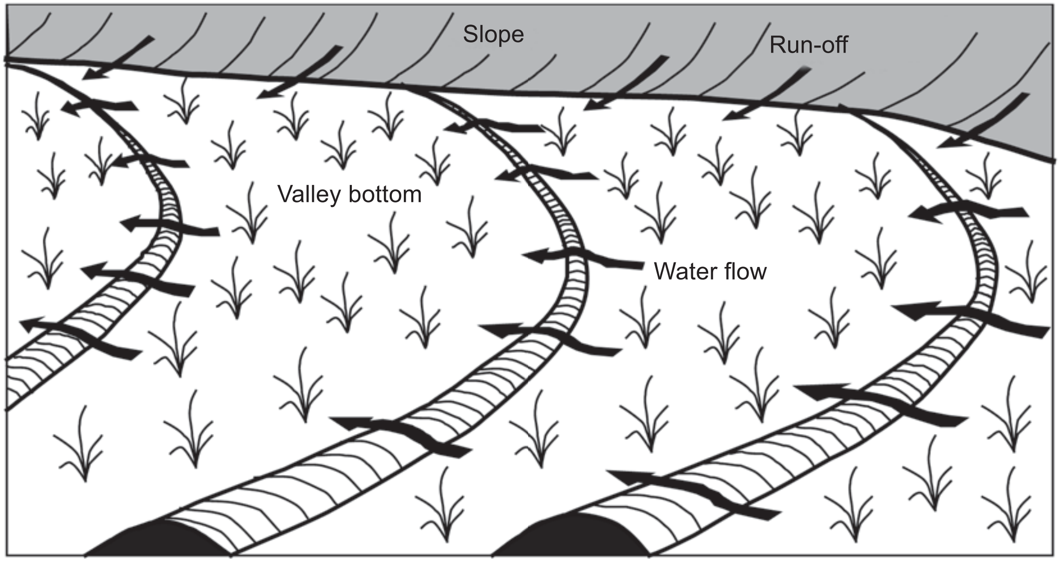


Figure 5.1. Simple contour bunds

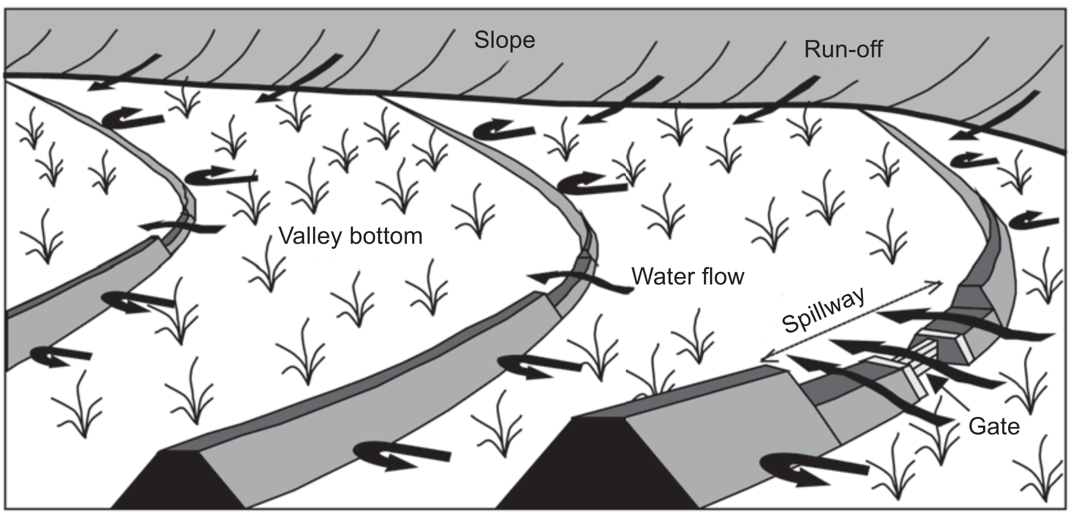


Figure 5.2. Contour bund system with spillway

The contour bund system with spillways is shown in Figure 5.2. The concept of this water control system is the same as the simple contour-bund system, but it is adapted to situations with high water flow through the inland valley. To enable the flow of a greater volume of water through the system, while avoiding erosion of the bunds, the bunds are 50 cm high. Moreover, spillways are installed in the bunds to evacuate excess water. These spillways have to be relatively wide to reduce the risk of erosion. They can be made of soil material, but have to be protected from erosion by (e.g.) plastic sheets. Spillways may also be constructed using sand bags or concrete.

As for the simple contour bunds, slope and soil permeability should not be too high, but the peak flow may be higher. A central drainage canal may be added to the system to facilitate evacuation of water flow.

Water-retention dikes

The principle of water-retention dikes is shown in Figure 5.3. These dikes are bigger and more robust than bunds, because they should be able to resist higher water pressures. The dikes are constructed perpendicularly to the valley bottom. In the dike, a gate is installed to regulate the water level and drain excess water. The water-retention dike dams up the water, and the flooded zone upstream of the dike is used for rice cultivation. Two different water-retention dikes are distinguished: the dikes with and without a seepage barrier.

Water-retention dikes can be introduced in inland-valley lowlands with decennial (once every 10 years) peak flow of less than 130 litres per second (L/s) per meter of valley-bottom width, with low longitudinal slopes, a shallow stream channel (to avoid too much pressure on the dike) and a soil permeability that is not too high (otherwise there would be too much leakage).

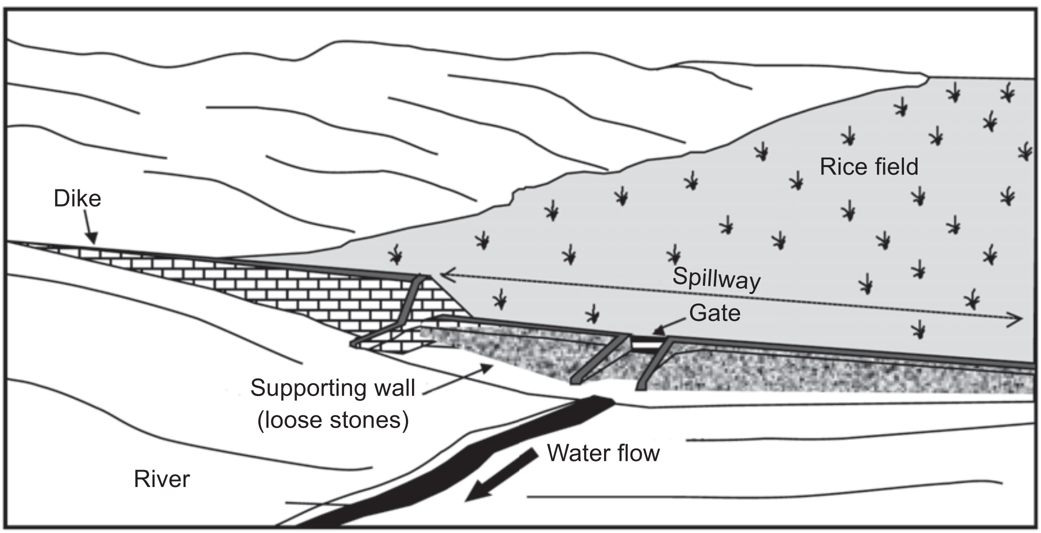


Figure 5.3. Water-retention dike

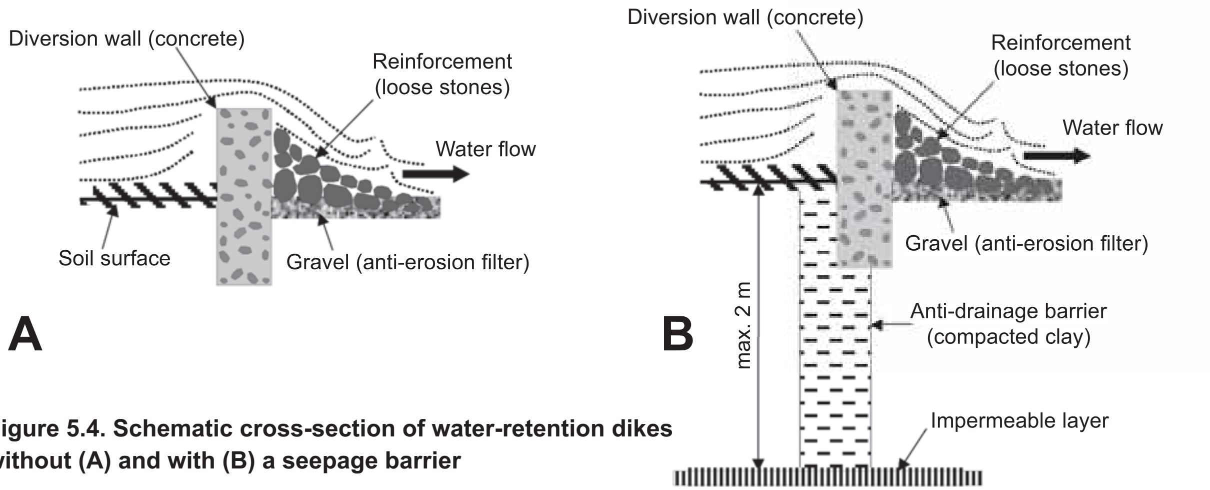


Figure 5.4. Schematic cross-section of water-retention dikes without (A) and with (B) a seepage barrier

If the permeability of the valley-bottom soils is very high, water losses through seepage underneath the retention dike become important and should be avoided. This can be done by constructing an underground seepage barrier by digging a trench and filling this with fine-textured material (Figure 5.4). To avoid seepage losses, the seepage barrier should be constructed on a subsoil layer with low permeability. The costs of seepage-barrier construction will depend on the depth of this impermeable layer. When the permeability of the lowland soils is high, the maximum depth of the impermeable layer should be less than 2 m, to make the construction of the retention dike with a seepage barrier economically profitable. When the impermeable layer is deeper than 2 m, another water management system can be applied (*see* below).

Diversion barriers

This type of water control system can be used in valley bottoms where a well-developed stream channel is present. In this stream channel, a concrete construction is made to dam up the water (Figure 5.5). After being dammed up, the water can be directed into peripheral canals to divert it to the sides of the valley bottom. Because the sides of the valley bottom are often slightly higher than the central part, the water in the canals can be used for surface irrigation of the bunded rice fields by gravity. The original stream canal can then be used for drainage of the rice fields and to drain the excess of water that is not diverted into the irrigation canals by the diversion structure.

This kind of system may be used in valley bottoms that have a longitudinal slope of less than 1% and a decennial peak flow of up to 200 L/s per meter of valley bottom width, and in which the soils have a low permeability. Moreover, this system will only be profitable when the base flow covers the irrigation requirement of the crop for at least one month a year.

The diversion-barrier system is commonly used in Côte d'Ivoire (*prise au fil de l'eau*) and in Guinea. In Benin and Nigeria, the system of irrigation water through diverting water to peripheral canals is

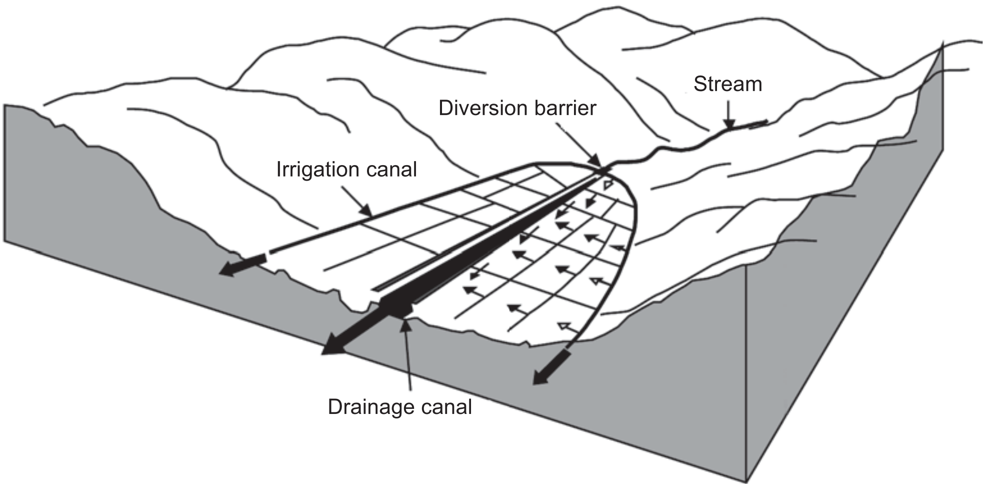


Figure 5.5. Diversion barrier to diffuse flow

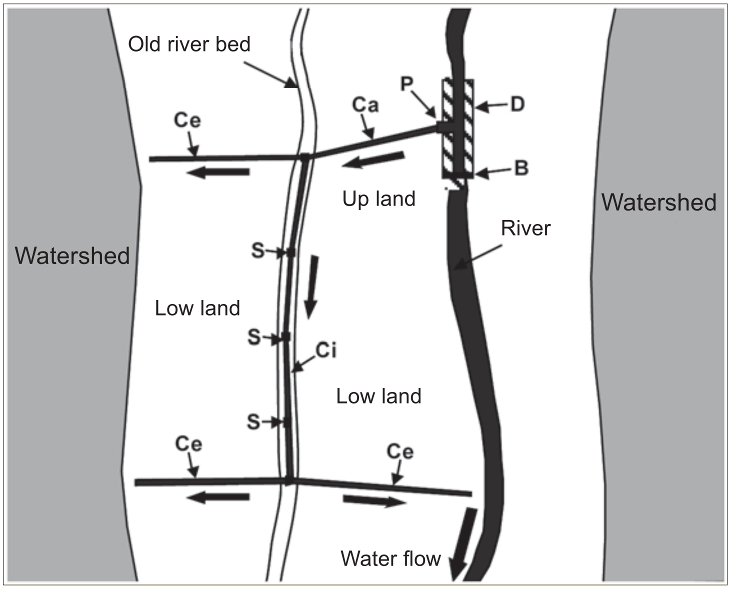
also used. In these last two countries, however, the water is not diverted from the stream canal into the peripheral canals by constructing a diversion barrier in the stream canal. Rather, water-retention dikes are constructed across the valley bottom in which two outlets are constructed through which the water flows directly into the peripheral (irrigation) canals. The main bunds between the rice fields can be constructed along the contour lines or the rice plots may have a rectangular field layout.

When the permeability of the valley bottom soils is rather high, surface irrigation will be difficult because large amounts of water will be lost through seepage. However, a diversion barrier may still be used, but the main objective changes from surface irrigation to recharging the groundwater table. Under such an approach, the groundwater level can be kept at (or near) the surface. The diversion barrier is the same, but will divert the water into canals across the valley bottom (Figure 5.6). From these canals, the water will seep into the soil and the groundwater will rise. Due to the constant flow of water, the groundwater level will remain high and crops will use this groundwater as a supplementary source of water.

For this management system, one additional physical criterion has been formulated. Recharging the groundwater table will be possible if the depth of the natural groundwater table is not too deep. In southern Mali, this system worked when the groundwater was within 2 m of the surface at the beginning of January.

Interception canal system

In very humid areas, it is necessary to increase the drainage of excess water during the main rainy season to avoid damage to the rice crop. This is done by widening and deepening the central drain



B: dam
P: inlet
D: dikes
Ca: supply canal
Ci: primary infiltration canal
Ce: secondary infiltration canal
S: flow regulator

Figure 5.6. Diversion barrier to recharge groundwater

and by constructing peripheral canals along the sides of the valley bottom. The main function of these peripheral canals is to intercept surface run-off and sub-surface groundwater flow from the uplands to the lowlands, decreasing water inflow and thus water excess in the lowland.

Small dam system

One of the most common water management systems not described above is the small dam that creates an artificial lake. The water from the lake will be used to irrigate the downstream parts of the valley. It is possible to cultivate rice (Côte d'Ivoire forest and savanna zones, and Guinea) or other crops during the rainy season (Burkina Faso), or dry-season crops (in several countries). An artificial lake allows the full control of irrigation water. However, this system is not considered to be an option for small inland valleys, because of the high construction costs of the dam and canals.

Maintenance of the development structures

The maintenance of irrigation and drainage structures is very important: water has to circulate easily and regularly—any narrowing of the structures will increase the power of water or block it completely. Blocked irrigation canals may cause flooding upstream and drought problems downstream. In case of floods, blocked drainage canals may not be able to evacuate water following the most direct route, which may lead to severe erosion damage.

Bunds

The main role of bunds is to keep the water in the plots. They also serve as walking paths between the plots. They degrade relatively rapidly because of water force, walking and rat damage. It is important to repair bunds before the start of the growing season.

Canals

Blocked canals full of weeds hinder the circulation of irrigation water. They also serve as pathways for weed seeds to enter the rice fields. Cleaning the canals before the beginning of the campaign is, therefore, very important.

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Reference 6 The seasonal work plan

Summary

Guidelines are given on how to develop a work plan for the coming rice-growing season to facilitate time management and implementation of the cropping calendar.

A prerequisite for a successful growing season is to plan the season well ahead of time. This work plan is a function of:

- Plot area to be cultivated;
- Inputs to apply;
- Labor available;
- Variety to choose;
- Sowing date.

The size of the surface area to cultivate depends, among others, on the availability of:

- Human resources, i.e. family and external labor for the management and maintenance of the plot.
- Financial resources, i.e. estimated costs of external labor, fertilizer and herbicides.
- Material resources, i.e. equipment to prepare the soil, and to harvest, thresh, transport and store the rice.

It is also important to estimate resources needed for maintenance and repairs of the irrigation and drainage infrastructure. Inputs needed during the cropping season, such as mineral fertilizers, are ideally bought and properly stored in an aerated place before the start of the season. Avoid storing fertilizers and phytosanitary products inside the house, and keep them out of reach of children.

The work plan

Development of the work plan aims to facilitate the organization of the growing season and to avoid delays that may affect crop performance.

The work plan is developed around the planned sowing date. Crop management interventions before and after sowing need to be well planned, for example:

- Access to credit—e.g. what is the last date for filing a request for credit, to obtain fertilizer vouchers, consider reimbursement delays.
- Input supply— access to inputs, prices, terms of delivery, conditions of delivery, etc.
- Marketing—market access, prices, purchase conditions, transport conditions, etc.

The work plan can be presented in a table, listing the different operations, dates of implementation with reference to the sowing date and to the development stages of the plant.

Table 6.1 Example of a work plan

No.	Date	Operations	DAT†	Development stage of the plant	Observations
1	10/06	Ordering inputs	–34		
2	23/06	Receiving inputs	–21		
3	24/06	Flooding before first plowing	–20		
4	28/6	First plowing; Installation of the nursery	–16		
5	29/06	Flooding before second plowing	–15		
6	12/07	Harrowing and leveling; Basal fertilizer	–2		
7	14/07	Beginning of transplanting	0		
8	30/07	Herbicide application	16	Start of tillering	
9	01/08	Urea fertilizer 1	18	Start of tillering	
10		Etc.			
11					
12					

† DAT = Days after transplanting (for days before transplanting, use the negative sign).

Reference 7 Field water management

Summary

Each stage of rice development stage has its specific water needs. Not respecting these needs may lead to substantial high yield losses. Therefore adequately managing water at the field level is essential to good yields. Being able to manage water in a rice field depends on the quality of land-leveling, and irrigation and drainage infrastructure. Good water management is based on good leveling and on the possibility to get water into and out of the field according to the plant's needs.This reference gives guidelines on field water management in transplanted rice. The crop-establishment mode usually encountered in inland-valley lowlands presents the optimal water management at field level for transplanted rice plots.

Field water management in transplanted rice plots

The guidelines presented here were originally for designed for irrigated rice cropping, but they can also be used for well-leveled inland-valley lowlands with good irrigation and drainage infrastructure. Substantial yield losses can be expected if these guidelines are not followed or if they cannot be followed because of poor land-leveling or absence of adequate irrigation or drainage facilities. When water management devices and leveling allow good water management. However this calendar can also be used when these conditions cannot be met. The essential point here is to demonstrate that, during the rice cycle, there are some critical stages when rice requires a lot, a little or no water. Taking into account these requirements will help the rice to express its potential. The paddy field should not be submerged throughout the cycle as this would be neither agriculturally nor economically beneficial. More generally:

- rice needs water during the vegetative phase (from germination to panicle initiation, PI).
- rice needs a lot of water during the reproductive phase and during the first half of the maturation phase (from PI to the moment when grain ripening has reached the dough stage; during ripening, the texture of the grains changes from a milky, semi-fluid stage to a hard and solid stage, the intermediate stage is called the dough stage).
- rice needs no water during the last half of the maturity phase (from dough stage to maturity).

Guidelines for good optimal water management in a transplanted rice field: may be summarized as follows :

- Transplant in floodwater with a 5 cm water level.
- Drain immediately after transplanting and leave to dry for two to three days.
- Irrigate, maintaining the floodwater level at about 5 cm until the end of the second or third week (according to the planning for herbicide[1] and fertilizer applications).
- Drain completely prior to herbicide application, then leave to dry for two days.

1. Some herbicides are applied in the floodwater; be sure to follow the manufacturers' recommendations.

- Irrigate again, while maintaining the floodwater level at a strict minimum for 4 to 5 days to allow for fertilizer application.
- Raise the floodwater level up to 5 cm, until panicle initiation (PI).
- Lower the floodwater level to a strict minimum for 4 to 5 days for fertilizer urea application.
- Raise the floodwater level up to 10 cm (4 to 5 days after PI) until dough stage.
- Drain the plot completely and stop irrigating (15 days after flowering).

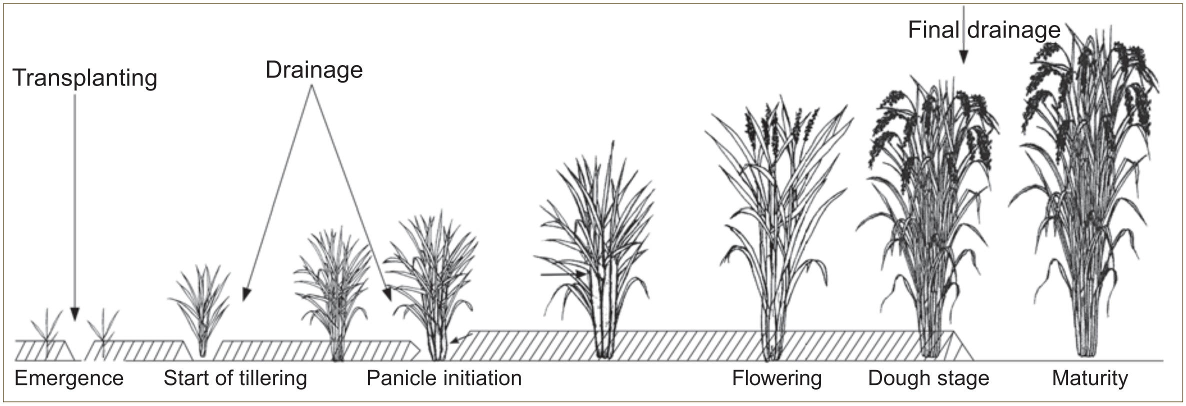

Figure 7.1. Water management in a transplanted rice field

Consequences of inappropriate water management

Too much water during the vegetative phase hinders tillering; too little water leads to thin tufts with few tillers whereas the absence of water during this phase favors weed growth development and may lead to a significant decrease in yield. Urea application should be applied in shallow water (3 to 5 cm) so as to increase its efficiency. A lack of water during the reproductive phase may lead to spikelet grain sterility and a corresponding drop in yield. Fields that are kept flooded beyond the dough stage will mature in a non-homogenous way and harvest will be delayed.

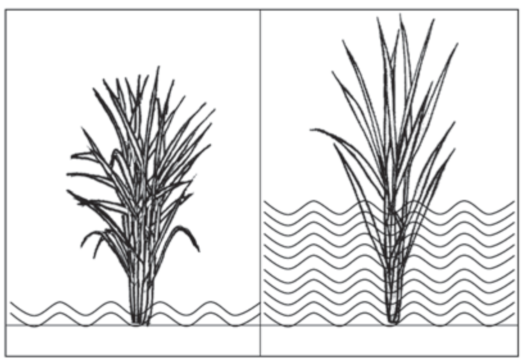

Figure 7.2. Excess water reduces tillering

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Reference 8 Knowing the rice plant

Summary

This reference provides insight into the origin, taxonomy, growth and development of the rice plant. Such knowledge is essential for making the right observations in the field. Such observations are usually the basis for a good analysis of production problems and opportunities, and sound decision-making.

Origin and taxonomy

Rice belongs to the family of Gramineae and the genus *Oryza*. *Oryzae* contains about 20 different species, of which only two are cultivated: *Oryza sativa* L. ('Asian rice') and *Oryza glaberrima* Steud. ('African rice').

The species *O. sativa*, of Asian origin, comprises two main types: *indica* and *japonica*.

The *indica* type from tropical Asia is usually characterized by:

- Long, wide to narrow, light green leaves;
- Profuse tillering;
- Usually long and thin grains; and,
- Several secondary ramifications (small branches in the panicle holding the grains).

The *japonica* type, from temperate and subtropical Asia, is characterized by:

- Thin, light green leaves;
- Medium tillering;
- Short to intermediate size; and,
- Rather short and round grains.

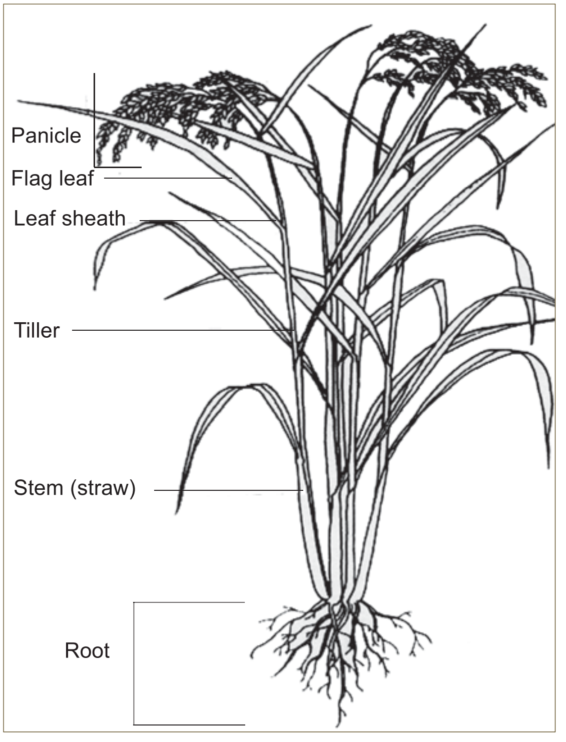


Figure 8.1. Example of an *Oryza sativa* plant type

Oryza glaberrima originates from the inland delta of the Niger River. It is characterized and differentiated by the following characteristics:

- Profuse vegetative development—glabrous leaves and glumes (smooth, hairless), small and round ligules.
- No or few secondary ramifications, red caryopsis (a grain with a red pericarp), long dormancy.

Nowadays, the Asian species (*O. sativa*) is cultivated far more than the African species (*O. glaberrima*), mainly because of its higher yield potential.

Figure 8.2. Comparison of panicles of *Oryza glaberrima* (right) and *O. sativa* (left)

Structure of the plant

- The rice plant has round and hollow stems, flat leaves, and panicles at the top of the plant. Rice is a very flexible/adaptable plant that grows well under both flooded and rainfed conditions.
- The plant comprises vegetative organs: roots, stems, leaves, and reproductive organs; the latter is the panicle made up of spikelets.

Vegetative organs

Roots: The roots anchor the rice plant in the soil and absorb water and nutrients. Like other Gramineae, the root system of rice is relatively shallow, especially under flooded conditions (95% of the roots are found in the top 0.2 m of soil).

Stems: The stem is composed of a series of nodes and internodes. The internodes are hollow, with a smooth surface. The lower internodes are shorter than the upper ones. The shorter the lower internodes, the more resistant the plant will be to lodging. Each node has one leaf and one bud that can develop into a tiller. The stem's main function is to transport water and nutrients and to bring air to the roots. The robustness (linked to their diameter) and height of stems are also criteria affecting resistance to lodging. From the nodes of the main stem, other stems, called secondary

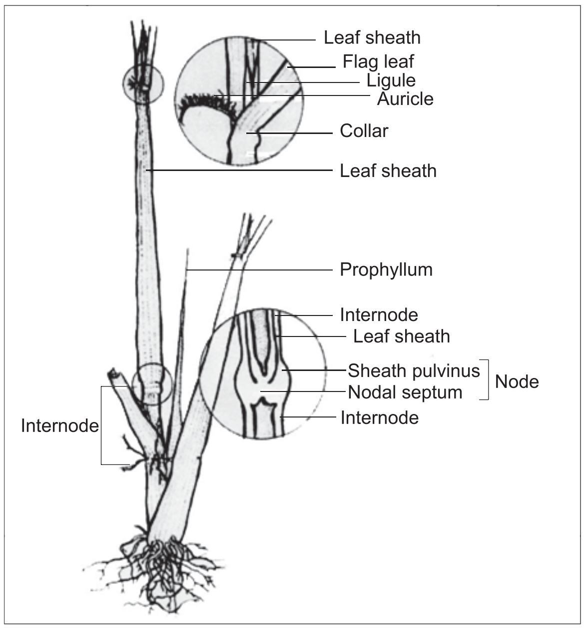


Figure 8.3. Vegetative organs

tillers, grow and can in turn produce tertiary tillers. The group of tillers produced by a single plant constitutes a rice hill. Tillering ability is a function of the variety, but is also influenced by growing conditions and crop management practices.

Leaves: The leaves grow alternately on the stem, with one leaf per node. The last leaf wrapping the panicle is called the panicle leaf or flag leaf. The leaves are the growth engine of the plant, as they capture solar radiation and produce carbohydrates. The plant breathes and perspires (transpires) through its leaves. Leaf architecture may be erect, oblique or drooping; this depends on the variety and is an important factor in the ability to capture solar radiation.

The *sheath* is the leaf part that wraps the leaf. At the junction point between the leaf and the collar, two elements can be found: the auricle and the ligule.

The *auricle* is a 2 to 5 mm appendix, crescent-shaped and covered with hair.

The *ligule* is a membrane whose length and shape depend on species and variety; it is rather long in *O. sativa*, but short and round in *O. glaberrima*. Rice is the only Graminea possessing both ligule and auricle, which allows distinction from weeds at the seedling stage.

Reproductive (flower) organs

Panicles: Panicles form the rice inflorescence. It is the top part of the rice plant, carried on the last inter-node. Panicles are composed of primary ramifications (small branches) that carry secondary branches themselves carrying the pedicels which carry the spikelets. The number of primary and secondary ramifications depends on species and variety. One single panicle can bear between 50 and 500 spikelets; however, in most cultivated varieties, their number reaches 150 to 350. There are variety differences in length, shape and angle of the panicles.

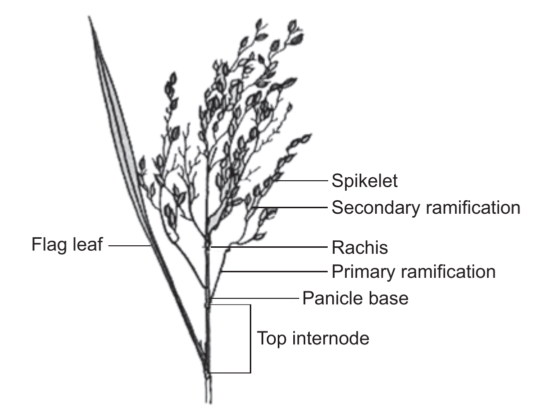


Figure 8.4. Rice panicle (*O. sativa*)

Flowers: The flower is composed of male reproductive organs (the anthers containing pollen) and the female organs (the ovary). Rice is self-fertile (autogamous) as fertilization occurs by the pollen of the same flower; this differs from allogamous plants where fertilization is by the pollen from another flower of the same or different plant, as is the case for maize.

Grain or paddy: The rice grain is composed of three main parts:

- The rice envelope made of glumes (large portions above the pedicels that link the spikelets to the secondary ramifications) and the two husks called palea (upper husk with three veins) and lemma (lower husk with 5 veins). The awns are the prolongation of the ventral vein of the lower husk. The husks, which wrap the rice grain (caryopsis), will constitute the chaff when husking.

- The endosperm will feed the embryo during germination.
- The embryo is situated in the ventral part of the spikelet.

Growth and development stages of rice

The rice life-cycle, whatever the variety and ecology, comes to an end after going through the following ten stages:

Germination (stage 0). The embryo will germinate as soon as it finds sufficient moisture (the equivalent of one-quarter of the grain weight) and a favorable temperature (optimum: 20° to 35°C). Germination marks the start of metabolic activity; emergence is when the coleoptile appears, from which will develop either the first leaf (under aerobic conditions) or the first radicle, i.e. the first root (under anaerobic conditions). The germination stage covers the period from the emergence of either the coleoptile or the radicle to the emergence of the first leaf.

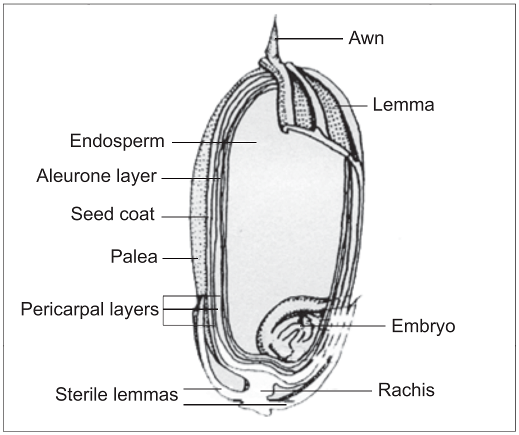


Figure 8.5. Rice grain

Seedling (stage 1). This is the period (about 14 days) that follows germination, during which the young seedling essentially feeds on the food reserve in the endosperm. Leaf production follows a rhythm of one leaf every three to four days. The seedling stage covers the period from the emergence of the first leaf to the emergence of the fifth leaf. During this stage the seedling also produces roots. This stage is critical and the plant is very fragile.

Tillering (stage 2). This is the period during which the seedling produces tillers. This stage starts with the emergence of the fifth leaf. The number of tillers increases until maximum tillering. Thereafter, some tillers degenerate and the number of tillers stabilizes.

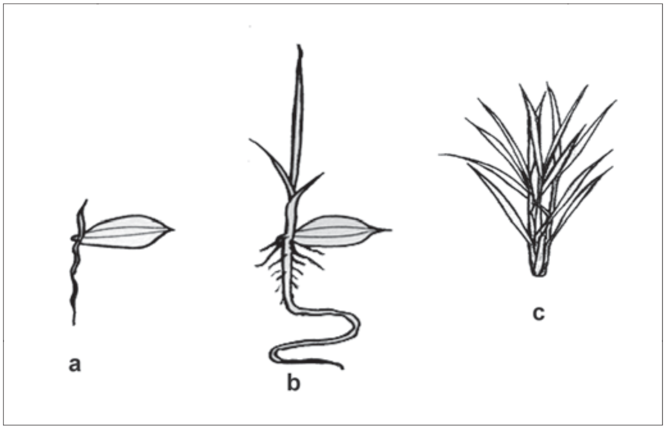


Figure 8.6. Germination (a), emergence (b) and tillering (c)

Internode elongation (stage 3). When the tillering stage comes to its end, the plant's internodes start to grow, leading to an increase in plant height.

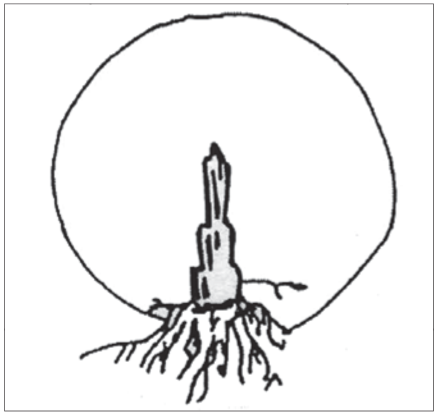
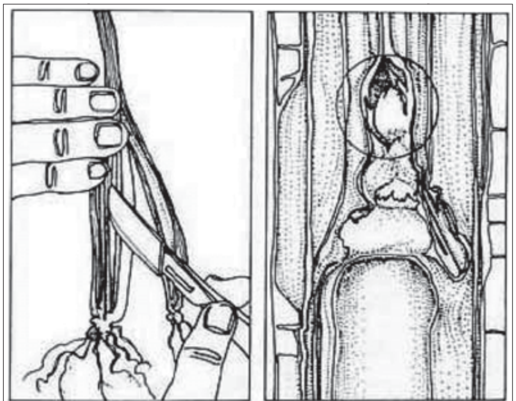


Figure 8.7. Internode elongation

Panicle initiation (PI) (stage 4). This stage is marked by the emergence of the panicle. The young panicle that emerges inside the bottom of the last node, is first a little feathery cone-shaped organ of 1–1.5 mm, which is only visible if the stem is dissected. In fact, the cone becomes visible only about 10 days after it is formed. At this stage, the number of grains in the panicle is already determined. In short-duration varieties, maximum tillering, internode elongation, and panicle initiation occur almost simultaneously. These stages occur in the above-mentioned order in medium- to long-duration varieties. Timing of panicle initiation in rice is influenced by many factors, among which some constants are inherent to variety, temperature and photoperiod (Reference 11). Panicle initiation is the beginning of the reproductive phase.



Exposing the developing panicle by longitudinal sectioning of the main stem

Position of the developing panicle in the main stem

Figure 8.8. Method to determine the moment of panicle initiation

Panicle development (stage 5). This stage is characterized by the swelling of the bottom of the panicle leaf, which is due to the panicle growing upwards inside the stem. After initiation, the panicle grows towards the top of the stem, causing a swelling in the stem called elongation. The organs of the flower develop and the panicle grows on until it reaches its final size before appearing from the flag leaf (heading).

Heading and flowering (stage 6). Heading is characterized by the emergence of the panicle from the bottom of the panicle/flag leaf. The panicle takes two to three weeks to emerge from the stem completely. Three days after heading, flowering occurs and the process goes on progressively until the panicle has completely appeared. Flowering means that the flower opens and that pollination takes place. The opening occurs under the pressure of two transparent structures called lodicules, situated at the bottom and inside the grain, which dilate with warming, at the same time pushing apart the two husks. In rice, this opening usually occurs between 9 and 11 a.m. As soon as the husks are open, the stamens stand up, and because of the outside temperature, the anthers dry out and liberate the pollen grains which then fall on to the stigmas first, then the pollen tube grows down the stigmata to the ovary, where fertilization takes place. Then the two husks come close together.

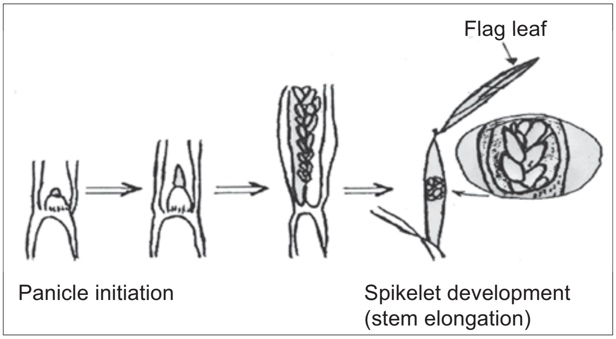


Figure 8.9. Development of the panicle

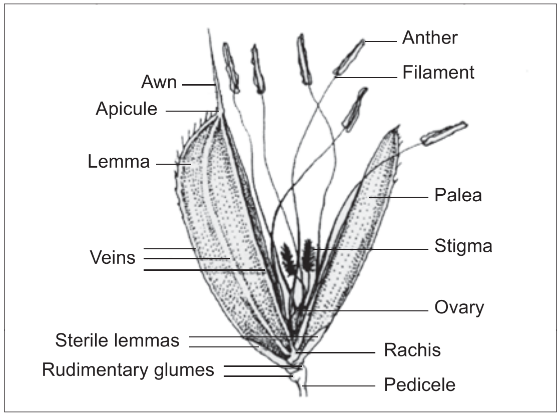


Figure 8.10. Heading and flowering stages

Milky stage (stage 7). After fertilization, the ovary swells and the caryopsis develops until it reaches its maximum size after seven days. The grain (caryopsis) is first aqueous and then reaches a milky consistency, which is perceptible when the grain is squeezed. At this stage, the panicles are still green and erect.

Dough stage (stage 8). The milky part of the grain becomes soft and then reaches a hard paste consistency about two weeks after flowering. The panicle begins to droop while the color of the grains, formerly green, progressively changes into the color that is characteristic of the variety (yellow, black, etc.).

Maturity (stage 9). The grain is ripe when it has reached its final size and maximum weight, giving the panicle its droopy appearance. Grains become hard and develop characteristic colors dependant on variety (yellow, black, etc.). This stage is reached when 85 to 90% of the panicle grains are ripe.

The development phases of the plant

The ten stages of rice development can be grouped in three larger phases:

- ***Vegetative phase*** covers the period from germination to panicle initiation;
- ***Reproductive phase*** covers the period from panicle initiation to flowering; and,
- ***Maturity phase*** covers the period from flowering to complete maturity.

The vegetative phase: During the vegetative phase, the plant goes through the following stages of development: germination–emergence, seedling growth, tillering and internode elongation (according to variety). The duration of the vegetative phase varies according to variety, but it is also influenced by temperatures and the photoperiod (day-length), which may, when the variety is susceptible, lengthen the phase (Reference 11). The relative length of the vegetative phase will determine whether the variety

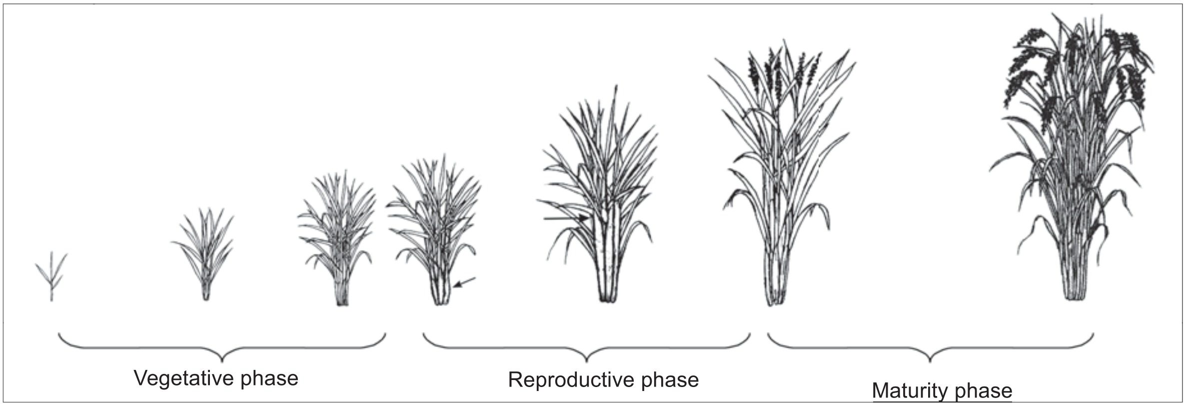


Figure 8.11. The three main phases of rice development

has a short, medium or long growing cycle. Most crop management operations have to take place during the vegetative phase, the most important being weed control (either by weeding or chemical herbicides), fertilizer application, insect and disease control.

The reproductive phase: This phase includes the following stages: panicle initiation, elongation and heading. It is characterized by the emergence of the panicle and by the development of the spikelets and reproductive organs. Its duration is relatively fixed—between 30 and 35 days—whatever the variety or season. The reproductive phase is not affected by photoperiod, but it is very susceptible to low temperatures, drought (water deficiency) and salinity, which can lead to sterility of the reproductive organs, which means the grains will be empty.

The maturity phase: This includes the following stages: flowering, milky and dough stages, and maturity. Its duration is also relatively fixed—about 30 days—whatever the variety or season. It is susceptible to climatic hazards, such as, for instance, high temperatures, violent winds, and drought (water deficiency) during the first 15 days following flowering (until dough stage). Draining the plots or stopping irrigation once the dough stage has been reached will not have negative consequences on production; it will, however, be beneficial to the rice plants as it will homogenize maturation and facilitate harvesting.

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Reference 9 Seed production

Summary

Seed quality is a key factor in rice production. The use of certified seeds is highly recommended. However, rice producers do not always have access to certified seeds. This reference explains how to produce seeds of acceptable quality in a farmer's field, how to determine seed quality and how to store seeds.

Seed quality is crucial to rice productivity. Quality seeds have a germination rate of above 80%, are pure (i.e. all belonging to one rice cultivar and are not mixed with weed seeds), and do not harbor diseases. Producing quality seeds requires far more care and expertise than simply producing rice for consumption purposes.

Certified-seed production by specialized farmers follows strict procedures, involving evaluation of the rice crop in the field by seed experts, and testing of seed quality in a laboratory. This process guarantees a quality product. The use of certified seed is highly recommended.

However, when producers do not have access to certified seeds, they may still be able to obtain seeds of an acceptable quality if they follow the recommendations below, a system referred to as community-based seed system (CBSS).

Recommendations to improve seed quality

Selecting part of the field to be used for seed production

Producing seeds begins a long time before harvest, as at maturity stage it is often too late to distinguish off-types. It is important to select an area of the rice field where the plant stand is healthy and homogenous. Next off-types and weeds need to be removed from this area. At maturity, seeds from this area should be harvested before the rest of the field, and dried and threshed separately.

Drying

When seed has just been harvested, it is still moist and should therefore be dried, since well-dried seed keeps longer, and insect attacks and fungus diseases are reduced. In order to achieve good drying, one should:

- Spread the seed in the open air for a few days; paddy should preferably be dried in the shade.
- Avoid drying seed under a hot sun, as cracks may appear in the seeds.
- Avoid drying on tarred roads, as this may damage the seeds because of the abrupt increases or fluctuations in temperature.
- Move the seeds from time to time to ensure good ventilation.

Threshing

Threshing must be done carefully in order to reduce the risks of damaging the seeds, contaminating them with diseases, or mixing them with other varieties. Therefore, one should:

- Carefully clean the threshing area. It should have a concrete or clay surface. If necessary, the ground should be covered with some tarpaulin, plastic sheeting or textile fabric.
- Thresh each variety separately.
- Winnow immediately after threshing.

If threshing is done with a machine, one should check that the thresher has been carefully cleaned before use. It is also advisable to let the machine run empty for a while to get rid of all the grains stuck inside. When beginning threshing, it is advisable to eliminate the first two or three kilograms to avoid mixing them with the grains that remained stuck inside even after running the machine empty.

Winnowing

Winnowing aims at cleaning the seeds, i.e. getting rid of impurities—straw, vegetation debris, insects and stones. To winnow properly, one should:

- Winnow each variety separately and preferably in a different place from other varieties.
- Keep containers holding the same variety in one place.

Just as for threshing, if winnowing is done with a machine (not frequent in West Africa), one should check that the machine was properly cleaned, let it run empty for a while, and do not use the first two or three kilograms as seed.

Storing

Storage is a critical step in seed management. It may last from a few weeks to several months and therefore deserves particular attention. Several conservation methods are currently in use. Traditional granaries are well-adapted to the farmers' environment and do not require much investment.

Granary storing in the savanna zone:

- Carefully clean the granary.
- Check that all the rice has been properly dried.
- Avoid mixing varieties (preferably store one variety per granary).
- Open the granary from time to time for ventilation. If necessary, use insecticides to remove insect pests. Natural insecticides can be made using local products, such as dried neem leaves, *caïlcedrat* (*Khaya senegalensis*) bark, black pepper, chili, mint (African tea), cinders (ash).

Apart from granaries, other storage means are often used, e.g. baskets, crates, pottery. Seeds can also be stored in bags. In these cases, the precautions to take are as follows:

- Check that the paddy has been properly dried.

- Apply insecticides; natural insecticides (neem or mint leaves) can be quite effective in controlling termites and stem borers.
- Place the bags on pallets (or pieces of wood) to ensure good ventilation.

When using a chemical insecticide, ask the local agent to recommend a product. The most often used products are Actellic 50, malathion and chlorpyriphos. These products must be handled with caution.

Germination test

Before sowing, it is essential to check the germination potential of the seeds, by following the procedure below:

- Spread a wet cloth on a dish.
- Place 100 grains on the cloth.
- Cover the grains with the corners of the cloth.
- Put the dish in the shade.
- Keep the cloth wet, adding water as often as necessary.
- After about a week, unfold the cloth and count the number of grains that germinated and survived:
  – If more than 80 grains germinated, the seeds are good and can be sown;
  – If less than 80 but more than 60 grains germinated, the quantity of seeds per hectare will have to be increased;
  – If less than 60 seeds germinated, do not use them and try to identify another seed source.

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Reference 10 Selecting a variety

Summary

Selecting the right variety depends on what constraints a farmer is facing (e.g. disease or iron-toxicity problems, poor water control) and on specific production objectives, such as home consumption or production for the market. The new WARDA rice varieties (New Rices for Africa, NERICAs), derived from crosses between African rice (*Oryza glaberrima*) and Asian rice (*O. sativa* subsp. *indica*), are expected to play a key role in rice cropping in inland-valley lowlands. Participatory Varietal Selection (PVS) is an effective tool to allow farmers to select varieties that suit their needs.

Selecting a rice variety depends on what specific constraints a farmer is facing, such as disease or iron-toxicity problems, or poor water control, but also on his or her production objectives, i.e. growing rice for home consumption or for sale in the local market. It is strongly recommended that national research systems be consulted to gain knowledge of what varieties have been released for inland-valley lowland conditions and their specific characteristics. The example of Côte d'Ivoire is presented in Table 10.1.

The new WARDA varieties (New Rices for Africa, NERICAs) derived from crosses between African rice (*Oryza glaberrima*) and Asian rice (*O. sativa* subsp. *indica*) have an important role to play in promoting rice cropping in both inland valleys (with and without good water control) and irrigation schemes. These varieties show good competitiveness against weeds, which is very important in such

Table 10.1. Some of the lowland varieties officially released in Côte d'Ivoire

Variety	Ecology	Height (cm)	Growth duration (days)	Characteristics
Bouaké 189	Inland-valley lowland	115	135	High yield
WITA 1	Inland-valley lowland	115	130	Tolerance to iron toxicity; resistant to blast; high yield
WITA 3	Inland-valley lowland	105	125	Tolerance to iron toxicity; resistant to blast; high yield
WITA 7	Inland-valley lowland	115	130	Tolerance to rice yellow mottle virus (RYMV); high yield
WITA 8	Inland-valley lowland	112	125	Tolerance to RYMV; high yield
WITA 9	Irrigated and inland-valley lowland	95	120	Tolerance to RYMV; high yield

environments, especially when rice is direct-seeded (irrigated systems) or where there is poor water control (a common problem in inland-valley lowlands). A range of NERICA lines is available, from which farmers can choose, especially if they are introduced using a Participatory Varietal Selection (PVS) procedure (Wopereis-Pura and Defoer, 2003).

Because of the diversity in soil types and degree of water control, and differences in farmers' objectives, it is crucial to involve farmers in the selection of varieties to ensure that such varieties respond to their needs.

WARDA uses a methodology that ensures farmer participation in varietal selection: Participatory Varietal Selection (PVS). PVS was initiated in Côte d'Ivoire in 1996 and adopted by the WARDA member countries from 1999 onwards. There are two types of PVS: PVS-research (PVS-R) and PVS-extension (PVS-E).

PVS-R is implemented and coordinated by researchers, in close collaboration with the farmers and the extension services. PVS-R leads the farmers to evaluate and select for themselves the varieties specifically adapted to their crop management conditions by using their own selection criteria. PVS-R runs as a three-year cycle. During the first year, 30 to 60 varieties are presented to the farmers in a rice garden. At different development stages, farmers are invited to visit and select the varieties they would like to grow in their own fields; they can then compare the performance of the different varieties according to their own evaluation criteria. During the second year, the farmers receive seeds of the varieties they chose. In the second year, the farmers grow their selected varieties for themselves, next to their traditional varieties. This enables them to determine whether they wish to continue to grow the new varieties. In the third year, the farmers buy the seeds of the varieties they have selected in order to cultivate them a second year in their own fields. PVS-R usually involves 40 to 60 farmers from two to four villages from the same site, representative of a given agro-ecological zone.

PVS-E is a two-year procedure, led and coordinated by extension services, NGOs or farmers' organizations, in close collaboration with the researchers working in PVS-R. PVS-E is designed to validate the PVS-R results with a larger number of farmers working more or less under the same conditions. The three or four varieties most frequently selected by the PVS-R farmers and the 10 main selection criteria identified during PVS-R are validated during PVS-E. This procedure usually involves about 500 farmers from 50 villages surrounding the PVS-R center.

The technical service in charge of proposing varieties for release and the community-based seed system (CBSS) are closely linked to PVS, in order to ensure seed supply for the varieties selected (Table 10.2, *see next page*).

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Table 10.2. PVS-R, PVS-E and CBSS involvement in the seed selection–diffusion

	Introduction	PVS-R	PVS- E	Homologation	CBSS
Year 0	Interesting varieties				
Year 1	➘	Rice garden			
Year 2		Year 1 of farmer tests			
Year 3	➘	Year 2 of farmer tests ➘	3–4 most selected varieties compared with local variety ➔	Year 1 multi-location experiments ➔	Pre-basic seeds (station)
Year 4		➘	3–4 most selected varieties compared with local variety ➔	Year 2 multi-location tests and diffusion ➔	Basic seeds (station)
Year 5					Beginning of CBSS program

Reference 11 Effects of temperature on rice development

Summary

Rice phenology (the succession of rice development stages) depends, among other factors, on air and water temperature and on photoperiod (day-length), and thus changes throughout the year. Phenology is essentially a function of varietal choice and sowing date. A good knowledge of rice development enables one to predict the best timing of crop management interventions. The timing of these interventions—e.g. application of fertilizer, weeding, last drainage before harvesting—is directly linked to rice development. Temperature also directly influences yield: high temperatures at flowering and low temperatures at panicle initiation stage both lead to spikelet sterility and, therefore, yield loss.

The rice plant develops over three phases (Reference 8): (i) the vegetative phase, from germination to panicle initiation; (ii) the reproductive phase, from panicle initiation to flowering; and (iii) the maturation phase, from flowering to maturity. Development rate is not constant, but fluctuates as a function of air and water temperature and of photoperiod (day-length); these factors are especially important during the vegetative phase. Cold during this phase slows down rice development and lengthens growth duration. Rice varieties can be characterized by a *base temperature* below which development stops (T_{base}), an optimal temperature (T_{opt}) at which development rate is the fastest, and above which this rate remains relatively constant, and a *'temperature-sum'* (T_{sum}, expressed in degree-days, °C*d), which represents the total number of thermal units necessary for the plant to reach flowering.

Table 11.1 illustrates this principle, assuming constant daily temperatures. At 10°C, a rice cultivar with a base temperature (T_{base}) of 10°C or lower will not develop and will never reach flowering. At 20°C, a rice cultivar with T_{sum} = 1000°C*d, and T_{base} = 10°C will need a total of 1000/(20–10) = 100 days to reach flowering. At 25°C, development will be faster: it will take only 1000/(25–10) = 66 days to reach flowering. At 30°C, development rate is comparable to the development rate calculated for 25°C, assuming T_{opt} = 25°C. In reality, development rate will start to slow down as temperature increases, especially at very high temperatures. Development rates will also decrease with an increase in day-length beyond 11 hours per day.

Table 11.1. Effect of temperature on the development of a variety of rice (simplified hypothetical example)

Constant temperature (°C)	T_{base} (°C)	T_{opt} (°C)	T_{sum} (°C*days)	No. days to reach flowering
10	10	25	1000	–
20	10	25	1000	100
25	10	25	1000	66
30	10	25	1000	66

Reference 11

Effects of temperature on rice development

Air temperature also has a direct effect on yield. In general, low temperatures at panicle initiation stage may cause spikelet sterility. Minimum air temperatures below 18°C will generally cause sterility. Sterility generally reaches 100% if the minimum air temperature drops below 16°C. Sterility can also occur due to extremely high temperatures during flowering. The percentage of sterile grains increases from 0 to 100% when the mean air temperature increases from 35°C to 45°C.

To illustrate how sowing date and varietal choice may influence yield and growth duration, results of an experiment conducted at WARDA's experimental farm at M'Bé (Côte d'Ivoire), in 2000 and 2001 are presented in Figures 11.1 and 11.2. Five cultivars (Bouaké 189, WITA 9, WITA 3, CK4 and Suakoko 8) were transplanted every month from December 2000 to September 2001, under irrigated conditions and with intensive fertilization.

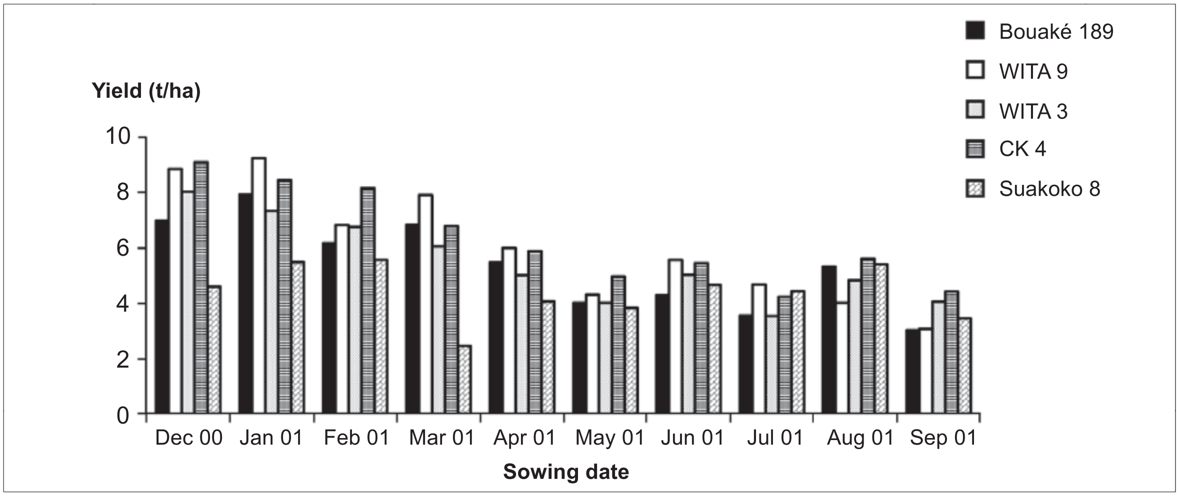

Figure 11.1. Yield variations for five inland-valley rice varieties (Bouaké 189, WITA 9, WITA 3, CK4 and Suakoko 8) as a function of sowing date. 'Rice garden' trials, conducted at WARDA, M'Bé, Côte d'Ivoire, 2000–2001.

Figure 11.1 shows the great variability that can be obtained in terms of yield as a function of sowing date and varietal choice. In this experiment, best yields were obtained in the off-season for varieties WITA 9 and CK4. Sowing in September to November is not advisable as these dates may lead to a decrease in yields because of cold around panicle initiation.

The effect of the sowing date on growth duration divides the five varieties into two groups: Suakoko 8 and CK4 in one group, and WITA 3, WITA 9 and Bouaké 189 in the other. The first two varieties are more susceptible to photoperiod and their development slows down when days become longer. In December and January, harmattan wind and low temperatures influence plant development and lengthen their growth cycle (Figure 11.2).

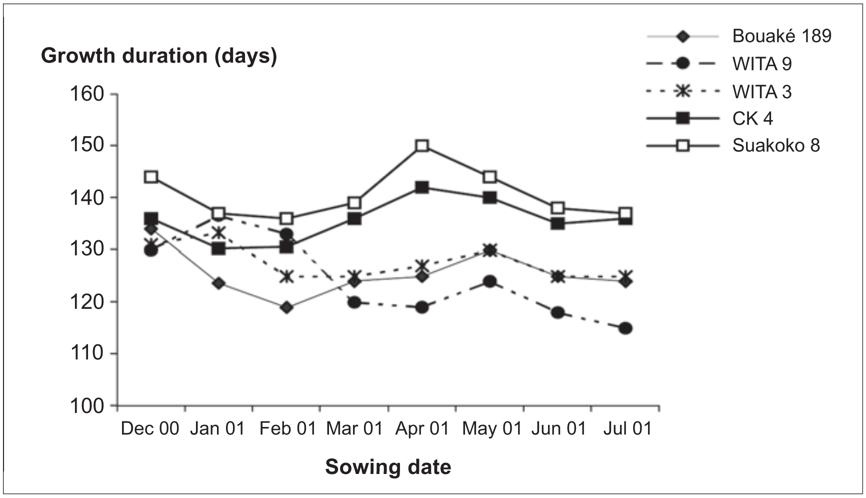

Figure 11.2. Growth duration of five inland-valley rice varieties (Bouaké 189, WITA 9, WITA 3, CK4, Suakoko 8) as a function of sowing date. 'Rice garden' trials, conducted at WARDA, M'Bé, Côte d'Ivoire, 2000–2001.

At the WARDA experimental farm in M'Bé (Côte d'Ivoire), for Bouaké 189, sown in July, the growth cycle reaches about 17 weeks under direct-sowing conditions, and about 18 weeks after transplanting (Figure 11.3; Tables 11.2 and 11.3). The period between panicle initiation and flowering usually covers about one month, as does the period between flowering and maturity. Thus, the Bouaké 189 vegetative phase lasts approximately 10 weeks when transplanted, and 9 weeks when directly sown. The difference is due to transplanting shock. During the off-season, the vegetative phase becomes one to two weeks longer because of the effect of cold on the development of the rice plant.

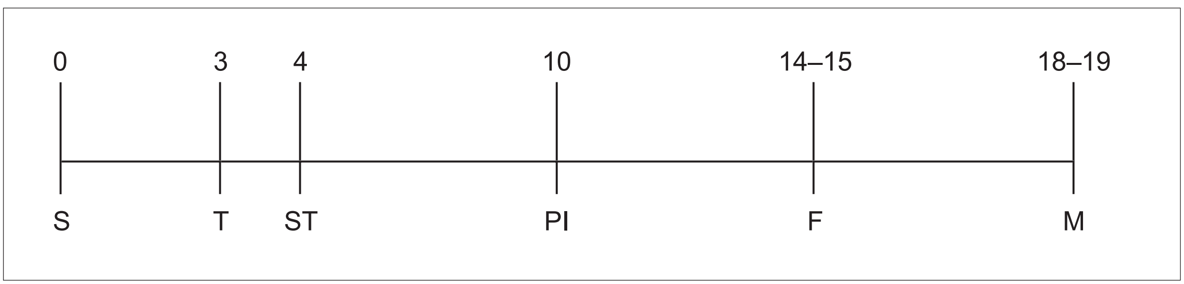

Figure 11.3. Phenology of Bouaké 189 (expressed in number of weeks), when sown in July and transplanted, M'Bé, Côte d'Ivoire. S: sowing; T: transplanting ; ST: start of tillering; PI: panicle initiation; F: flowering; M: maturity.

Table 11.2. Development stages of Bouaké 189, sown in July, M'Bé, Côte d'Ivoire

Development stage	No. days after sowing	No. weeks after sowing
Emergence	3	
Start of tillering	20	3
Mid-tillering	40	6
Panicle initiation	60	9
Elongation	80	11
Heading	85	12
Flowering	90	13
Maturity	120	17

Table 11.3. Development stages of Bouaké 189, transplanted in July, M'Bé, Côte d'Ivoire

Development stage	No. days after sowing	No. weeks after sowing
Emergence	3	
Seedlings transplanted	20	3
Start of tillering	30	4
Mid-tillering	50	7
Panicle initiation	70	10
Elongation	90	13
Heading	95	13–14
Flowering	100	14–15
Maturity	130	18–19

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Reference 12 Field preparation before the start of the rice-growing season

Summary

Rice cropping requires adequate land preparation. Optional operations include land clearing, weeding, pre-irrigation, plowing and harrowing, and leveling. The reasons for each of these operations are discussed in this reference.

The main objective of land preparation is to create a favorable environment for the rice plants to germinate and grow. Adequate land preparation will help to:

- Improve soil structure (better ventilation, permeability, and loosening of the root zone) to make root penetration easier.
- Improve field topography in order to facilitate irrigation and drainage.
- Distribute weeds and crop residues evenly over the field and incorporate them into the soil.
- Obtain good recovery of fertilizer nutrients.
- Control weeds.

The operations

Land preparation may include several operations, which are only options. For instance, in undeveloped inland valleys, the option often chosen is 'zero-tillage': the field is cleared and flooded for one to two months before transplanting without plowing or leveling.

Clearing and weeding the field

Clearing and weeding involves cutting the weeds and stacking them on the bunds, or spreading them out over the field.

Pre-irrigation

Pre-irrigating involves flooding the field for two to three days before the first plowing to moisten the soil and facilitate plowing.

Plowing

Plowing may be done by hand with a traditional hoe, by tractor or with an animal-drawn plow. Some guidelines:

- Depth of plowing should be about 10–15 cm. Superficial plowing will not favor plant development, while plowing too deeply may bury nutrients beyond the reach of rice roots.
- Plowing should ideally be done a few weeks before sowing to allow enough time for the weed and crop residues to decompose.

Flooding

After plowing, the field is flooded for about two to three weeks to kill insects and weeds. Some weed seeds may germinate, but these will be destroyed at the time of the second plowing. In phosphorus-deficient soils, it is advisable to apply a fertilizer containing phosphorus (Reference 15) just before the second plowing. Applying compost or any other source of organic matter may also help fill nutrient deficiencies (Reference 15).

Leveling

Leveling facilitates water management and weed control. Leveling is usually done in two phases:

- A first rough leveling to lower the higher parts of the field, from which soil will be spread out over the lower areas.
- A second more precise leveling after plowing and flooding.

Rakes are usually enough, as the higher parts and lumps move towards the flooded areas thanks to the water level.

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Reference 13 The seedling nursery

Summary

A good seedling nursery produces vigorous seedlings. This reference describes how to install and manage a nursery, from the soaking of the seed to the removing of the seedlings ready for transplanting.

In inland-valley lowlands, water control is usually poor. This is the main reason why rice is mostly transplanted in inland-valley lowlands. Particular care should be given to the installation and management of the seedling nursery. Good management will ensure that seedlings are vigorous, which is essential for their ability to face flooding, insect attacks, weed competition, etc. The different steps for obtaining a good nursery are presented below.

Seed pre-germination

Pre-germination involves two distinct steps, i.e. soaking and incubation. Soaking means that seeds are soaked in a loosely closed cloth or jute bag for 24 hours. Soaking allows the grain to absorb the quantity of water that is necessary to trigger germination. Incubation means that the seeds are withdrawn from the water and kept in a ventilated place, at a temperature close to 30°C, until they germinate, usually after 24 to 36 hours.

Preparation of the nursery

The nursery is prepared like the rice field itself, but with some extra care. Avoid clayey soil to facilitate the removal of seedlings, but the nursery should not be too sandy either, to prevent seedlings from drying out too easily. If clayey soils are used, it is advisable to spread a thin layer of sand (about 1 cm) on the sowing bed (at seedbed preparation) to facilitate the pulling of the seedlings that are ready to be transplanted.

After puddling and leveling the area that will be used for the nursery, 1 m × 10 m seedling beds (about 5 to 10 cm high) are constructed, separated by irrigation canals. Canals surrounding the nursery beds (30–40 cm wide) serve as pathways for transplanters to pull the seedlings, and as a barrier against insect pests.

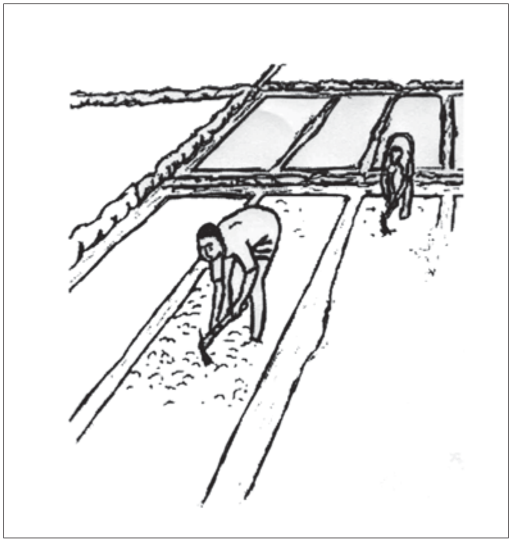

Figure 13.1. Preparation of the nursery's sowing beds

Reference 13

The seedling nursery

Nursery site

The nursery must be installed in an accessible and sunny place, close to the rice fields and the water source, and sheltered from animals, including birds. Avoid installing nurseries in the shade of trees, as this will weaken the seedlings.

Sowing density

In order to obtain vigorous seedlings for transplanting, it is recommended to sow approximately 0.2 kg of seeds per m^2 to reach the appropriate seedling density. A 2500-m^2 field can be transplanted with the seedlings from a 50-m^2 nursery, which is five 10-m^2 beds, which will require 10 kg of seeds.

To obtain a good density at emergence, the following measures are recommended:

- Make sure that good-quality seeds are used (germination test, *see* Reference 9).
- Install the nursery on appropriate soil, well plowed and well leveled.
- When sowing, it is important to throw the grains with force onto the sowing bed to fix them in the mud, thus preventing them from being carried away by the irrigation water.
- Make sure that irrigation is well managed and protect the beds from birds, other animals and other pests.

Seedling age

Seedling age at transplanting depends on the season and on the characteristics of the plot. It is usually recommended that transplanting be done when seedlings are two to three weeks old during the rainy season, because the climate conditions will allow them to develop fast. However, during the dry season, three- to five-week old seedlings are recommended for transplanting, because plant growth will be reduced by cold temperatures. When water control and leveling are relatively poor, which is often the case in undeveloped inland valleys, it is advisable to transplant four- to five-week old seedlings in order to avoid damage by flooding.

Nursery water management

It is essential that the nursery never dries out; however, excess water will lead to weak seedlings that are too tall. Prolonged flooding may cause seedling death. The canals surrounding the sowing beds allow draining of the nursery while maintaining moisture levels. With good water control, the following recommendations may be followed for irrigating a nursery:

- Sow on drained soil. (Bring water back only two or three days later, to give the roots enough time to fix in the soil.)
- Maintain water level at 2 to 3 cm for 10 days.
- Drain the plot for 24 to 48 hours.
- Progressively raise the water level until seedlings are pulled for transplanting (5 cm).

During the dry season, it is advisable to drain the plot in the evening to avoid exposing the young seedlings to low water temperatures during the night. Irrigation is resumed rather late the next morning to let seedlings benefit from the sun. (This is particularly pertinent where night temperatures are low, e.g. in the north of West Africa, especially in the Sahel.)

When the nursery is installed in a place where it is not possible to irrigate, watering-cans can be used. The soil must be kept moist until emergence (i.e. for 3–4 days) and then progressively increase the number of waterings. In general, in such cases, hand-weeding becomes necessary and this should be done approximately 10 days after sowing.

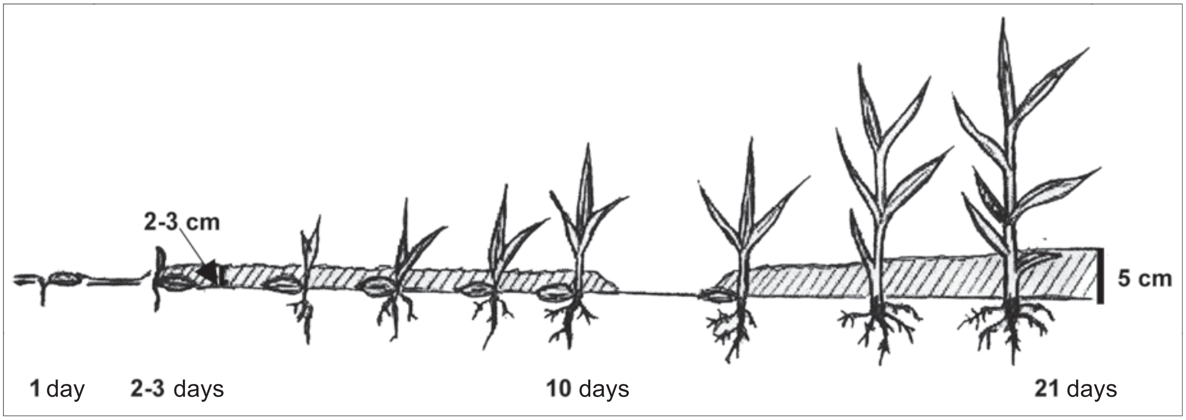

Figure 13.2. Water management in the nursery

Nursery fertilization

In case of poor soil fertility, or during the dry season, when growth is slower, it is recommended that nitrogen be applied—about 10 g of urea per m^2—as top-dressing at about two weeks after sowing.

Pulling seedlings

Pulling rice seedlings is a delicate operation that is too critical to be left to children (which is often the case) or to paid outside labor (always wanting to finish the job quickly). If done without care, roots will be damaged, which may lead to substantial yield loss (‘missing hills’) or the need to re-transplant such missing hills.

Seedlings should be pulled under water and, to avoid damage, the following technique is recommended:

- Hold two or three rice seedlings between thumb and index finger, positioning the index finger almost perpendicular to, and the thumb parallel to the seedlings (Figure 13.3).
- Exert a little pressure downwards before slowly pulling the seedling toward oneself. Be careful to hold the seedlings close to the root.

Reference 13

The seedling nursery

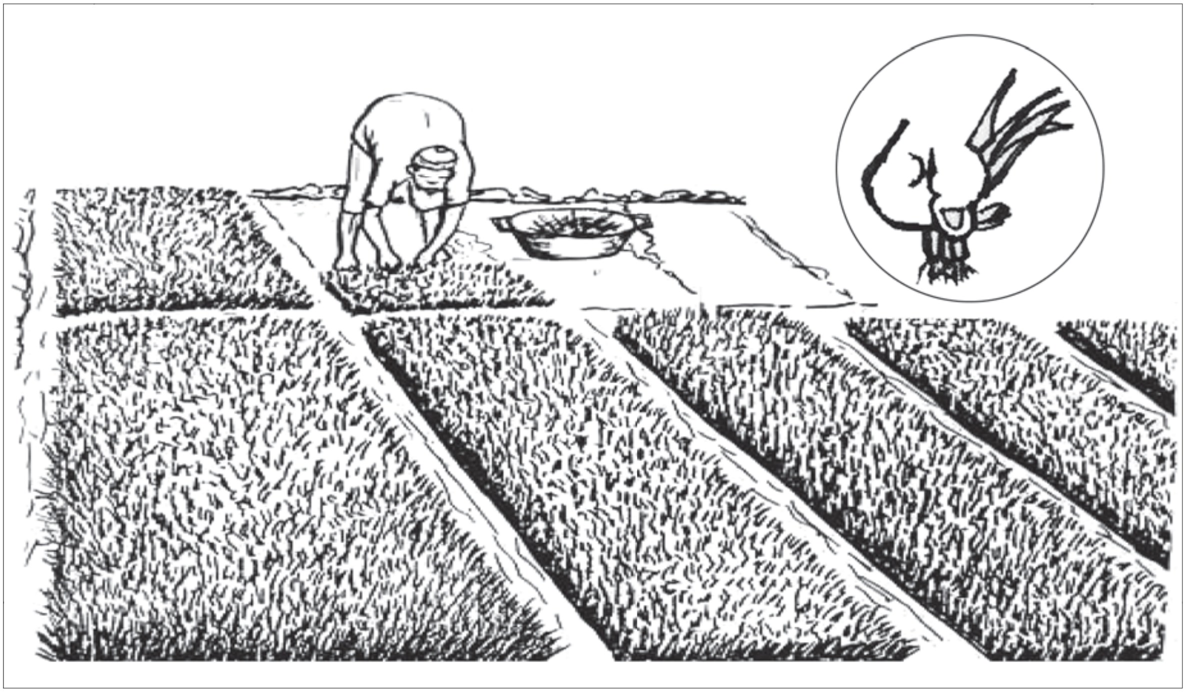

Figure 13.3. Pulling seedlings ready to be transplanted to the main field. (Inset shows how to hold the seedling between the thumb and the index finger)

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Reference 14 Plant nutrients

Summary

This reference is about the importance of nutrients for rice production and the symptoms of nitrogen, phosphorus, potassium and zinc deficiencies. Together with Reference 3, this reference serves as a basis for Reference 15 (integrated soil-fertility management).

Essential nutrients

In order to grow, plants need solar radiation (light), water and nutrients. These nutrients are present in the soil, air, or in water (soil solution). In general, 18 different nutrients are necessary for normal growth and full development.

There are major nutrients (present in at least 0.1% of plant dry matter) and micro-elements (present in less than 0.1% of plant dry matter). The major nutrient coming from the air is carbon (C). Hydrogen (H) comes from water, and oxygen (O) from water and the air. These elements—C, H and O—are transformed by photosynthesis (the engine of plant growth) into carbohydrates for the plant. The major nutrients present in the soil are:

- Nitrogen (N);
- Phosphorus (P);
- Potassium (K);
- Calcium (Ca);
- Magnesium (Mg);
- Sulfur (S).

The essential micronutrients from the soil are: iron (Fe), manganese (Mn), boron (B), zinc (Zn), copper (Cu), chlorine (Cl), cobalt (Co), molybdenum (Mo) and nickel (Ni).

All these elements play an important role in plant growth. We will consider three major nutrients—nitrogen, phosphorus and potassium— and some micronutrients—iron and zinc. In general, the most limiting factor for rice growth in inland valleys is nitrogen, followed by phosphorus and potassium.

Nitrogen

Nitrogen is undoubtedly the most vital nutrient for rice growth. Rice absorbs large quantities of nitrogen to enhance growth, development, yield and grain quality. Nitrogen is present in the soil, but often in insufficient quantities. Rice needs nitrogen almost throughout the vegetative cycle, but in particular at tillering and panicle-initiation stages. Nitrogen accumulates first in the leaves (vegetative phase), then migrates to the panicles and grains (maturity). At maturity, 75% of the nitrogen assimilated is present in the grains. Nitrogen is essential for the normal development of the plant. Nitrogen deficiency induces stunting and a uniform yellowing of the plants (*see* Photo pages: Photo 14.1).

Nitrogen is a very mobile nutrient. Two to three days after an application of N fertilizer, the leaves turn back to green. Excess nitrogen induces high sensitivity to diseases and can lead to lodging.

Because of its high mobility, nitrogen is easily lost to the plant. Leaching due to rain or stagnant water in the plots can transport nitrogen deeper into the soil, out of reach of the roots. Nitrogen can also be transformed into gaseous forms (especially in alkaline soils with high pH) or fixed in the soil (micro-organisms capture N for the decomposition of organic matter).

After a dry period, rains can rapidly start the decomposition of organic matter in the soil. This can cause significant movement of nitrogen from the uplands towards the inland-valley lowlands. This nitrogen flow has been estimated at 80 kg/ha per year, an important loss to the uplands. Crops growing in the hydromorphic zone (e.g. arboriculture, bananas or plantains) or lowland zone (rice) benefit from this flow.

The nitrogen content of the soil can be estimated by observing its surface color, texture and structure. A dark, clayey and well-structured soil with plenty of active soil fauna (especially worms) indicates, in general, good levels of nitrogen.

Phosphorus

Phosphorus is normally applied as basal fertilizer during land preparation (Reference 12). The effect of phosphorus application is not as visible as it is for nitrogen. However, it has been proven that phosphorus plays an important role in the physiological development of the plant. Phosphorus stimulates root development, tillering and pollination, and reduces the period to maturity. Phosphorus stimulates recovery after stress (rodent attack, cold, etc.). Lack of phosphorus can reduce yields. The symptoms of phosphorus deficiency are dark green leaves and reduced tillering (*see* Photo pages: Photo 14.2); plant development is delayed and is very heterogeneous. Most inland-valley soils contain a large quantity of phosphorus.

Phosphorus is not a mobile nutrient and will not be lost easily (as N is) and applying P fertilizer can be a good investment in soil fertility that will bring returns over many years. When organic matter is added to the soil, phosphorus may become more mobile.

Potassium

As for phosphorus, potassium application has no immediate visible effect. However, it coordinates the biochemical activity of nitrogen and phosphorus. Potassium plays an important role in the synthesis, transformation and transport of carbohydrates to the grains. This explains why a lack of potassium induces low grain weight.

Potassium also plays an important role in the resistance to some stresses such as drought, insects and diseases. Indicators for potassium deficiency are dark green leaves with yellowing leaf tips and margins, and small brown spots (*see* Photo pages: Photo 14.3). Symptoms first appear on older leaves and develop from the margins of the leaves towards the center. The color of the old leaves changes from yellow to brown, and the leaf margins and tips dry out. If no potassium is applied, the young leaves will also be affected. Potassium is a mobile element in the soil.

Micro-nutrients

Mineral fertilizers are applied to satisfy the plant's nutrient needs: nitrogen, phosphorus and potassium. In general, soils do not contain these major elements in sufficient quantities that can be easily absorbed by the plant. Micro-nutrients are generally present in higher quantities than the plants need; the most common micro-nutrients are calcium, magnesium, iron and manganese. Lack or excess of micro-nutrients induces physiological disorders, but these are rarely observed except for iron toxicity.

Zinc

Zinc plays an important role in the biochemical processes of the plant; for instance, to produce chlorophyll. Inland-valley or irrigated rice is often confronted with a lack of zinc, in particular on rich, calcareous or limestone soils. The indicators of zinc deficiency are the appearance of brown spots on young leaves two to four weeks after transplanting, resulting in spots of low productivity in the field (*see* Photo pages: Photo 14.4). In severe zinc deficiency, tillering and rice development are hampered. Calcareous or limestone soils with a relative high content of organic matter (>1.5%) are at risk of zinc-deficiency problems. Symptoms are rather similar to those of iron toxicity.

Zinc application

A basal application of 5 to 10 kg Zn/ha, as zinc sulfate or zinc oxide, is often sufficient. Zinc can also be sprayed onto the leaves after transplanting. The roots can also be bathed in a zinc solution before transplanting. If zinc is applied as top-dressing, it should be mixed with sand to get a more homogeneous application.

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Reference 15 Integrated soil fertility management

Summary

Integrated soil fertility management (ISFM) aims at the optimal and sustainable use of soil nutrient reserves, mineral fertilizers and organic amendments. We explain in this reference how to calculate mineral and organic fertilizer needs to obtain target yields as a function of the soil nutrient-supplying capacity (mainly nitrogen, N; phosphorus, P; potassium, K) and taking into account yield potential (determined by cultivar choice, sowing date and climate). Analysis of soil fertility using laboratory procedures is seldom possible in farmers' fields, and the relation between such analyses and rice growth is often poor, especially for nitrogen. This reference offers another method to determine the soil nutrient-supplying capacity. The rice yield from a mini-plot, with good soil-fertility management but without application of one nutrient (for instance, without N, P or K) is considered as an indicator of the capacity of the soil to supply that 'missing nutrient.'

To increase yield by 1 t/ha, nutrient uptake at maturity needs to increase by 15 kg N/ha, 6 kg P_2O_5/ha and 18 kg K_2O/ha. A well-balanced fertilization thus requires an application of 50 kg N/ha, 30 kg P_2O_5/ha and 60 kg K_2O/ha to increase yield by 1 t/ha, based on a recovery rate of applied fertilizer of 30% for N and K and of 20% for P. The recovery rate is the percentage of fertilizer effectively absorbed by the plant as compared to the quantity applied. These relations are approximate and only valid for yields not exceeding 70 to 80% of the potential yield. For higher yield targets, more nutrients have to be applied to get the same return, and this is not usually cost-effective. Nitrogen losses are irreversible, thus it is very important to increase the recovery rate of this nutrient. The recovery rate of nitrogen is strongly related to crop management. This reference provides instructions to help increase this recovery rate. For P and K, losses are much less (P and K are absorbed by the soil), and the residual effect of the fertilizer applied is often visible several years after application. Organic fertilizer can, to a certain extent, replace mineral fertilizers, but large quantities need to be applied as organic fertilizers have a low nutrient content. However, using both mineral fertilizers and organic amendments often has synergistic effects, increasing the soil's nutrient-supplying capacity in the long term and in some cases increasing the recovery rate of mineral fertilizer nutrients.

Soil fertility depends on the soil's origin (alluvial soils, soils derived from different types of parent rock, etc.), its texture, structure and organic-matter content, and the farmer's soil-fertility management in the past. Dark soils usually have high organic-matter content. Red soils, characteristic of a large part of Sub-Saharan Africa, are in general acidic and poor in organic matter.

Soils differ in their capacity to store nutrients available to plants. Clayey soils have a good capacity to store nutrients and to release them gradually to the plant roots, because they are composed of very fine particles. Sandy soils have a very limited capacity to store nutrients. Thus, the application of large quantities of fertilizer to sandy soils is not advised, because significant losses can be expected.

Organic-matter content is also important. A low organic-matter content has a harmful effect on soil structure and increases erosion risks. Soils with high organic-matter content have a higher water-holding capacity and are an important source of nutrients for the plants. Nutrients easily available to plants are localized either in the soil solution, or are adsorbed (concentrated in the topsoil) by the well-decomposed soil organic matter or the available clay particles. The outside surface of this well-decomposed soil organic matter and of available clay particles together form the *exchange complex*. Nutrients adsorbed by this exchange complex form a reserve of nutrients easily available to plants. This stock is gradually recharged by soil nutrient reserves that are less accessible to plants.

An increase in the organic-matter content cannot be reached within one or two cropping seasons, it is a long-term project. Improving soil texture requires large investments and is in practice impossible.

Soil-fertility management is crucial for maintaining or increasing the yields and incomes of the majority of farmers in Sub-Saharan Africa. How they manage that fertility not only determines the yield during the current season, but it can also have a significant impact on future yields.

The soil's nutrient stock can be enriched or depleted through farmers' management practices. For instance, the incorporation of crop residues in the soil and fertilizer application increase nutrients in the soil, while harvesting removes nutrients. This means that there are nutrient cycles in the soil that can be balanced or unbalanced. Without human intervention, these nutrient cycles are generally balanced. But such a situation is exceptional. Human intervention, e.g. introduction of mineral fertilizer or increase of cropping intensity (e.g. two crops per year on the same field instead of one crop) requires changes in soil-fertility management to avoid unbalanced nutrient cycles. Such instability may result in decreasing fertility and lower yields in the long run.

In sub-Saharan Africa, farmers are often obliged to mine their soils: they remove more nutrients than they return. In the uplands, farmers' practice of burning vegetation to facilitate soil preparation for cultivation decreases the carbon ratio in the soil and may result in leaching of significant amounts of other nutrients with the first rains. Farmers are also often obliged to use the same plot for several years without any fertilizer input. With each harvest, nutrients leave the field without being replaced. In order to increase soil fertility, farmers used to leave the plot fallow for some time. Unfortunately, this practice is increasingly being abandoned in Sub-Saharan Africa, where farmers are obliged to intensify their land use, often without compensating for nutrient losses. Without compensation, excessive nutrient exportation from the field may result in an imbalanced nutrition situation in the long term. Lowland soils are in general more robust and fertile than upland soils, but poor soil-fertility management of lowlands may also lead to nutrient-deficiency symptoms in the long term.

It has been estimated that during the last 30 years, an average of 22 kg nitrogen, 2.5 kg phosphorus and 15 kg potassium per hectare has been lost each year on 200 million of hectares of cultivated land in Sub-Saharan Africa (not including South Africa). This negative balance has a depleting effect on soil fertility and results in yield decreases.

Nutrient stocks in the soil

Soil nitrogen reserves are localized in the organic matter. These reserves can be significant, but they are not easily available to plants. Nitrogen becomes available after the mineralization (decomposition) of this organic matter by micro-organisms in the soil. The nitrogen available to plants is either localized in the soil solution, or adsorbed on the clay–organic matter exchange complex (Box 15.1).

Phosphorus reserves are mostly found in organic matter and fixed by aluminum and iron oxides in the soil (Box 15.2).

Potassium reserves are largely dependent on the type of soil and on the minerals present. Clayey soils have large reserves of K. Available K is the sum of the soil-solution K and the K adsorbed by the exchange complex. Sandy soils are poorer in K than clayey soils (Box 15.3).

Box 15.1. How to estimate soil nitrogen reserves

For light-textured soils, 1 liter of soil weighs about 1.5 kg. Clayey soils tend to be heavier: about 1.7 kg/L of dry soil.

The volume of 1 ha of soil with a depth of 0.2 m is:

10,000 m^2 × 0.2 m of depth = 2000 m^3 of soil, i.e.

2000 × 1000 L = 2,000,000 L

This equals 2,000,000 × 1.5 kg of soil = 3,000,000 kg. A soil with a good supply of nitrogen contains about 0.1% nitrogen, i.e. 1 ha will contain about 3,000,000 kg × 0.1/100 = 3000 kg of nitrogen. Out of this, 1500 kg (50%) represents the 'dynamic reserve.' Only about 2% of this dynamic reserve is directly available for plants.

Estimation of nitrogen reserve (N) in the root zone (depth: 0.2 m)

N level in soil	% soil N	Available for crop (kg/ha)	Dynamic reserve (kg/ha)	Inert reserve (kg/ha)
Good level	> 0.1	> 30	> 1500	1500
Low level	0.05 – 0.1	15 – 30	750 – 1500	750 – 1500
Very low level	< 0.05	< 15	< 750	< 750

Box 15.2. How to estimate soil phosphorus reserves in the soil

Assuming we use the same soil as in Box 15.1. If soil analytical data indicate a P-Bray content (a proxy for plant-available P) of about 6 mg/kg, a total of 3,000,000 × 6 = 18,000,000 mg of P is available for the crop per hectare, or 18 kg of P per hectare. Total reserves in the soil are much more important. If soil analytical data indicate a P-total of 800 mg/kg, total reserves are about 2400 kg/ha.

Estimation of phosphorus reserves (P) in the rooting zone (depth: 0.2 m)

P level in soil	P-Bray		P-total	
	Laboratory data (mg/kg)	Available for crop (kg/ha)	Laboratory data (mg/kg)	Total reserves (kg/ha)
Good	> 25	> 75	> 800	> 2400
Average	6 – 25	18 – 75	200 – 800	600 – 2400
Low	3 – 6	9 – 18	100 – 200	300 – 600
Very low	< 3	< 9	< 100	< 300

Box 15.3. How to estimate the availability of potassium in the soil

Assuming we use the same soil as in Box 15.1. If laboratory data indicate a 0.10 cmol/kg of exchangeable K (a proxy for plant-available K) we first have to convert cmol into grams. This is possible using the atomic weight of K (39): 1 mol of K is equivalent to 39 grams, i.e. 1 cmol is equivalent to 0.39 grams of K. A ratio of 0.10 cmol/kg of exchangeable K represents for this soil a quantity of (3,000,000 × 0.1 × 0.39)/1000 = 117 kg of K/ha. The reserves in K are usually much higher, but can be very variable.

Estimation of potassium (K) available (exchangeable K) in the rooting zone (depth: 0.2 m)

K level in soil	Exchangeable K	
	Laboratory data (cmol/kg)	Available for crop (kg/ha)
Good	> 0.25	> 300
Average	0.10 – 0.25	120 – 300
Low	0.05 – 0.10	60 – 120
Very low	< 0.05	< 60

Mineral fertilizers

Nitrogen fertilizers

Two types of nitrogen fertilizer are commonly used in West Africa: urea containing 46% N and ammonium sulfate containing 20–21% N. Complex fertilizers used for phosphorus fertilization (such as di-ammonimum phosphate, containing 18% N and 46% P_2O_5) also sometimes contain N (*see* under phosphate fertilizers). For nitrogen fertilization, urea is the best type of fertilizer to use. It is not advisable to use fertilizer containing nitrate (NO_3) as a source of nitrogen, because nitrate is easily leached to the bottom of the profile, out of reach of the rice roots.

Example: a bag of 50 kg of urea contains 50 × 0.46 = 23 kg N.

Phosphorus fertilizers

Phosphorus can be applied as rock-phosphate or as mineral fertilizer. Phosphorus application has to be supported by N application. Red soils contain significant amounts of iron oxide. These oxides form a complex with P and fix P so that it is not available to the crop. With such soils, farmers will have to use very large quantities of phosphorus fertilizer for some to be available for the plants.

Single super phosphate (containing 18% P_2O_5) and triple super phosphate (TSP) (containing 46% P_2O_5) can be used. However, di-ammonium phosphate (DAP) or 18-46-0, containing 46% P_2O_5, is also available.

Examples: one 50-kg bag of TSP contains 50 × 0.46 = 23 kg P_2O_5, or 23 × [(2 × 31)/{(2 × 31) + (5 × 16)}] = 10 kg of P. (In this calculation, 16 is the atomic weight of O, and 31 the atomic weight of P). A 50-kg bag of DAP contains 50 × 0.18 = 9 kg N and 50 × 0.46 = 23 kg P_2O_5, or 10 kg of P.

Potassium fertilizers

Potassium sulfate and potassium chloride are the potassium fertilizers used in Sub-Saharan Africa. Nowadays, few farmers still use them, particularly when crop residues remain in the field. Potassium is mainly found in compound fertilizers, such as 10-20-20.

Example: a 50-kg bag of 10-20-20 contains 50 × 0.2 = 10 kg of K_2O or 10 × {2.39 / (2.39 + 16)} = 8.3 kg of K. (In this calculation 39 is the atomic weight of K, and 16 is the atomic weight of O.)

Organic amendments

An interesting option is the introduction of legumes into a crop production system. Legumes are often cultivated in rotation with cereals and are incorporated into the soil when they are still green. In the lowlands, this can be done during the dry season following wet-season rice. The advantage of green manure is that it increases the N content, improves the soil structure and increases the organic-matter content. They also often increase P availability in the soil. *Mucuna pruriens* is a rapidly growing legume, it suppresses weeds and can fix up to 60 kg N/ha per year. Other legumes, such as *Sesbania rostrata*, *Sesbania sesban*, *Tephrosia vogelii* and *Crotalaria* spp., have an N-fixing capacity of 10 to 50 kg N/ha. The N content of this green manure is between 2 and 4.3%. The N content of animal manure is extremely variable and mostly depends on the storage method. In general, the N content is rather low and does not exceed 0.5 to 1%.

The incorporation of crop residues will not always increase N availability. This is often the case when these residues, e.g. rice straw, have a poor N content as compared to their C content. The micro-organisms in the soil fix nitrogen to decompose the residues with large C/N ratios, which means that there is less N available for the plants in the short term. Rice straw is, however, an important source of K (straw has a K content of about 1.5%).

Compost is a mixture of partially decomposed plant material, such as weed and rice straw. Nitrogen content of compost is often between 0.3 and 0.9%.

When comparing the N contents of organic and mineral fertilizers, it is evident that large quantities of organic fertilizer are required to apply 30 or 40 kg N/ha. However, applying both mineral fertilizer and organic amendments often results in synergistic effects, increasing soil nutrient-supplying capacity in the long term, and sometimes even the recovery rate of nutrients applied with mineral fertilizers.

Site-specific integrated soil-fertility management

Integrated soil-fertility management aims at the optimal and sustainable use of nutrient stocks from the soil, mineral fertilizers and organic amendments. A procedure is given below for calculating fertilizer needs to reach target yields as a function of the soil nutrient-supplying capacity and potential yield.

Three steps are necessary:

- Fix a target yield.
- Estimate the capacity of the soil to supply N, P and K.
- Calculate fertilizer requirements.

Fixing a yield target

The potential or maximum yield of a crop (Y_{max}) is determined by the climate (minimum and maximum temperatures and solar radiation), sowing date and the characteristics of the variety chosen by the producer. For a given sowing date, Y_{max} is not constant but fluctuates from year to year because of climatic variability. It is evident that the producer cannot change the weather, but he/she can choose a sowing date that will allow him or her to exploit the weather conditions more productively and to choose a variety adapted to these conditions. Y_{max} can be obtained on experimental plots conducted under optimal growing conditions, where plant growth and development are not limited by factors other than solar radiation and temperature. Y_{max} is the real yield ceiling, limited by climate, sowing date and varietal choice. In practice, this yield cannot be reached in farmers' fields, and it would also not be cost-effective to try to do so. From an economical point of view, the maximum attainable yield,

Y_a is situated in the range of 70 to 80% of Y_{max}. The actual average farmer yield (Y_f) is often much lower because of a range of constraints that interfere with the rice crop, i.e. growth-limiting factors, such as lack of water and nutrient deficiencies, and growth-reducing factors, such as weed pressure, diseases and pests. With optimal management, best farmer yields (Y_{bf}) can be considerably higher than Y_f. Yield gaps between Y_{max}, Y_a , Y_{bf} and Y_f can be very important.

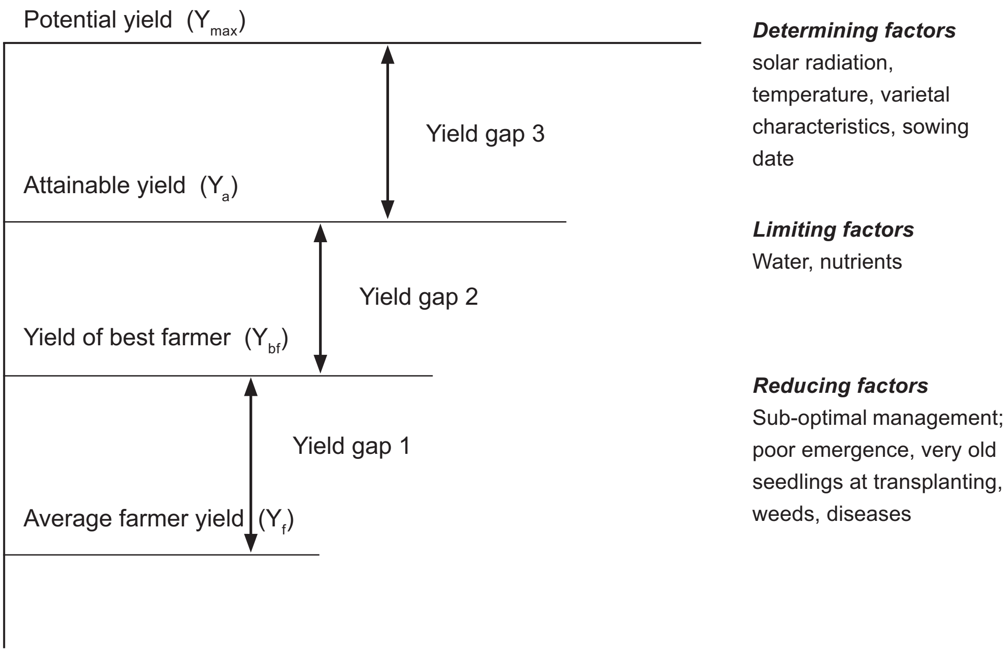

Figure 15.1. Yield gaps between average yield (Y_f) in farmers' fields, the yield of the best farmer (Y_{bf}), attainable yield (Y_a) and potential yield (Y_{max})

Farmers often achieve far less than Y_{max}. It is, however, important to choose a realistic target yield. Yield increases of 0.5 or 1 t/ha compared to previously obtained yields are often possible in farmers' fields. The target yield should not be higher than the attainable yield of 70 to 80% of the potential yield. This is very important as the response of rice to nutrients is not linear from this point onwards, i.e. larger and larger fertilizer quantities are required to obtain the same increase in yield. Targeting high yields is often neither economical nor realistic, especially when water management is not optimal (in such cases, the application of large quantities of fertilizer becomes too risky).

Estimate the capacity of the soil to supply N, P and K

The soil's capacity to supply N, P and K nutrients can be estimated through chemical soil analysis, as indicated in Boxes 15.1 to 15.3. However, the relationship between these analytical data and crop growth is often poor, especially for N. A more direct method is to determine the soil nutrient-supplying capacity through small, well-managed plots in farmers' fields that receive adequate quantities of fertilizer nutrients to reach the target yield, minus one nutrient (for instance, without N, P or K). The yield obtained in these plots is considered an indicator of the soil capacity to supply this 'missing nutrient'. The principle of these small zero-N, zero-P and zero-K plots is explained in Table 15.1.

Figure 15.2 gives an example of the results obtained for these zero-nutrient plots. For the yield target, the soil nutrient-supplying capacity is limiting in the order of N > P > K. For the yield obtained, soil K-supplying capacity is not a limiting factor but N and P are limiting factors, in the order of N > P.

Table 15.1. The principle of zero-N, zero-P and zero-K plots

Mini-plots	N	P	K
Plot 0-N, +P, +K	0	+	+
Plot 0-P, +N, +K	+	0	+
Plot 0-K, +N, +P	+	+	0
Plot +N, +P, +K	+	+	+

0- = nutrient is not applied, it is the 'missing nutrient'; + = nutrient is applied sufficiently so as not to limit crop growth (the exact amount will depend on the growth conditions, one may refer to recommendations currently used by extension staff, or to what is done by the best farmer).

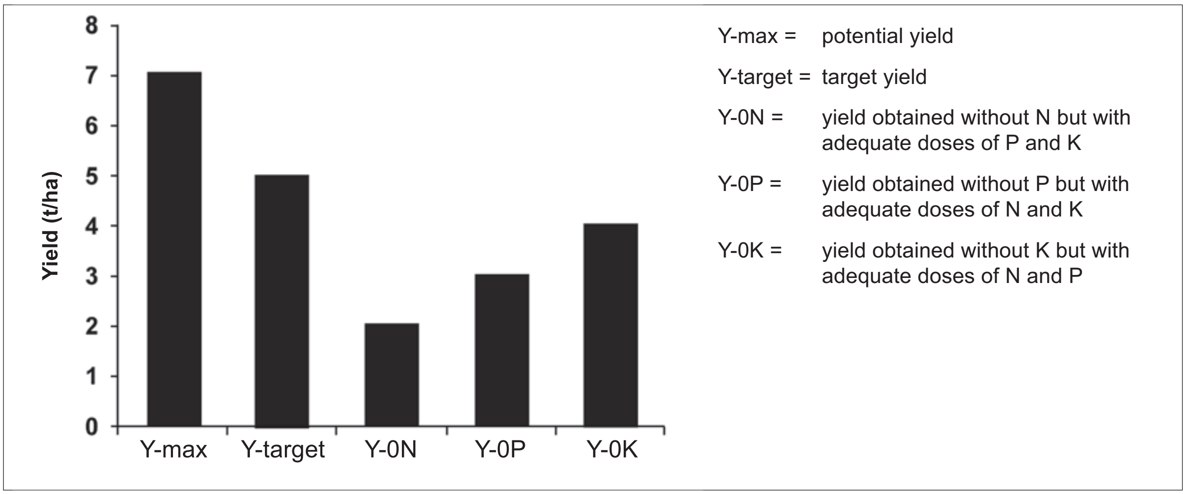

Figure 15.2. Example of yields obtained in zero-nutrient plots, potential yield and target yield

Calculating fertilizer requirements

Nitrogen, P and K rates for rice straw and rice grains are indicated in Table 15.2. Nutrients leave the plot at harvest with the rice grains. Straw is often burned or incorporated into the soil. Using straw has little effect on the soil capacity to supply P or N, but it increases K supply. If the straw is not returned to the field, significant quantities of K are lost to the system.

Table 15.2. N, P and K concentrations in rice grains and straw (%)

	N	P_2O_5	K_2O
Grain	1.0	0.4	0.3
Straw	0.5	0.2	1.5

Field research in Asia and West Africa has shown that for a yield increase of 1 t/ha and balanced N, P and K nutrition, rice consumes:

- 15 kg N/ha.
- 6 kg P_2O_5/ha.
- 18 kg K_2O/ha.

Nitrogen

The recovery rate of N in a farmer's field is on average about 30%. This means that about 70% of N-fertilizer is lost because of many constraints, such as late urea application, weed pressure and seedlings that are too old at transplanting. To obtain a balanced consumption of 15 kg N/ha for a yield increase of 1 t/ha, one has to apply 50 kg N/ha, thus a little more than two bags of urea per hectare. Better field management can increase the recovery rate and diminish fertilizer losses (*see* Box 15.4). In the example of Figure 15.2, the yield of the 0-N plot is 2 t/ha. To obtain the target yield of 5 t/ha, one should apply 150 kg N/ha.

It is better not to apply more than 50 kg N/ha at one time. The best times for N application in rice cropping are at the start of tillering (once rice seedlings have recovered from transplanting shock), at panicle initiation and at heading.

For smaller quantities, it is advised to make two applications of 50% each at the start of tillering and at panicle initiation. For larger quantities, it is advised to apply in three splits: at the start of tillering (40%), at panicle initiation (40%) and at heading (20%). Avoid applying fertilizer in deep water (> 5 cm) or in weed-infested plots.

Box 15.4. Increasing the recovery rate of nitrogen

A number of good crop management practices help limit losses of N applied with mineral fertilizers:

- Using good-quality seed (Reference 9).
- Transplanting seedlings at the right age (References 13 and 16).
- Using a plant spacing that is adequate for the variety used, usually 0.2 × 0.2 m.
- Removing weeds before fertilizer application.
- Using pest and disease control.
- Harvesting on time, at maturity.
- Applying N when the crop most needs it: at tillering, panicle initiation and, if required, at heading; for small N doses, apply at tillering and panicle initiation.
- Using N in two splits of 50% each, at the start of tillering and at panicle initiation, or in three splits of 40%, 40% and 20%, respectively, at the start of tillering, at panicle initiation and at heading.
- Using a good application method:
  - Lower the water level to a strict minimum (about 3 cm);
  - Broadcast in a homogeneous way (without incorporation);
  - Prevent field from drying out immediately after application;
  - Irrigate again 4 to 5 days later.

To maximize fertilizer uptake by crops, fertilizer should be applied in a homogeneous way, when needed, after weeding and after reducing the plot water-level. Never use fertilizer when the sky is threatening, during rain or immediately after rain. If these crop management practices are followed, N losses can be minimized and the N-recovery rate by the crop will increase.

Phosphorus

The recovery rate of phosphorus is on average about 20%. Nevertheless, the phosphorus not absorbed by the crop remains available for the next year. In the first year, for a yield increase of 1 t/ha, about 30 kg P_2O_5/ha will be required. Figure 15.2 shows that the yield of the 0-P plot is 3 t/ha. The target yield of 5 t/ha can be obtained with an application of 60 kg P_2O_5/ha. Phosphorus application is preferably done basally. If not, it should be applied very early to stimulate tillering.

Potassium

The recovery rate of K is on average about 30%. As for phosphorus, the potassium not absorbed during the campaign is (normally) available the next year. To cover the K requirement in the first year, to obtain a yield increase of 1 t/ha, one should apply 60 kg K_2O/ha. The example of Figure 15.2 indicates that the yield of the 0-K plot is 4 t/ha. To reach the target yield of 5 t/ha, an application of 60 kg K_2O/ha is required.

Potassium can be applied as basal fertilizer or as top-dressing. Small quantities of K can be used at transplanting or as basal fertilizer. It is advisable to apply larger quantities (> 50 kg K_2O/ha) as basal fertilizer (50%) and at panicle initiation (50%).

Avoid soil nutrient mining!

The small zero-N, zero-P and zero-K plots are good soil-fertility indicators. It is advisable to use them each year, but not in the same spot. Good management of these mini-plots is essential to ensure that the yields obtained actually express the capacity of the soil to supply the 'missing nutrient.' These well-managed mini-plots can become a means of evaluating the evolution of soil fertility in farmers' fields over time.

Careful! Even if the yields of the small zero-nutrient plots do not indicate the need to apply fertilizer, it is possible that a maintenance application is necessary to prevent soil fertility from being mined over time. Table 15.2 could help estimate the requirements for a maintenance application. For instance, considering Figure 15.2, a target yield of 4 instead of 5 t/ha does not require K application. However, the soil loses a considerable quantity of K, especially when straw is exported from the plot. A grain yield of 4 t/ha is usually equivalent to a straw yield of 4 t/ha. Which means that, with each harvest, the soil loses (Table 15.2) (4000 × 0.015) + (4000 × 0.003) = 72 kg K_2O/ha.

Combining organic amendments and mineral fertilizers is often the best strategy for maintaining or even increasing soil fertility.

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Reference 16 Transplanting

Summary

Water control in inland-valley rice cropping is often relatively poor, resulting in problems with flooding or weeds. These are the main reasons why farmers mostly transplant, rather than direct-seed rice in inland valleys. This reference will provide guidelines to consider when transplanting rice seedlings.

The main crop-establishment method for rice in inland valleys is transplanting rather than direct-seeding. This is because transplanted seedlings can, to some extent, resist the effects of flooding, a common problem in inland-valley lowlands that are often poorly leveled and without adequate water control structures. Transplanting rice also gives the crop a considerable advantage over weeds. Weed infestation is, therefore, generally much lower in transplanted plots compared to direct-seeded plots. Transplanting also helps save water and seeds, and facilitates weeding and other crop management interventions as compared to broadcast direct-seeding.

However, the growth duration of transplanted rice is somewhat longer than that of direct-seeded rice because of the stress induced by transplantation ('transplanting shock'). Another very important drawback is the considerable amount of labor that is required to transplant: approximately 30 to 40 person-days per hectare.

When a young seedling is transplanted too deep, the bottom node cannot produce tillers as it is deprived of oxygen. Before producing tillers, the seedling has in that case to develop a second node, a little higher on the stem, resulting in loss of tillering capacity. However, when seedlings are transplanted too superficially (i.e. at too shallow a depth), they may be easily uprooted by incoming floodwater. The ideal transplanting depth is about 3 cm.

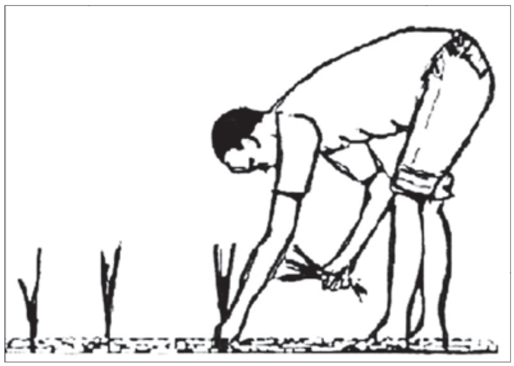
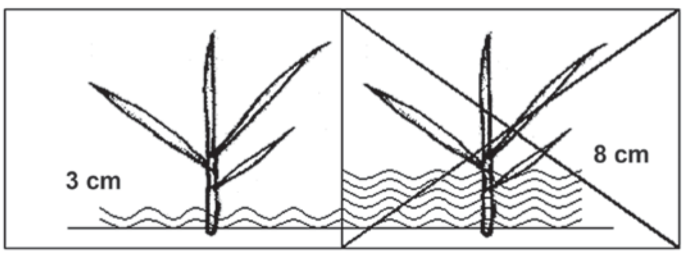


Figure 16.1. Transplanting

Figure 16.2. Transplanting depth should be about 3 cm to favor tillering from the bottom node



Reference 16

Transplanting

Transplanting mode and density

Transplanting density and tillering during the vegetative phase determine to a large extent the number of panicles that are formed per unit surface area during the reproductive stage. A crucial indicator is the canopy cover that has been obtained at panicle initiation, as this is the start of the reproductive phase. A good transplanting density will produce a closed canopy cover that will optimize the use of solar radiation, water and fertilizer nutrients. A density that is too low will not result in closed canopy cover at panicle initiation and solar radiation will, therefore, not be optimally used (light is hitting the soil or the water surface instead of rice leaves). Moreover, weeds will take the place of the rice plant and will start competing for light, water and nutrients. Conversely, a density that is too high will lead to competition between seedlings and a reduction in tillering. The transplanting density to choose depends on the tillering capacity of the rice cultivar used. Most varieties produce the best yields at transplanting densities of between 15 cm × 15 cm and 20 cm × 20 cm.

Transplanting along a line

This involves transplanting along a string with the transplanting interval clearly marked on the string. This takes a bit of organization but time lost may be mostly gained at a later stage, because this method allows the use of a rotary hoe for weeding. Moreover, moving inside the field will be easy, thus facilitating all other crop management interventions that require entering the field. Transplanting density will be uniform.

Random transplanting

Random transplanting is the method commonly used in farmers' fields. This is a much faster method than transplanting using a line or other device, and it does not require synchronizing work as for line transplanting. However, weeding using a rotary hoe will be impossible and, in general, moving around in the field without damaging the plants becomes very difficult. Transplanting density will not be uniform.

Replacement of missing hills

Seedlings that are pulled from the nursery may be damaged to such an extent that they do not survive after transplanting. To ensure that planting density is not affected, missing hills should be replaced as soon as possible, preferably within two weeks after transplanting.

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Reference 17 Farmers' experimentation

Summary

This reference presents six important steps to promote farmer experimentation: (*i*) meeting for consensus-building and planning, (*ii*) lay-out of the experiment, (*iii*) monitoring of the experiment, (*iv*) field visits, (*v*) managing and analyzing the data, and (*vi*) evaluation.

The experimentation phase can be split into six steps, in the context of participatory learning and action research (PLAR) (Table 17.1). It should be noted that farmer experimentation is designed only for a group of test-farmers within the group of farmers following the PLAR for integrated rice management (IRM) curriculum.

STEP 1: Consensus-building and planning meeting

This section describes how to design and monitor experiments with test-farmers in an action-research context. The facilitator guides the discussion to help farmers define clearly the objectives of the experiment or test and what they hope to learn from it. Farmers are encouraged to outline the objectives as hypotheses, which will help them design the experiment and specify the information to be collected. They also discuss how they want to try out the new methods, which will involve describing the new practices, and how they will fit into existing management strategies. The discussions cover the following issues:

- How to implement the new practice.
- Which current practice the new method should be compared with.
- The number of treatments (different new practices).
- How and where to lay out the experiment, etc.

The PLAR-IRM team then outlines how to design an experiment. It is necessary to follow certain guidelines and use a systematic approach so that the results of the experiments can be analyzed and used. A checklist is given below.

- The choice of treatments to be compared: the range of choices is determined by the hypotheses of the experiment and is guided by the number of factors to be compared and the levels for each factor.
- It is necessary to include the farmers' practices as 'control' treatment.
- Specify the niche (and adequate conditions needed) to apply the new practices in the farmers' current management strategy: this will raise questions about the location of the test-site and the site itself—the sites should be representative.

Reference 17

Farmers' experimentation

Table 17.1 Six steps to promote farmers' experimentation

Description	Objectives	Expected outputs
Step 1 **Planning meeting**	• Assist farmers in defining objectives and designing, monitoring and evaluating experiments • To agree on procedures for experimental designs and for monitoring the experiments	• Objectives and hypotheses of experiments are clearly defined • Experiments designed • An agreed procedure for the lay out and monitoring of the experiments, including the roles and responsibilities of the PLAR-IRM team and test-farmers
Step 2 **Lay-out of the experiment**	• To train the farmers how to lay out experiments • To allow farmers to implement the experiment on their own • To agree on procedures for experimental designs and for monitoring the experiments	• Test-farmers trained to lay out experiments themselves • Facilitators and farmers agree on procedure for monitoring experiments
Step 3 **Monitoring of the experiment**	• To see how the experiment performs • To assess the farmers' opinions about the experiments • To collect the information needed to interpret and judge the experiment's performance	• General data about the experiment's performance • Farmers' opinions and preferences and their reasons for them • Data to enable analysis of the experiment's performance
Step 4 **Field visits**	• To encourage participating farmers to exchanging their experiences • To share information among test- and non-test-farmers (within and between villages)	• All test-farmers to be well-informed about new techniques • Non-test farmers informed about the experiments conducted • Information exchanged between farmers and PLAR-IRM team
Step 5 **Managing and analyzing data**	• To enter and process data • To analyze data • To organize results in tables, figures, etc. • To summarize results, so that farmers can easily understand them	• Data processed on computer spreadsheets • Data analyzed • Results accessible for farmers
Step 6 **Evaluation: discussing results with farmers**	• To present the results of data analysis • To gather what farmers think about the results • To identify suggestions for follow-up	• All farmers informed about the results of data analysis • Farmers' comments on results • List of suggested follow-up activities

- The arrangement of the treatments, how they will be laid out in the field: the arrangement has to be as simple as possible and the different treatments will be preferably lined up and separated by narrow walkways.
- The plot size: the plot has to be large enough to include all treatments including the borders and walkways.
- The replications between farms: avoid replications in the same plot or on the same farm.
- Non-experimental variables should be kept in mind.

Depending on how the farmers view experimentation, some aspects will receive more attention than others. The experimentation will allow farmers and the PLAR-IRM team to:

- Compare the results obtained by different test-farmers, thereby increasing the farmers' learning capacity and knowledge.
- Draw conclusions about the effectiveness of the techniques and practices tested (involving statistical analysis).
- Convince other farmers to start similar experiments.
- Convince partners (other researchers, extension workers and policy-makers) of the validity of farmers' experimentation.

The farmers should then discuss the monitoring and evaluation of the experiment, and the indicators (criteria) used to assess its results. These may include agronomic criteria, such as crop development, yield, height of plants; socio-economic criteria, such as labor demand, input costs and cash income; or both.

The farmers should also consider the following issues: what external inputs are needed? What are the requirements for labor or other farm resources? What kind of knowledge does the new practice require? What are the benefits of the new technology in terms of increased yield, economic or other advantages? What is the risk involved?

The farmers must then discuss how to collect information; what they will observe and measure; the usefulness of a notebook or recording sheets to keep records of what happens in the field and what management practices they apply.

The PLAR-IRM team should make complementary suggestions as to what to monitor, how to monitor, and how to evaluate the findings. It is important to establish a clear link between the objectives of the experiment and the data required to assess whether it has achieved the desired results. Monitoring their experiments will show the farmers how various factors influence the results. Monitoring will also help explain the different results obtained by different farmers, and should also improve how future activities will be planned.

The PLAR-IRM team might have additional objectives, particularly when farmers' experiments are part of their own research activities. In this case, other monitoring–evaluation sheets have to be developed in order to collect the additional information:

- Information related to the new practice or technology being tested. This information will be based on the farmers' criteria for success, such as plant growth, leaf color, crop development or yield.
- Data related to factors that are likely to influence the technology's performance, which include (1) environmental variables such as soil types, climate and pest infestation, and (2) management practices such as land preparation and fertilizer application.
- Socio-economic data that might influence whether farmers adopt the new practices: input costs, produce prices, farmers' access to resources (farm size, labor, etc.) and to markets.
- It is very important to know, and to assess, what farmers think of the new practice or technique being tested and to understand the reasons for its adoption or rejection.

The PLAR-IRM team needs to be careful not to overload the farmers with a lot of data collection, particularly when these data are not of great importance to the farmers. The exchange of views between farmers and the PLAR-IRM team should lead to a consensus on how to lay out and monitor the experiment, and to an agreement about the roles and responsibilities of the test-farmers and the PLAR-IRM team.

STEP 2: Lay-out of the experiment

The demonstration of the lay-out of the experiment is a kind of training session given on a farm. Participants are shown in a practical way how to lay out an experiment. Although the overall design of the experiment has been agreed upon during the design and planning meeting (see Step 1), it may have to be adapted to the prevailing conditions, which implies that the training session should review site selection, experimental plot size, border effects, marking out plots, etc.

The training session often starts with a short explanation of the underlying principles of the lay-out followed, by the lay-out itself being implemented by the participants and a member of the PLAR-IRM team. In principle, the demonstration only covers the specific treatments, although the practical fieldwork often actually includes activities that do not directly relate to the treatments. As a rule, farmers generally follow their own practices for these activities.

STEP 3: Monitoring the experiment

Monitoring is an integral part of the experimentation phase since it provides information that is needed in order to learn from the experiment. To a large extent, the type of information and data to be collected are determined by the objectives (see Step 1).

We can generally group the type of information that needs to be collected into four categories:

- Data related to the performance of the new practice or technology (also called farmers' indicators of success): observations.
- Data related to factors that may affect how the experiment performs: environmental factors and management practices.
- Socio-economic data that might influence the adoption or non-adoption of the new techniques.
- Information on what farmers think about the new technology (their perception).

If illiteracy is widespread among the participants, they should use forms and symbols to assess the technologies. In our experience, farmers are keen to record the information linked to the lay-out and management of the experiments. They are also able to evaluate crop performance in terms of plant growth and color, pest damage and crop yields. However, the information collected by farmers tends to be qualitative and is often only recorded on an irregular basis, depending on the farmer's curiosity and available time. Although most of the monitoring is done by farmers, there is still plenty for the PLAR-IRM team to do. They should visit the experimental sites regularly and encourage farmers to monitor their experiments by observing and recording what they see.

If the farmers' experiments are part of a wider research program, the PLAR-IRM team will also have to record data and should visit each site regularly, noting their observations on a pre-established monitoring form. This form should be designed on the basis of discussions about monitoring held at the experiment-design meeting (see Step 1). The type of data recorded will not only depend on the experiment's objectives, but also on the PLAR-IRM team's interests and agenda. They may focus on estimating quantitative data related to factors that influence how the new techniques perform, such as farmers' access to credit and control over resources (water, land) or their use of inputs. The team may also want to record quantitative information on yields using yield sampling.

The PLAR-IRM team should note what farmers think of the new test practices and, for experiments that consist of several different treatments, they can compare and rank treatments. This kind of exercise is usually done twice for crop-related experiments, once during the vegetative stage and once after harvest. Comparing pairs of treatments is a very useful way of determining farmers' preferences. Experiments are monitored not only on the individual test-farmer plots, but also at farmers' meetings during which participants discuss the advantages and disadvantages of the newly tested practices.

STEP 4: Field visits

The information gained from the experiments should not be restricted to the test-farmers. During the observation modules, the experiments will be visited by all the PLAR-IRM participants.

STEP 5: Managing and analyzing data

Once collected, the data must be entered, analyzed and presented in a user-friendly way for farmers and be easy to manipulate. It should be managed in a way that will facilitate communication between farmers and the PLAR-IRM team. All participants should agree on how the data should be handled and managed. The PLAR-IRM team should refer to group field observations and to farmer meetings to better understand results obtained by test-farmers and discuss with them the practices that have been tested.

All the information collected in the course of the experiment is summarized on a monitoring sheet designed for each specific experiment. Additional information may also be needed on labor inputs, fertilizer prices, etc. The information collected can be entered into a computer and processed into data spreadsheets. There are various software packages available for organizing and analyzing data, but we recommend that the analysis be kept fairly simple, so that it remains meaningful for farmers.

However, the PLAR-IRM team may have their own research objectives that require a more refined analysis. The initial analysis consists of calculating mean values for all the criteria identified by farmers as representing ‘successful’ performance, e.g. yield. Different tools can then be used to generate a more specific set of analyses, such as adaptability analyses and cost–benefit analyses.

We mainly use more qualitative analytical tools to analyze the results of farmers’ experiments, giving priority to the evaluation criteria proposed by the farmers. The information obtained from ranking and paired comparisons is particularly useful for this. The next step is to compare the results of the analysis with observations made by the PLAR-IRM team and the farmers’ comments on the different tests.

Before the results are discussed with farmers they are drawn up into a series of visual aids (*see* Step 6). Analytical results are most commonly presented in tables, charts and graphs, with quantitative and qualitative information shown as scores, pictures or symbols.

STEP 6: Discussing results with farmers

Once the data have been analyzed, all interested farmers are invited to discuss the results in a community meeting. The presentation starts with a review of the farmers’ indicators of success, followed by a presentation of the means calculated for each indicator. The farmers are then asked to comment on the results and to discuss what they think has caused the differences between results obtained by different farmers: environmental factors, differences in management practices or any other factors. If management seems to be the major cause, it is important to identify why some farmers have managed the experiments more successfully than others. This discussion should help to highlight how differences in access to and control over resources influence the practices being tested.

The farmers’ views of the tests are discussed next, starting with a presentation of how farmers ranked the different treatments, and the percentage of farmers strongly for or against the new practice. Farmers should be encouraged to discuss why some are in favor of the practices being tested and others are dissatisfied with them.

The meeting concludes with the farmers' suggestions on how to follow up on the experiment. They might decide to reject the new practice or to try it out for a second season, possibly with an adapted design, or they might propose widespread trials.

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Reference 18 Getting acquainted with weeds of rice

Summary

Weeds can be divided into three groups: grasses, sedges and broad-leaved weeds. Good knowledge of weeds allows us to recognize the different species in the field, assess the severity of the situation and decide on the actions to take (see References 19 and 20).

In West Africa, weeds constitute one of the most important constraints to inland-valley rice production. They compete with rice for soil nutrients, water and light. Weeds reduce rice yield and quality, and may act as alternative hosts for insect pests, but also for their natural enemies (*see* Reference 21). Weeds can be categorized into three main groups: the grasses, sedges and broad-leaved species. Weeds may also be grouped according to whether they are annual (dying after producing seed) or perennial (surviving repeated cycles of seeding).

Grasses

Grasses (Gramineae) may look like rice when they are young (in fact, rice is a grass). They have long, thin leaves, usually with parallel vein, and the round and hollow stems are composed of segments separated with nodes. The roots are fibrous, rather than having a principal root.

Common annual grass weeds are *Echinochloa crus-pavonis*, *E. colona* and *Ischaemum rugosum*.

Sedges

Sedges (Cyperaceae) may look like grasses. They tend to have long, thin leaves, smooth solid stems that are triangular, polygonal or rarely round in cross-section; and, in general, they do not have nodes.

Sedges are widespread in inland-valley rice fields. The most frequent annual sedges are *Cyperus difformis, Cyperus iria* and *Kyllinga pumila*.

Getting acquainted with weeds of rice

Echinochloa colona (L.) Link

Echinochloa crus-pavonis (Kunth) Schultes

Ischaemum rugosum Salisb.

Figure 18.1. Three widespread grasses found in inland valleys

Cyperus difformis L.

Cyperus iria L.

Kyllinga pumila Michaux

Figure 18.2. Three common sedges found in inland valleys

Broad-leaved weeds

The leaves of broad-leaved weeds are usually wider than those of the grasses and sedges, and have branched veins. The first leaves of seedlings are a pair. Broad leaves often have one principal root that develops into a tap root.

Broad-leaved weeds frequently found in rice fields in inland valleys are: *Ludwigia abyssinica*, *Sphenoclea zeylanica*, *Ipomea aquatica* and *Heteranthera callifolia*. In general, they are easier to control than grasses and sedges.

Ludwigia abyssinica A. Rich. | *Ipomoea aquatica* Forssk. | *Sphenoclea zeylanica* Gaertner | *Heteranthera callifolia* Rchb. ex Kunth

Figure 18.3. Four broad-leaved weeds dominating in inland valleys

Bibliography

Johnson, D.E., 1997. *Weeds of Rice in West Africa / Les adventices en riziculture en Afrique de l'Ouest*. WARDA/ADRAO, Bouaké, Côte d'Ivoire, 312 pp.

Reference 19 Integrated weed management

Summary

Integrated weed management consists of the combination of different control methods, in order to ensure good control of weeds. Combination of methods does not mean that they are simultaneously applied. There are preventive and curative methods, and the combination of different practices will depend on the weed species present, the severity of the problem, and on the crop and plot conditions, but also on the farmers' socio-economic environment and on his technical level of expertise. For technical and economic reasons, integrated management should be used rather than any single method on its own. Several weed management methods are treated in this reference.

Preventive control methods

To prevent weed infestation in rice fields, the following measures can be used:

- Prepare the land well: good land preparation, followed by flooding for at least two weeks kills existing weeds. Good leveling is also important because, if the soil has been well leveled, it will be easier to flood the field to a uniform water depth.
- Clean the irrigation canals and the borders of the field: these areas should be cleaned regularly to avoid weed seeds from entering the rice field with irrigation water.
- Pre-irrigate the field: pre-irrigation induces germination of weeds, most of which can then be destroyed by cultivation.
- Good-quality rice seed is not contaminated with weed seeds and will give good germination rate and good emergence, leading to better and easier control of weeds in the field.
- Varietal choice: a vigorously tillering variety will be competitive with weeds. Some new rice varieties of WARDA, the NERICAs, from a crossbreeding of African rice (*Oryza glaberrima*) and Asian rice (*O. sativa* subsp. *indica*) have good capacities to promote the development of rice production in inland valleys. Some of these varieties have characteristics that challenge weeds (early and vigorous growth, high tillering capacity, appropriate leaf position). The NERICAs are a very flexible technology, especially when introduced to farmers using the PVS (participatory varietal selection) approach (Reference 10).
- Rogue the field: remove rice off-types and weeds that have escaped other measures.

Crop management techniques

The following crop management techniques contribute to weed control in irrigated rice:

- Transplanting rice instead of direct-seeding gives the crop an advantage over weeds, reducing the competitive effect of weeds. Rice can be either transplanted into standing water or the field flooded immediately afterwards to reduce the numbers of germinating weeds.

- Direct underwater sowing of pre-germinated seeds, while maintaining the water level, reduces weed growth; a high crop density can also make the crop more competitive with weeds.
- In both cases, water management is essential. Good water management in the field helps reduce the weed population, as flooding prevents most weeds from germinating. For instance, it has been proven that *Echinochloa* spp. can be controlled if a water layer of at least 2 cm can be maintained in the field.

Curative control methods

The following weed control strategies are very efficient:

- Hand-weeding (including roguing).
- Mechanical control.
- Chemical control (Reference 20).

Hand-weeding and mechanical control are easier to implement if rice has been transplanted or sown in rows, as the rotary hoe, the *daba*, and other traditional instruments can be used. Although hand-weeding requires a lot of labor, it is often effective. Hand-weeding after direct broadcast sowing is difficult and not very efficient, as it takes time and may damage the crop.

Cleaning up the field

The field may have to be cleaned (rogued) if weeds have escaped earlier control. Grasses are not easy to identify before flowering and should be removed by hand before they are able to produce seed. Roguing is the removal of any plant—including weeds, rice off-types and wild rice—other than the rice cultivated. A mixture of varieties decreases the quality of the paddy, as it not only affects the quality of white rice after processing (heterogeneous product), but also affects the cooking quality (heterogeneous cooking, changed taste); thus, possibly resulting in a depreciation of the production value. From flowering onward, it is important to start cleaning up the field. However, because flowering is a very critical stage (Reference 8), entering the field can cause damage to the crop. For this reason, when cleaning up, keep to the following instructions:

- Locate the rice off-types and enter the field slowly from the closest edge, using your arms to clear the way (avoid wearing wide clothes).
- If weeds flower earlier than the cultivated rice, start removing them before rice is flowering; if the cultivated rice is earlier, wait for the rice off-types to flower and enter the field only in the evening (after 16:00) or very early in the morning (before 09:00) to clean up.

Bibliography

Johnson, D.E., 1997. *Weeds of Rice in West Africa / Les adventices en riziculture en Afrique de l'Ouest*. WARDA/ADRAO, Bouaké, Côte d'Ivoire, 312 pp.

Reference 20 Safe and correct use of herbicides

Summary

Farmers' knowledge regarding safety, application techniques, timing and dosage of herbicides use is often inadequate. As a result, the effectiveness of herbicides is often low, resulting in persistent weed growth, health problems for farmers and environmental pollution. This reference gives guidelines on safe and well-informed use of herbicides. Many integrated weed management options other than herbicide use are available to farmers and, as much as possible, these options should be promoted or combined with herbicides to reduce farmers' reliance on herbicides.

If not correctly used, herbicides may be dangerous to the health of the farmer, his or her crops, and the environment as a whole. Chemical control should be the last resort in the range of integrated weed management options (Reference 19). It should be stressed that herbicides are poisons that may be harmful to health, the crop and the environment if not used properly.

Farmers may not appreciate the importance of a number of factors that influence the efficacy of herbicides. To increase the efficacy and safe use of herbicides, farmers can often improve on one or more of the following seven points:

- Choice of product.
- Timing of the treatment.
- Water management.
- Equipment inspection and maintenance.
- Calculation of dose to apply.
- Application techniques.
- Safety.

Choice of product

There are different groups of herbicides:

- Selective herbicides: these herbicides affect certain weed species, but not others. When used as indicated, they will control susceptible weeds without damaging the crop for which they are recommended. They are usually specific to certain types of weeds (products against grasses, sedges or broad-leaved weeds).
- Non-selective herbicides kill a large range of species. They must therefore be applied under certain conditions to avoid damaging the crop, e.g. Gramoxone (paraquat) or Roundup (glyphosate).

Selective and non-selective herbicides can work either as contact or systemic herbicides:

- Contact herbicides kill parts of the plant that the product comes into direct contact with when applied. They are not very efficient against perennial weeds whose underground parts are not reached by the product.

- Systemic herbicides enter the plant and can, therefore, reach and affect all organs. Such herbicides, although efficient against annual plants, are most useful for the control of perennial species, such as wild rice (with rhizomes), and perennial grasses and sedges.

It is important to choose the herbicide suited to the weeds in the field and also those that are recommended for lowland rice cropping.

It is important to follow the directions that are usually printed on the label of the container — FOLLOW THE MANUFACTURER'S INSTRUCTIONS.

Two names are printed on a herbicide container: the *commercial* name, e.g. 'Stam,' 'Herbextra,' or 'Basagran,' and the *common chemical name of the active compound*, e.g. propanil, 2,4-D, bentazone. Commercialized products may also contain two chemical compounds: for example, 'Rical' contains propanil and thiobencarb.

Weeds can be classified into three groups (*see* Reference 18): grasses (Gramineae), sedges (Cyperaceae), and broad-leaved weeds.

Grasses (Gramineae)

One of the most widely-used active compounds against grasses is propanil, which can be found in 'Tamariz,' 'Rical' and 'Garil.'

Sedges (Cyperaceae)

Active compounds effective against sedges include 2,4-D and bentazone, which can be found in 'Herbextra' and 'Basagran.'

Broad-leaved weeds

There are several active compounds that are used against broad-leaved weeds, for example 2,4-D, which can be found in 'Herbextra,' 'Herbazol' and 'Calliherbe.'

Treat at the appropriate time

Weeds cause most damage within the first six weeks after sowing or transplanting. Contact herbicides are most efficient when weeds are very young (2 to 3 leaves). This is very important for grasses and sedges. If the treatment is applied late, more damage is done to the rice crop and the herbicide is usually less efficient.

Do not forget the water!

For many herbicides (but not all), the field should be drained 24 hours (1 day) before application and re-flooded 2 to 3 days after treatment to prevent new weeds from germinating. However, some compounds—such as Londax or Ronstar 12L—should be applied in flooded fields.

Sprayer nozzle

Two nozzles are commonly used: cone nozzles that produce a circular shower of droplets (they are to be used with insecticides) and fan or flood nozzles produce bigger drops and are suitable for herbicides. Cone nozzles should be used with higher pressure settings and fan nozzles should be used with lower pressure settings.

Nozzles are usually made of plastic and are easily damaged. Before beginning the treatment, the condition of the nozzle should be checked: fill the sprayer half full with water and test the nozzle by spraying water onto a dry surface. A nozzle in good working condition will produce a uniform shower; if it does not, change the nozzle. Nozzles wear out rapidly and should be changed regularly.

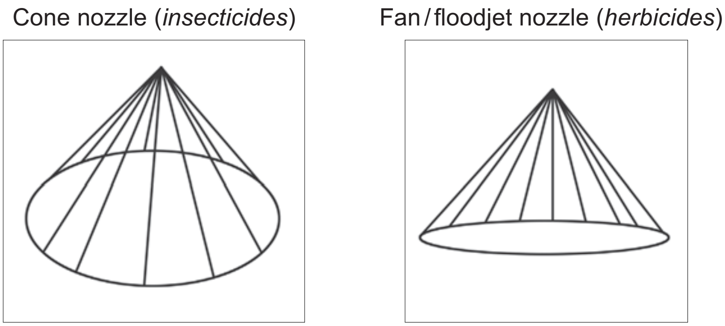


Figure 20.1. Different nozzle types

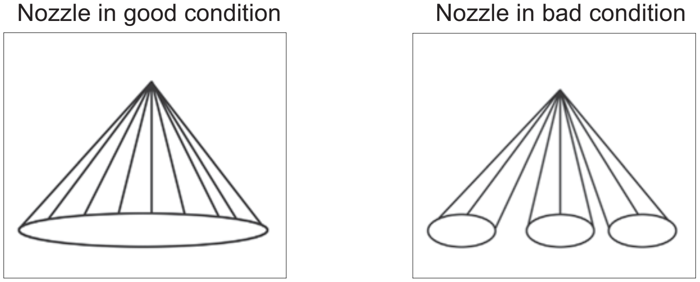


Figure 20.2. Example of the effect of nozzles in good and bad working condition on the application of herbicides

Dosage

Calculating what dosage to apply is often a problem for rice-growers and for extension agents. We have tried to simplify calculations by calculating the number of sprayers per hectare to apply and by using a measuring unit that is easy to find in most West African markets: the small tomato can containing 50 to 60 ml of tomato paste. Experience has shown that to spray one hectare with a nozzle in good working condition and a 15 liter sprayer, one will need 300 liters of solution, i.e. 20 sprayer-loads.

Note: calculations will have to be adapted if sprayer content is not 15 liters or if fewer or more than 20 sprayer fills are required per hectare.

If the field's surface area is known, it is possible to calculate whether the application has been correctly done. For example, when a farmer treats a field of one-quarter of a hectare with 5 sprayer tanks, it means that he/she walked at the intended speed. If he/she walks slower, he/she will use more and if he/she walked faster he/she will use less.

The small tomato can

To control sedges and broad-leaved weeds, 1 liter of 2,4-D should be applied per hectare. This dosage corresponds to one little tomato can of a herbicide containing 2,4-D (e.g. Herbazol) per 15-liter sprayer.

i.e. 1 liter = 1000 ml
20 sprayers (15 L each) per ha
1000 ml / 20 = 50
i.e. 50 ml (1 small tomato can) per sprayer

To control grasses, 5 liters of propanil should be applied per hectare.

This dosage corresponds to 5 small tomato cans of a herbicide containing propanil (e.g. Garil) per 15-liter sprayer.

Take care! These calculations are valid only when the sprayer's capacity is 15 liters, and the application rate is 300 L/ha, otherwise they must be adapted.

Use the right application techniques

Using the right application techniques will result in the uniform application of herbicide and facilitate good weed control. If treatments are not applied uniformly, some areas will be correctly treated or receive an over-dose, and others will receive an under-dose or no treatment.

Half fill the sprayer container/tank with water and test the width and evenness of the spray on bare soil away from the field. Check the nozzle and change it if the spray is not evenly distributed. Move the sprayer arm up and down and observe how it modifies shower width. If the hose is lowered, its width decreases, whereas when it is raised, the surface area treated increases. It is usually recommended to spray from 0.7 m height. When spraying, the height of the nozzle above the ground should be kept constant.

When the sprayer is half full with water, add the herbicide using the small tomato can as a measure. Rinse the can with clear water and pour its contents into the sprayer. Put the lid back onto the sprayer and shake it. Fill the sprayer tank up with water and shake again.

Once again outside the field, test the sprayer for 5 seconds, to check that the hose is filled with the solution. Start treating the field, keeping the sprayer arm at a constant height. Pump slowly and regularly, i.e. once every two steps.

Walk with regular, even strides. Less of the herbicide will touch the weeds if one walks too fast. Too much is applied if one walks too slow. The right speed is about 60 m per minute.

The field should be treated completely. If rice has been planted in lines, they will be used as guiding marks; if not, one's own steps can be followed or guide posts can be placed at regular intervals.

After treating, the sprayer and other equipment should be carefully cleaned with clean water. Hands and clothes should be washed too.

DO	***DO NOT***
• Use the appropriate herbicide. • Treat early when weeds are small. • Check that the nozzle works properly. • Remember to flood the field 2 to 3 days after treating. • Follow the manufacturer's recommendations on the label.	• Treat when it is windy, when rain threatens or immediately after rain. • Walk in the field at random waving the sprayer arm around while treating. • Contaminate waterways and drains with herbicides.

Reference 20

Safe and correct use of herbicides

Safety rules to be respected

Beware of herbicides: they are poisonous!

- Do not let children handle herbicides or their containers.
- Keep children away from the field while treating.
- Wear gloves, glasses and a mask while treating.
- Wash carefully with soap after touching the herbicide bottle and after treating.
- Clean clothes and equipment with soap.
- Never eat, drink, smoke, or touch mouth or eyes while handling herbicides.
- If the solution enters the eyes, rinse with lots of water and go as quickly as possible to the nearest health center (clinic).
- Always follow the manufacturer's recommendations.
- Dispose of empty containers carefully.

Figure 20.3. Use gloves, a mask and glasses during herbicide spraying. Wash your body, the equipment and clothes with soap after using herbicides

Table 20.1. Herbicides used for weed control in inland-valley rice and guidelines for application

Names	Active ingredients (g/L)	Target weeds	Stages	Dosage (L/ha)	When to apply	Obser-vations
Propanil Stam F 34 Surcopur	Propanil: 360	Grasses and some broadleaved weeds	2–3 leaf stage of weeds	5 to 8	After drainage	Contact herbicide
Weedone TP	2,4-D: 480	Broad leaves and sedges	2–3 leaf stage of weeds	1 to 1.5	After drainage	Contact herbicide
Basagran PL2	Bentazon: 140 Propanil: 360	Broad leaves and sedges	2–3 leaf stage of weeds	6 to 8	After drainage	Contact herbicide
Garil	Triclopyr: 72 Propanil: 60	Grasses, sedges and some broad-leaved weeds	2–3 leaf stage of weeds	5	After drainage	Contact herbicide
Ronstar 12 L	Oxadiazon: 120	Grasses, sedges and broad-leaved weeds	Before emergence of rice and weeds	6	Apply on water layer, three days after sowing or transplanting	Contact herbicide
Ronstar PL	Oxadiazon: 120 Propanil: 360	Grasses, sedges and broad-leaved weeds	After emergence of rice and weeds	5	After drainage	Contact herbicide
Ronstar 25 EC	Oxadiazon: 120	Grasses, sedges and some broad-leaved weeds	Before emergence of rice and weeds	4	Apply on moist soil	Pre-emer-gence herbicide
Londax	Bensulphu- ronmethyl	Sedges and broad-leaved weeds	2–5 leaf stage of weeds	80 g/ha	Applied to the floodwater	Apply using a bottle

Reference 21 Insects in rice cropping

Summary

Insects can be either harmful or useful to rice cropping. The integrated management of insects, in which the use of insecticides is reduced to the minimum, requires good knowledge of their development cycles. This reference describes the main families of insects that are either harmful or useful to rice cropping, details their development cycles, and presents methods for the integrated control of harmful insects. The dangers of using and manipulating insecticides is also presented.

An ecosystem is a natural environment made up by dynamic interactions between biotic and abiotic elements within well-defined boundaries. The biotic elements include plants, insects (pests, natural enemies, decomposers), microbes and other living organisms. The abiotic elements include the weather, relative humidity, wind, sunlight, rain and soil. Each element has its own specific characteristics and plays its own particular role in the system in space and time, influencing the distribution of living organisms. The term ecosystem also includes the flows of nutrients and energy inside the system.

The rice ecosystem is a grouping of biotic and abiotic elements complex enough to provide a measure of stability. However, pesticide use will generally disturb this balance, because both natural enemies and other non-target organisms may be killed by the treatment.

The concepts underlying the integrated management of insect pests and integrated rice management (IRM) are based on the stability of the agro-ecosystem and on economic efficacy. When the stability of the agro-ecosystem is maintained, the populations of insect pests can be kept to levels that are easy to manage. In order to achieve this, the following points must be taken into account:

- The number, position, role and intensity of all the elements in the ecosystem change, transform or evolve continuously. They build a living system, continually changing, i.e. it is a dynamic ecosystem.
- In all ecosystems there is a hierarchical structure. For instance, plants produce biomass that feeds herbivores (which include insect pests). These are in turn eaten by carnivores (including their own natural enemies) that are in turn eaten by other carnivores. At the end of the process, all organisms feed the decomposers. If, in an agro-ecological system, there are no natural enemies at all, the insect pests will multiply and destroy the crop. This is why natural enemies living in the fields are an important mechanism of protection—maintaining the balance among all the elements in the ecosystem is essential for its sustainability.

Biodiversity

A healthy ecosystem has a high degree of diversity, in terms of the number of species and the genetic diversity of the individuals within the species. In practice, this means that in such an ecosystem there are several different kinds of plants and animals. Among the useful animals, one may include worms that increase soil fertility and 'natural enemies' like spiders, scale insects, frogs and lizards, which help reduce or destroy insect pests. If there are few useful animals in an agro-ecosystem, this may be due a number of problems, e.g.:

- Too much pesticide has been used and these useful animals have been killed.
- There is not enough food for these natural enemies. In their larval stages, most natural enemies eat other animals (e.g. caterpillars, grasshopper nymphs), whereas adults can live from nectar or pollen from the wild plants in the environment. That is why a large variety of plants is necessary in order to maintain the populations of natural enemies. The more diversified the vegetation of an agro-ecosystem, the more diversified the populations of natural enemies, which means that the chances of naturally destroying the populations of insect pests will be greater.
- The structure of the soil does not allow worms and insects to grow. Unfavorable conditions for soil inhabitants include soil not containing enough organic matter or fields being flooded too frequently.

Natural enemies

Large animals usually live longer and have fewer offspring, while smaller animals have shorter life cycles and more offspring. Insects have huge numbers of offspring. One pair of stem borers may have 100 offspring that will all become adults. If, in one month, each female produces 100 surviving and productive offspring, the stem-borer population would reach 30 billion within six months. Fortunately, several mortality factors naturally reduce the increase of insect populations. The growth of all living organisms is regulated by unfavorable environmental conditions and by natural enemies.

What is a natural enemy?

A natural enemy is a living organism that kills, harms and causes disease in other living organisms. There are three types of natural enemies:

- Predators
- Parasites
- Pathogens.

Predators

Predators are animals that hunt and kill other animals, e.g. tigers, snakes, spiders or ladybird (ladybug) beetles. The body of a predator is adapted to hunting, killing and eating its prey. In general, predators have strong teeth and mouths, acute vision and strong legs.

Parasites

Parasites also consume other organisms, but they enter (or attach themselves to) the body of their victims and feed on their tissues and fluids, which weakens and even kills them. Parasites thus live at the expense of another organism that is the victim or 'host' on which the parasite feeds.

Pathogens

Pathogens are micro-organisms that cause diseases. Like many parasites, they enter the body of their host, in which they live and multiply, weakening and finally killing their host. Bacteria, fungi and viruses are pathogens.

Rice predators: useful insects

Rice predators include spiders, ants, some insect families (e.g. Carabidae), plant bugs, amphibians, dragonflies, and other beetles and water bugs; however, the most important ones are the spiders—one spider can consume about 30 white leaf hoppers in a day. Spiders do not belong to the insect group but are arachnids; that is, animals whose head and neck are not separated. One peculiarity of spiders is that they never eat rice, and only feed on insects, whereas insect predators feed both on rice and insects.

The main spider families that can be found in African paddy fields are:

- **Lycosidae**: They are often called 'wolf' spiders as they are often found in packs of 3 or 4 like wolves. E.g. *Pardosa* spp., *Lycosa* spp., *Wadicosa* spp.
- **Thomisidae**: They are often called 'crab' spiders because they actually look like crabs and can move in all directions without turning around. E.g. *Thomisus* spp.
- **Tetragnatidae**: They are giant spiders, sometimes known as 'long-jawed' spiders, and their bodies are long and well developed. E.g. *Tetragnata* spp.
- **Araneidae** *or* **Argiopidae**: They are the best weavers and really weave spider webs. E.g. *Argiope* spp., *Gasteracantha* spp.
- **Pholcidae**: They are often called 'grand-dad long-legs' as their legs are very long and very thin. E.g. *Pholicus* spp.
- **Salticidae**: They are often called 'jumping' spiders as they leap and jump instead of running or walking. E.g. *Salticus* spp.

The most important rice insect pests: harmful insects (Table 21.1)

The insects that harm rice can be classified into five main groups according to the type of damage they cause:

- Stem borers.
- Defoliators.
- Piercing–sucking insects.
- Root cutters.
- Storage pests.

Table 21.1. Insects in rice cropping

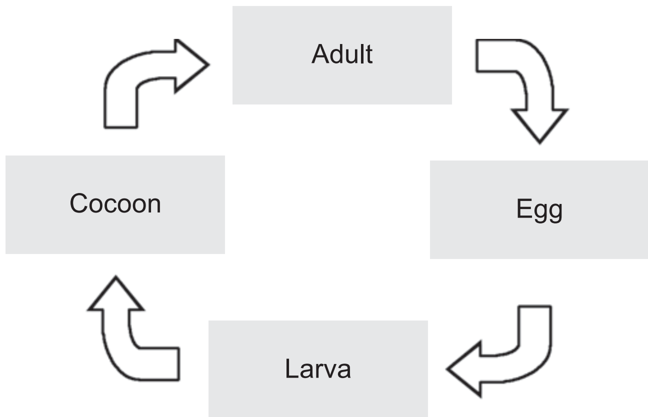
Name of damage	Order/ Family/ Species	Type of damage	Symptom description	Stage of insect causing damage	Susceptible plant stage	Impact on yield
Rice Yellow Mottle Virus (RYMV)	Coleoptera Locusts Leafhoppers	Leaf destruction Cut leaves Perforated spots with minute strips	Early yellowing Stunting	Adult	Vegetative stage, even when transplanted	Sometimes no yield at all
Onion tube	Fly (African Rice Gall Midge)	No leaf destruction	Some leaves change into yellowy-white tubes, looking like onion leaves	Larva (small yellow worm)	Vegetative stage	Sometimes no yield at all
Dead heart	Red flies with black antennae: *Diopsis* and butterflies: *Chilo*, *Sesamia*, *Scirpophaga*	No leaf destruction	Some leaves change into yellowy-brown tubes called dead heart Plants can be pulled up easily	Larva (small yellow worm)	Early vegetative stage	High yield despite attack
Defoliation	Small white butterflies *Nymphula*	Many leaf fragments floating on water: they are the sheaths/ covers that protect the larvae	Tips of rice leaves are cut Field whitening	Larva	Early tillering	Rice fields usually recover without losses
Destruction of roots	Termites *Microtermes* *Macrotermes*	No tube formed No leaf destruction	Early yellowing and drying of leaves	Adult termite "workers"	Any time in cycle whenever water is lacking	Losses may be high
Grain blackening	Stinking bugs *Aspavia leptocorysa*	Small black or brown spots on grains	Bad grain quality (color, fragrance, flavor)	Adult	Reproductive stage and maturity	Small-scale indirect losses

Reference 21

Insects in rice cropping

There are about 50 different species from two families: Lepidoptera and Diptera. The most frequent Lepidoptera are: *Chilo* spp*., Maliarpha separatella, Sesamia calamistis, Nymphula depunctalis*, *Eldana saccharina, Scirpophaga* spp. The most frequent Diptera are *Diopsis* spp. and *Orseolla oryzivora*, the 'African rice gall midge' (Reference 22).

The development cycle of most insects follows four stages: adult, egg, larva, and pupa or cocoon.



Stem borers

Stem borers cause the worst damage, as they infest rice plants from the seedling stage to maturity, including:

1. Damage on young plants during early and later tillering. Caterpillars enter the leaf sheath and the young stem from the bottom, causing the death of the stem: such damage is often called 'dead heart' (*see* Reference 23).
2. Damage to the panicle, causing 'white panicles' (*see also* Reference 23). The young caterpillars (mostly from the second generation) gather a few centimeters below the panicle inside the flower stalk, which then dries up entirely. According to the timing of the attack, it becomes either a completely white or a dried panicle, which may eventually break.

Apart from these two visible cases, any attack on the stem is just as harmful. If the insect attacks when the plant has already reached an advanced stage of development, the older caterpillar embeds itself in the lower parts of the stem and reduces or even stops the nourishment of the panicle. Damage then shows through the drying of some of the spikelets, leading to a decrease in the number of grains at harvest. This effect, which is far less visible, reduces the weight of the harvest and can only be measured by weighing the harvest.

Defoliators

The damage caused by leaf defoliators usually concerns fragments on leaf edges and tips, but in some cases, the leaves can be cut off. When the plant is already grown, such damage is usually without great economic importance. However, when such infestations take place in the early development of the plant (until mid-tillering), they may harm a great part of the plant and lead to irretrievable losses.

One of the most widespread species is *Nymphula depunctalis.* It is a small (10–12 mm) pearly-white butterfly that lays its eggs in tight rows along the leaves. The larva crawls on a leaf and cuts it crosswise a few millimeters from its end, leaving only a tiny part connected to the remainder of the leaf. Because of the lack of turgidity, the leaf fragment wraps itself around the caterpillar, which then closes the part of the leaf that is almost cut off with a few silk threads, cuts the part that is still attached to the remainder of the leaf, and falls into the water. It is then well protected and can move on the water, with only the upper part of its body out of the leaf. It can then easily swim from rice stem to rice stem, climb up and feed. During the larva stage, it will change its protecting leaf many times. Drying the field for at least 3 days is an efficient method of control.

Other species of defoliators are: *Cnaphalocrosis medinalis, Marasmia trapezalis, Diacrisia scortilla, Parnara* spp.*, Hispides* spp.

Piercing–sucking insects

Piercing and sucking insects can attack the leaves, stems and grains. They may be numerous and cause significant damage. This category includes bugs, whiteflies and acarids (i.e. micro-mites, parasitic micro-worms); they mostly cause damage during maturation, at the milky and dough grain-filling stages.

Root cutters

Root cutters are insects that partially or totally develop in the soil. Some can be found only in inland valleys, while others live only in the upland areas.

Rice mole cricket (Gryllotalpa africana)

These belong to the locust/grasshopper family. They mostly live in the upland areas, but can live in all kinds of ecosystems. They mostly damage field borders.

Termites

These can be found in both inland valleys and upland areas, especially when water is lacking, which explains why flooding the fields is the easiest way to control them. They feed on roots and underground elements of the plant, leading to yellowing and drying of the leaves. The most widespread species found in rice fields are *Microtermes*, *Macrotermes* and *Trinervitermes* spp.

Water weevils (Afroryzophilus djibai)

This insect lives exclusively in the muddy waters of inland valleys. The harmful stage is the larva which feeds exclusively on rice roots.

Storage pests

Stored rice can be attacked by a wide range of insects whose identities and cycles differ from those found in the fields. Most feed on rice and any other stored grain. They can be classified into two groups according to the infestation mode: some begin attacking the crops in the field and are brought into the granary or store with the harvest, as is the case for weevils and moths; others attack only stored grains, and can come from either inside or outside of the store.

Insect control

Crop management practices

These practices both hinder the multiplication of harmful insects and favor rice growth. The most efficient practices are the following:

- Destruction of rice stubble and crop residues, i.e. the places where larvae and nymphs can survive between seasons.
- Respect and synchronization of cropping calendars to avoid insect proliferation.
- Use of good-quality or treated seeds.
- Careful monitoring of crops and destruction of primary infection sources, including host weeds.
- Where possible, avoid mono-cropping and use crop rotations to disrupt insect cycles and prevent proliferation.
- Associated or row intercropping cultures to limit insect propagation among plants.

To be efficient, crop management practices aimed at insect control must be implemented over large areas. As most farmers manage surface areas of one hectare or less, such practices require agreements and organization over the whole inland valley.

Biological control

Biological control aims at limiting the density of insect pests by using natural enemies as predators, parasites or pathogens. Two strategies may be used, namely preserving the density of natural enemies or increasing their density. Preservation simply means that one avoids destroying natural enemies through crop management practices or some interventions like the use of pesticides. Increasing natural enemies means that the number of natural enemies will be artificially increased in the environment: this implies that natural enemies will have to be bred and released, and this is difficult to implement in Africa. Therefore, natural preservation will be chosen to increase the population naturally. The most well-known example is that of two parasites of African rice gall midge: farmers should be told to keep *Paspalum scrobulatum* (Reference 22) around their fields, as it is the favorite dwelling of these two parasites. The more this plant grows, the denser the natural enemies, which naturally leads to a decrease in gall-midge populations.

Furthermore, it has been shown that after weeding, putting the weed residues in heaps around the rice straw leads to an increase in spider populations which hide there during the day, and at night hunt the nocturnal stem borers. These methods are called preservation and increase methods, which show that some crop management practices are also biological control practices.

Some other biological control methods can also be used, including in particular the promising use of very specific sexual attracters (pheromones), which, once synthesized, may help destroy insect pests by simply trapping them or can be used in combination with insecticides. This method is beginning to be used for some Lepidoptera that attack fruit. The pheromones of *Chilo suppressalis* and *Chilo zacconius* are known and some synthesized components are being tested. Such 'products' are very interesting as they may also help 'predict' infestations and help choose which kind of control to use, as pheromones allow the detection of very small populations of insects, especially before they begin multiplying. However, stem-borer pheromones are not yet available in Africa.

Biological control has the great advantage of being harmless to health and the environment. Nevertheless, it often demands relatively complex management, and requires rather high investments and a certain level of technological expertise.

Genetic control

This type of control requires the use of tolerant varieties; it is usually not very expensive for farmers and imposes few constraints on the environment. Varieties can be differentiated according to the degree of resistance and classified as: low, medium and highly resistant. There are two types of genetic resistance: vertical resistance, to some insects, and horizontal resistance, to most insects.

Chemical control

Chemical control is usually quite affective, as insecticides kill the insects in a short time. Furthermore, insecticides are usually widely available in stores. Nevertheless, insecticides are expensive and impose technical constraints. Spraying liquids is not very precise and is less efficient than using granules, which can be applied by hand or with cheap equipment. Some farmers use Furadan to prevent stem borers from multiplying. However, the danger of frequently using insecticides is that some insects adapt to insecticides and become resistant. Furthermore, most insecticides are not specific and kill both harmful and useful insects. Using insecticides can therefore be dangerous to the ecosystem and the environment, and such an option should be used only as a last resort, after considering all other possibilities.

Integrated insect control

Integrated insect control means that the populations of harmful insects will be kept as low as possible so that the ecosystem stability is not disturbed and rice cropping can be economically efficient. Integrated control means that one is led to think and to combine judiciously the different control techniques.

Pesticides and natural enemies

What is a pesticide?

In most local languages, the word used for 'cure' or 'medicine' is also often used for pesticides. However, pesticides are neither cures nor medicines, but rather poisons that kill. This becomes clearer when one studies their names and meanings:

- Insecticide = kills insects.
- Raticide = kills rats.
- Fungicide = kills fungi.
- Bactericide = kills bacteria.
- Herbicide = kills weeds.
- Nematicide = kills nematodes (nematodes are microscopic worms).

Some pesticides have an effect on respiration or on digestion. Others kill indirectly by their effects on development or reproduction. Whatever the mechanism of action, the result is identical: the harmful insect is killed. However, it is not only the harmful insect that is affected! Other insects, including natural enemies, and even animals or humans may fall ill or die because they came into contact with pesticides.

We should avoid calling pesticides 'cures' or 'medicine' and call them what they are: *poisons*. By doing so, we remind ourselves and others that pesticides are dangerous and that their use ought to be as limited as possible. If it becomes essential to use them, they must be used with great care, as they are dangerous for human health and for the environment.

Insecticides can be divided into two groups according to the way they work. Some are immediately absorbed by the insects when they come into contact with the insecticide: these are contact insecticides. These insecticides are sprayed over plants and the insects come into contact with them while moving over the plant. The other insecticides are systemic, as they enter the insect body through their food, and the insecticide will kill the insect when it goes through its intestines. Systemic insecticides are applied as granules sprinkled on the ground, which are absorbed by the plants. When the insects eat the plants, they also swallow the pesticide. Both insecticides are toxic to natural enemies.

Pesticides, natural enemies and harmful insects

Most farmers have noticed that the problems with insect pests like aphids and other small insects appeared after they began using insecticides. Two reasons can explain this phenomenon:

- Insecticides never kill all the insect pests in a field. The insects that survive are more resistant to the pesticide than those that died. The surviving insects are those which will reproduce and transmit their resistance characteristics to the next generation. If the insecticide is applied often and at high doses, the selection for resistant insects occurs very quickly. Insects with a short life cycle like aphids can rapidly develop resistance to insecticides.

- Pesticides kill natural enemies, which are more susceptible to pesticides than the insect pests are. Furthermore, the life-cycle of natural enemies is generally longer than that of harmful insects, which means that natural enemies need a longer period to recover and thus for their population to reach its previous size. Without their natural enemies to limit their numbers, the harmful insects can multiply very rapidly.

Pesticides and human health

Pesticides can have acute or chronic effects on human health. The acute symptoms of poisoning are nausea, vomiting, disturbed vision and trembling. When pesticides are frequently used over a long time, the effects can become chronic and the symptoms may be blood-pressure changes, heart problems, skin (dermatological) problems, neurological problems and cancers. Pesticides can kill human beings. The United Nations World Health Organization (WHO) has published that, each year, about 1 million people are poisoned by pesticides, and that 20,000 die from their effects.

Some safety rules

To prevent dangers linked to pesticide use, it is important to follow some basic safety rules:

- Always wear protection equipment (mask, glasses, gloves and boots) while treating.
- Respect recommendations about doses and associations with other products.
- Avoid, as much as possible, applying products when it is very hot or very sunny (between 11:00 and 16:00), and walking into the wind.
- Never smoke while treating, or before washing thoroughly.
- Ask people standing close, especially those placed down-wind, to move away while treating.
- Thoroughly clean treatment and protection equipment after use and store far from food and out of the reach of children.
- Take care not to clean the equipment or to throw away any solution remaining in an area close to a source of water used for home or cooking purposes.
- If, by accident, the product comes into contact with the eyes, nose or mouth, rinse with abundant water and go to the closest health center, if possible, with the references of the product (packaging or label).

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Reference 22 African rice gall midge

Summary

This reference complements Reference 21, which presented an overview of the insect pests and useful insects. African rice gall midge, *Orseolia oryzivora*, causes such severe damage to rice crops and has such a complex behavior that it requires a special reference. This reference provides more detailed information about the insect to help the facilitators develop a strategy to control it. This reference presents the life-cycle of African rice gall midge and also some integrated control methods.

Description

In the inland valleys in Sub-Saharan Africa, African rice gall midge (*Orseolia oryzivora* Harris and Gagné) causes significant damage. During its life-cycle, it completes four stages:

- ***The egg*** is elongated and about 0.5 mm long; initially a brilliant white color, it becomes yellow then amber with red dots before hatching (when the larva leaves the egg).
- ***The larva*** is initially whitish with two pairs of spines at the abdomen; at the end of the larval stage, the larva is milky white, the mouth spirals brown, and the abdominal spines have disappeared.
- ***The pupa*** (female gall midge 5 mm) is pale pink except for the wing buds. The legs, eyes and antennae become brown first, well before emergence. The leg buds are detached from the abdomen, the back-end segments have rows of strong spines bent backwards.
- ***The adult***: a rice gall midge is the size of a mosquito (4.8 mm long), is reddish with dark antennae and thorax, and black eyes.

Biology and damage

The adult often enters the rice field unnoticed. It lives 2 to 4 days. The female lays 200 to 400 eggs, individually or in groups of 3 to 5 on the stem base, on or in the vicinity of the ligules, on the underside of the leaf sheath or even on the surface of the water. Incubation takes 2 to 5 days.

At hatching, the larva makes its way down between the leaf sheaths and the stem to the growing point (apical meristem), and then penetrates into the tiller. The larva causes the plant to form an initially oval, hollow gall at the tiller's growing point, within which it stays its whole life. In each gall there is one larva. The gall develops on young tillers, before distinct internodes can be observed. The gall is formed by a bulbous thickening at the growing point (which is destroyed).

After about two weeks, the larva transforms into a pupa (cocoon). The pupa is mobile. Towards the end of the pupal stage (which lasts 3–5 days), the gall elongates into a hollow tube, very long and pearly white, so that the plant looks like an onion leaf. The pupa moves upwards inside the gall tube near to the tip of the gall. Here it cuts a hole in the wall and the adult midge emerges and crawls out leaving the pupal skin protruding from the exit hole.

Recognizing gall midge damage

The long, silvery galls are obvious on young rice plants; however, on older plants they are less conspicuous, either because they are hidden by the rice leaves, or else because they are green under poor growing conditions (and therefore not easily distinguished from plant leaves). Each 'onion leaf' is a lost stem. After the emergence of the adult, the 'onion leaves' become yellow, then dry; after which further elongation is impossible. The plant reacts by producing new tillers, which are often infested too.

Orseolia oryzivora can proliferate locally for years, or when two rice crops a year are cultivated. Every year, the midge is found at certain locations, particularly in the Guinea and derived savanna and humid forest zones. Rapid population growth is favored by sequential or asynchronous planting of rice (enabling midges to infest one field after another) and cloudy, humid weather (more than 50% relative humidity favors egg laying and incubation). Only rice fields at tillering stage can be infested. The younger the plant at the time of attack (28 to 42 days after transplanting), the worse the infestation.

Gall midge survives the dry season on cultivated-rice ratoons and volunteers, or on wild rices (*Oryza barthii, O. longistaminata*, *see* Figures 22.1 and 22.2). Infestation is most severe when rains are early and followed by a dry period delaying transplanting or sowing. A first infestation then builds up on wild rice and when the rice crop grows, it is immediately severely infested. In irrigated regions, a second rice crop can be severely attacked at the beginning of the dry season.

Control

Crop management practices

The following crop management practices should be used:

- Early sowing/planting: to avoid the peak period of the insect.
- Synchronized planting: farmers have to plant their rice at about the same time so that the insect does not continually find young plants to build up its population.
- Fertilizer doses: avoid over-doses (especially of nitrogen) as these lead to over-profuse leaf formation and favor gall-midge infestation.
- Destruction of wild rice, *O. longistaminata*: this is a perennial weed in which the insect survives during the dry season and transfers to young rice plants at the beginning of the rainy season. The ratoons and volunteers of cultivated rice should be destroyed for the same reason.
- Preservation of *Paspalum scrobiculatum* (*see* Figure 22.3): this is a host plant for gall midge parasites: *Platygaster diplosisae* and *Aprostocetus procera*.

Using crop management practices to control gall midge requires a certain organization among farmers. They may find difficulties in implementing the activities requiring joint action (e.g. synchronized planting), or because of socio-economic problems (e.g. meeting the requirements to be able to sow or transplant at the same time).

Figure 22.1. ***Oryza barthii***

Figure 22.2. ***Oryza longistaminata***

Figure 22.3. ***Paspalum scrobulatum***

Biological control

Biological control means trying to preserve the life of useful insects (Reference 21):

- Predators: red ants, damsel flies, crab spiders, long-jawed spiders, wolf spiders and jumping spiders eat adult and larval midges.
- Parasitoids: the most common parasitoids of gall midge are *Platygaster diplosisae* and *Aprostocetus procera*. Both are small wasps living on another gall-midge species associated with the weed *Paspalum scrobiculatum*. This is the reason why this weed is useful in the integrated control.

Indeed, during the dry season, *Platygaster diplosisae* and *Aprostocetus procera* develop on the other midge species on *Paspalum scrobiculatum* and increase their population. During the rainy season, when the rice is in place and African rice gall midge appears, they attack and destroy the gall midge. They lay their eggs inside the midge eggs, larvae and pupae, thus killing the gall before it reaches the adult stage. *Platygaster diplosisae* attacks the eggs and the larvae of gall midge on the outside of the rice plant, and *Aprostocetus procera* only attacks the pupa inside the plant. So, if farmers destroy *Paspalum scrobiculatum*, they destroy at the same time the useful insects *Platygaster diplosisae* and *Aprostocetus procera*. Thus, *Paspalum* (the main host plant for these insects) has to be preserved, whereas *Oryza longistaminata* (which hosts African rice gall midge itself) has to be destroyed.

Control with insecticides

The use of insecticides to control gall midge does not seem a good option, especially because the two control methods mentioned above are effective. They not only preserve useful insects, but also do not harm the environment.

Control through varietal resistance

This is using rice varieties that are resistant to the pest or tolerant to the presence of the pest. This ability to resist can result from the morphological constitution discouraging the insect (hard plant tissue, bad taste, repulsive odor, leaf characteristics not appropriate to hatching, etc.). All these different characteristics may be inherent to the plant or introduced through breeding.

The two cultivated rice species *Oryza sativa* (Asian) and *O. glaberrima* (African) both have gall-midge-resistant varieties. Resistant varieties from the African species are: TOG 7106, TOG 7206 and TOG 7442. Several varieties of *O. sativa* are resistant: Cisadane (released in Nigeria), BW348-1 (selected in Burkina Faso and Nigeria, but not yet released) and TOS 14519 (a traditional variety in The Gambia). WARDA is developing interspecific resistant varieties from crosses between *O. glaberrima* and *O. sativa*. On the photo pages, images of the life cycle of the African rice gall midge (Photos 22.1; 22.2; 22.3; 22.4) and damage symptoms on the rice plant (Photos 22.5; 22.6) can be found.

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Reference 23 Rice stem borers

Summary

This reference presents the life-cycle of rice stem borers and how to implement integrated control management. Because of the damage they produce on rice crops, this reference is entirely devoted to stem borers. This reference complements Reference 22 dealing with African rice gall midge and Reference 21, which presents an overview of insect pests and useful insects.

Stem borers collected in African rice fields are from the orders Lepidoptera and Diptera.

Lepidopteran borers

Biology

In general, the eggs of lepidopteran borers stick to the leaves or are sunk between the leaf sheath and the stem in more or less aligned groups. Adults are active at night and hide during the day. The caterpillars move on the surface of the plant and migrate to neighboring plants by hanging down from a silk thread attached to the leaf tip. They first feed on the leaf blade, then quickly penetrate in the main nerves of the leaf, enter the leaf sheath and soon enter inside the hollow stems.

Some species complete their larval development in one stem; others start in one stem and continue in another. The passage from the larval to the pupal stage takes place inside the stem or in the folds of the leaf sheaths; rarely on the ground.

Symptoms of stem-borer damage

There are two main types of damage:

- In young plants at the beginning of, and during, tillering, caterpillars enter the leaf sheaths at the base of the young stem. The damage can cause 'dead heart' (*see* Photo pages: Photo 23.1). New tillers are grown, but with a delay, affecting heading and resulting in heterogeneity at maturity. 'Dead hearts' are the dried up central shoots of tillers on the rice plant.
- At flowering, young caterpillars meet some centimeters below the panicle inside the flower stalk. The stalk dries up entirely, resulting in a completely 'white panicle' (*see* Photo pages: Photo 23.2). Stem borer can also induce abortion or drying up of a part of the panicle, when an older caterpillar settles in the lower parts of the stem, which hinders the feeding of the panicle, resulting in a reduced number of filled grains.

Reference 23

Rice stem borers

Chilo zacconius Blez.

The most common and most destructive lepidopteran borers in Africa are *Chilo zacconius* Blez. (syn. *Proceras africana* Auriv.; family Pyralidae). *Chilo* is common in West Africa in Benin, Burkina Faso, Cameroon, Côte d'Ivoire, Mali, Niger, Nigeria and Senegal.

<u>Description</u>

The life-cycle of stem borers, and many other insects in general, consists of four stages: egg, caterpillar, pupa and adult.

- Eggs: the egg batch is elongated and consists of several lines of flat, light-yellow eggs, overlapping like fish scales.
- Caterpillar: the body of the caterpillar is ivory colored, and has seven longitudinal pink stripes. The ventral stripes are incomplete and partly absent. The head is dark brown.
- Pupa: is dark brown, elongated (11–12 mm); the head shows two humps above the eyes, protruding spiracles, and the wing buds slightly protrude in the middle of the body.
- Adult: has pale yellow wings with small irregular black dots on the tips. The male is darker than the female. The female is 9–11 mm long and the male 11–13 mm. The adult flies generally only at night (*see* Photo pages: Photo 23.3).

<u>Biology and damage</u>

Two generations can develop on the same plant. The first feeds on the leaves and the leaf sheaths, living between the sheaths. From flowering onwards, the second generation penetrates the floral stalk, resulting in white or dried panicles. Subsequently, the caterpillar moves down the stem perforating it at various places. A single stem can host several caterpillars. During the dry season, the caterpillars continue their development on rice stubbles and on weeds, e.g. *Echinochloa* spp., *Oryza barthii, Sorghum arundinaceum*. There are several other *Chilo* species, including *C. diffusilineus* J. de Joannis and *C. aleniellus* Strand.

Maliarpha separatella Rag. or white borer

<u>Description</u>

- Egg batch: a cluster of overlapping eggs, glued to the upper side of the leaf by strong cement, which causes a characteristic pinch of the leaf blade wrapping the complete batch as it dries.
- Caterpillar: small shell-colored head; the mouth and borders are brown-black. The body is elongated, pearly white to yellow.
- Cocoon: elongated (20 mm), light brown. The ends of the leg buds do not extend beyond the ends of the wing buds. The abdomen is simple, without spines or crests, with three pairs of long, fine hairs at its end.
- Adult: a straw-yellow butterfly whose first wing pair shows a marked brown line.

Biology and damage

Maliarpha separatella is a specific pest of the *Oryza* genus. It can be found only on cultivated and wild rices (*O. barthii*, *O. longistaminata* and *O. punctata*). The female lays eggs on mature leaves only, during tillering (from 15 days after transplanting). Egg-laying is rare from heading onwards. As soon as it hatches in the morning, the caterpillar moves actively from one plant to another, hanging from a silk thread and transported by the wind. At the end of the first day, it penetrates between a leaf sheath and the stem, moves down and goes deeper into the sheath, and then into the stem above an internode, entering the inside of the stem. It will complete the larval stage in the same stem, digging small circular cavities in its wall, but never piercing it, moving from one internode to another, piercing the nodes one after the other. Pupation takes place, about 30 to 50 days after hatching, in the first big internode above the crown. In the meantime, the caterpillar has prepared a conical silky pipe allowing the young adult to move towards the wall of the stem. It is exceptional to have more than one caterpillar or chrysalis (cocoon) in one stem. It is difficult to estimate the damage. There is no mortality comparable to 'dead heart.' An early infestation results in 'white panicles.' However, if the panicle is developed, the larvae affect neither maturation nor grain fertility, but reduce grain weight.

Sesamia sp. (pink borer)

Description

- Egg: flattened at the poles, and has numerous longitudinal stripes. It is grooved and yellowish; the batch is inserted, without particular alignment, in the leaf sheaths that will protect them.
- Caterpillar: generally pink, especially on the darker abaxial face, the adaxial face being lighter. When fully developed, the caterpillar is 30–40 mm long, it has false legs with hooks shaped in a wide-open arc. The anal scuttum of the last abdominal segment is yellow with brown spots.
- Cocoon: 17 mm long, chestnut brown, paler on the adaxial face. The leg and antenna buds never exceed the end of the wing buds. The tip of the abdomen has two dorsal spines and a small ventral bump.
- Adult: light beige and has faint brown stripes; the forewings are speckled with darker small spots and have a big whitish fringe. The back wings are pearly white.

Biology and damage

The nocturnal adults can cover large distances. The young caterpillars feed first on the leaf sheaths and then dig cavities between sheaths and stems. The damage is very variable, depending on the age of the plant and on the abundance of the insect, and looks like the damage caused by *Chilo*. Early infestation on rice is rare. At heading stage, the young caterpillars active in the upper parts of the stem cause the 'white panicle' symptom. When young, the caterpillars live in small groups, they then disperse and move down to the lower internodes that they can sever completely even at the base. The cycle is almost continuous in humid tropical regions, where the number of generations varies between 5 and 6 per year, compared to 3 in the Sahel.

Dipteran stem borers

Dioposis thoracica W. (Syn. *D. macrophthalma* Dalman)

Description

- Egg: elongated, with nerves, with a small fleshy excrescence at one end.
- Larva: yellowish with two elongated abdominal prolongations, with black hooks, folded forward.
- Cocoon: elongated, brown-red, with well-marked segments.
- Adult: can measure 10 mm, the thorax is shiny black, the wings transparent, the abdomen is red-orange and covered with fine, dense hair (*see* Photo pages: Photo 23.4).

Biology and damage

Each female lays 30 isolated eggs, spread over 20 days, with a maximum of 4 to 5 eggs a day. Hatching takes 2 to 3 days. Duration of larval life is 25 to 33 days. Pupa, 10–12 days. Adult stage, 14 days.

The adult gets through the dry season when still immature, adults swarm in the vicinity of permanent pools or wet inland valleys, preferably in the shade. When the first rains begin, sexual maturity is reached and the females start laying eggs on young tillers. During crop development, depending mainly on the rainy season, *Diopsis thoracica* is only common in rice fields or on wild rice.

Soon after hatching, the larva penetrates the stem at the sheath level and feeds on healthy tissue. There is usually only one larva per stem; the stem's 'heart' is cut wedge-like about 10 cm above the soil. When decomposition due to this cutting begins, the larva leaves the stem to go on to another one, and thus destroys an average of three stems during its development. Pupation begins inside of the last stem visited, unless the stem is too small. The larva lives exclusively in stems that are still flat when tillering. Exceptional late attacks can affect heading. There is only one generation developing in a given plot, as the adults from the first generation look for younger stems.

Evaluating damage by estimating the number of stems infected is not sufficient. Moreover, a compensatory tillering results from the loss of destroyed tillers. This mechanism depends on the precocity and intensity of infestation, on the tillering capacity of the variety, and on development conditions. The visible 'dead hearts' are often numerous, but 80% of the tillers can be infested without considerably affecting the yield.

The losses—difficult to estimate—are essentially visible when there is a high concentration of egg-laying at the beginning of tillering on early varieties. However, for the same level of infestation, differences are considerable depending on the resistance of the variety and on its tillering capacity.

Methods to control stem borers

While it is possible to control some kinds of insects after visible signs of infestation have appeared, stem-borer control needs to be preventive. Indeed, the larvae are very young and hardly visible when they penetrate the stems and it is too late for control when the damage begins. Given that stem-borer losses do not change a lot year after year, it is possible to establish systematic intervention procedures adapted to each agricultural and economic complex.

Chemical control

Only improved irrigated rice crops, with highly productive varieties, justify the use of insecticides against stem borers. The application of insecticides on rainfed, less-productive rice, is not cost-effective. When the farmer decides to apply an insecticide, he/she has to be sure that this operation is cost-effective and, most of all, he/she has to follow the recommendations to guarantee the efficiency of the treatments and his/her own safety. In areas at high risk of stem-borer infestation, carbofuran, diazinon or lindane at a rate of 2 kg a.i./ha can be recommended to be applied 20 days after planting to combat *Diopsis* spp., and 50 to 70 days after planting to combat lepidopterous stem borers.

Crop management practices

Early sowing, narrow spacing of plants and maintaining weed-free fields can minimize stem-borer infestation. It is possible to limit infestation by *Chilo zacconius* by synchronized planting over large areas.

Several tillage practices can interrupt the life-cycle of stem borers:

- *Stubble plowing* kills the caterpillars in the stalks and crop residues.
- *Fallowing* (interruption of cultivation).
- *Destroying* intermediate host plants to eliminate breeding sites.
- *Flooding* the rice fields after harvest.

These solutions require sufficient time, labor and adequate water control. Tillage practices and manure application favor good plant development and the resistance of the crop, but they can increase infestation at the same time.

Biological control

There are a variety of earwings, dragonflies and spiders that feed on larvae and adult stem borers.

Among the numerous parasitoids on *Sesamia* spp., the braconid *Cotesia* (= *Apanteles*) *sesamiae* Cameron and the eulophid *Pediobus furvus* Gahan are the most important.

Research on biological control has just begun in Africa. Based on the inability of the indigenous natural enemies to suppress insect populations, *Cotesia flavipes* Cameron was imported from Asia and released in Côte d'Ivoire and Senegal against *Chilo zacconius* in rice, but with no lasting success. Further biological programs must be considered with caution, since there is a need to know more about interactions of indigenous natural enemies before embarking on classical biological control by the introduction of parasitoids.

Varietal resistance

This is using varieties that are resistant or tolerant to insect pest damage. The following resistant *O. sativa* lines have been identified:

- ITA 121 (tolerant to *Diopsis* spp.).
- LAC 23, IR 4625-132-1-2, IR 2035-120-3, Colombia 1, N 21-1 (tolerant to *Chilo zacconius*).
- IR 1108-3-5-2, SML 140/10, SML 140/5 ´ TN 1, SML 140/5 ´ IR 8, IR 2871-53-2, TOS 4153, B2850, BS-1-2-2, IET 5905, IR 9872-144-3-3-3 (tolerant to *Maliarpha separattela*).

Several promising lines that show appreciable resistance have been identified, particularly among African rices *O. glaberrima*. NERICA4, an upland interspecific (*O. sativa* × *O. glaberrima*) shows good tolerance to stem borers. However, no commercial varieties resistant to *C. zacconium* and *M. separatella* suitable for West African lowland conditions have been released yet.

Integrated stem borer control

Integrated control aims at keeping the populations of stem borers as low as possible without disturbing the ecosystem's stability. Integrated control views the different control measures as complementary and not as alternatives.

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This reference has been adapted from:

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Reference 24 Major diseases in rice

Summary

This reference presents the causes and symptoms of the three main diseases of inland-valley rice: blast, rice yellow mottle virus and bacterial leaf blight.

Diseases are considered major constraints in rice production. Rice diseases are mainly caused by fungi, bacteria or viruses. Stunting is one of the symptoms; others are: color changes, wilting or abnormal development of certain organs. These symptoms can be found in all the organs of the plant. The most common and most severe diseases in rice are blast, rice yellow mottle virus (RYMV) and bacterial leaf blight.

Blast

Blast is caused by the fungus *Pyricularia oryzae*. Blast can infest any organ of the plant: leaf, neck, panicle rachis, stem node, grain, etc. When the disease attacks the leaves, we talk of leaf blast (*see* Photo pages: Photo 24.1). There are other kinds of blast: neck blast when the base of the panicle starts to rot, and node blast at the level of the stem nodes (*see* Photo pages: Photo 24.2). When blast infests the neck of the panicle, nutrients cannot reach the grains.

The disease multiplies rapidly by spores, multiplying on leaves and panicles, which then penetrate into tissues; a few days later, the lesions or symptoms appear. The tips of leaf lesions are typically spindle-shaped, wide in the center and pointed at the ends. Large lesions usually develop gray centers bordered by brown to dark red. Chlorophyll disappears in the parts attacked, which means that photosynthesis and yield are reduced.

On the base of the ear, the same symptoms can be present (neck blast): blast infects the tissue, the ear pivots and breaks off. If the infestation starts at the milky grain stage, the panicle remains empty; if it starts later, the grains do not fill well and the rice quality is affected (chalky, brittle or greenish). Stem blast causes soft rot at node level, the nodes break resulting in different degrees of damage depending on the crop development stage. Blast is favored by too high a dose of nitrogen and high humidity.

Rice yellow mottle virus

Rice yellow mottle virus (RYMV) is a plant virus disease. The most important symptom on a rice plant is that leaves turn yellow, with alternate yellow and green stripes that give its typical mottled appearance to the plant (*see* Photo pages: Photo 24.3). The other symptoms are: stunting, reduced tillering, leaf mottle with yellow stripes, incomplete panicle exsertion, the panicle sometimes being badly formed, and spikelet sterility.

In natural conditions, RYMV is transmitted from an infested plant to a healthy plant by insect vectors of the beetle group (most important *Sesselia pussilla* and other vectors such as *Chaetocnema* spp., *Aulacophora africana*, *Trichispa sericea* and *Dicladispa viridicynea*), or by lesions caused by tillage practices (transplanting, weeding, etc.). The disease can be transmitted mechanically; touching an infested plant and later a healthy plant can transmit the disease. In an infested field, yellow patches indicate the infestation.

Bacterial blight

Bacterial blight is the third main rice disease in West Africa; it is confined to the Sahelian region (Mali, Senegal, Niger, etc.). This disease is caused by *Xanthomonas oryzea* pv *oryza*. Transparent stripes appear on the leaves, later these lesions dry and become brown and opaque (*see* Photo pages: Photos 24.5 and 24.6). In severe cases, the whole field seems to have been burnt. The spread of this disease (also known as bacterial stripe) is favored by wind, storm and ill-balanced mineral nutrients in the soil.

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Table 24.1. Classification of rice diseases in western Africa

Category	Disease name	Pathogen	
		Scientific name	*Nature*
Major pathogens	Blast	*Magnaporthe grisea*	Fungus
		Pyricularia oryzae	Fungus
	Rice yellow mottle virus	RYMV	Virus
	Bacterial blight	*Xanthomonas oryzae orysae*	Bacterium
Secondary pathogens	Brown spots	*Drechsiera oryzae*	Fungus
		Bipolaris oryzae	Fungus
		Gerlachia oryzae	Fungus
	Leaf blast	*Monographella albescens*	Fungus
		Rhizoctonia solani	Sterile fungus
	Sheath blight	*Thanatephorus cucumeris*	Fungus
Minor pathogens	False smut	*Ustilaginoidea virens*	Fungus
		c. *oryza sativa*	Fungus
	Bakanae disease	*Fusarium moniliforme*	Fungus
		Gibberella fujikuroi	Fungus
	Cercosporiosis	*Cercospora oryzae*	Fungus
	Sheath rot	*Acrocylindrium oryzae*	Fungus
	White gall	*Corallocytostroma oryzae*	Fungus
	Fading color of sheaths	Fungi complex	Fungus
	Culm disease	Fungi complex	Fungus
	Bacterial stripes	*Xanthomonas oryzae*	Bacterium

Reference 25 Integrated rice disease management

Summary

Integrated rice disease management is the combination of different methods to control diseases in a cost-effective way, based on sound environmental management. Pathogen populations are kept at low levels, not causing economic damage, using a combination of appropriate technologies. None of these methods or techniques can by itself ensure efficient and sustainable protection.

Varietal resistance and crop management practices—primary elements of integrated management

Integrated disease management focuses on varietal resistance, because it is the simplest and cheapest way to limit pathogen populations, and thus the most accessible method for farmers.

This means that varieties are chosen because they are resistant to disease infestation. The method gives good results, especially in the case of rice yellow mottle virus (RYMV) and blight.

However, varietal resistance is often not enough to protect the crop in a sustainable way. For instance, for blast, the occurrence of new pathogen races or environmental conditions favorable to the disease (high level of inoculum, overcast sky, high atmospheric humidity) can trigger epidemics on previously tolerant varieties. For this reason, WARDA recommends an integrated control strategy in which varietal resistance is accompanied by preventive measures both favorable to rice and reducing disease proliferation. These measures are detailed below.

Crop management techniques

- Appropriate sowing or transplanting date to avoid flowering coinciding with high atmospheric humidity (generally during the rainy season). High humidity is favorable to blast infestation.
- Synchronized sowing and transplanting to avoid build up of insect pests that can transmit diseases such as RYMV.
- Using healthy or treated seed—fungal diseases (blast) and bacterial diseases can be transmitted via seed.
- Destruction of weeds and crop residues that can act as reservoirs for pathogens and insect vectors.
- Balanced and reasonable fertilizer use: high doses of N can increase blast infestations, while high doses of K generally limit blast infestation.
- Destruction of rice stubbles and vector host plants to avoid pathogen build up and to interrupt the life-cycles of insect vectors.
- Cleaning of canals and borders of plots that can be reservoirs of RYMV, alternative hosts and insect vectors.

Chemical control—secondary elements of integrated management

Chemical control consists of using preventive or curative products to treat the crop. Chemical control is only justified when no other method is available. In the case of rice, this form of control is hardly ever used. However, sometimes it is recommended that seed be treated to prevent diffusion of pathogenic fungi associated with seed transportation.

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Reference 26 Harvest and post-harvest

Summary

Timely harvesting, threshing and drying are essential operations to guarantee an abundant and good-quality harvest. All the efforts put forth from land preparation onward can be compromised when these operations are badly implemented. This reference gives guidelines that help avoiding large paddy losses, both in quality and quantity, during these operations.

Harvesting date

Determining the optimal date for harvesting is the most important factor, as mistakes could lead to high losses and affect the quality of paddy.

- Harvesting too early means that a high percentage of grains will be immature: the yield will be reduced, and grains will break easily.
- Harvesting late favors lodging, and exposes the crop to birds, rats and insects. The yield will be reduced and the quality of paddy will be lower with high rates of broken rice and low processing yields.

The factors indicating the most appropriate moment for harvesting are the following:

- 80% of the panicles are yellow.
- 20% at least of the lower panicles have reached the dough (hard) stage.
- If the husk is peeled off, the grain is light-colored and hard.

Harvesting methods

Harvesting by hand is usually done with a sickle. The plot should have been drained 15 days before harvesting, in order to facilitate moving in the field and also to prevent grains from germinating if they were in contact with water, and from being soiled by mud, both of which affect paddy quality. The cutting height depends on the post-harvest objectives of the farmer (threshing method, selling the straw, etc.) and also on the harvesting devices used. Hand-harvesting is tiresome and time-consuming: it requires 15 to 20 people with sickles to harvest one hectare. Harvesting can also be done with knives, and then only the panicles are harvested.

Mechanical devices are seldom used in inland-valley rice cropping in Africa. The 'ISA' reaper-harvester, developed by WARDA and its partners, could improve harvesting, especially on small farms.

Yield losses are usually relatively high (depending on varieties and on the crop condition), but can be significantly reduced when harvesting is done on time. When harvesting is late, losses can easily reach 15–20% of the production.

Drying

The sheaves harvested are spread in the sun to dry for 24 to 48 hours. This makes threshing easier and reduces the moisture content to a convenient level (14–15%) for processing and storing.

After drying, the sheaves are stacked. To facilitate handling when threshing and reduce bird damage, the stack should be circular or rectangular, and the sheaves set so that the panicles are towards the center.

Leaving the panicles to dry for too long reduces grain quality and exposes the panicles to rat or bird damage, but if panicles are too moist threshing becomes difficult and bacteria and fungi may develop on them during storage.

Threshing

This is the operation that separates the grain from the panicle without damaging it. It can be done by hand or mechanically. Mostly in small farms, hand-threshing is usually done with a flail or on an empty barrel. It is hard work and requires a lot of labor.

Mechanical threshing is done with fixed threshers (Borga, Votex, ASI). It is much faster and indispensable in intensive rice cropping. However, the equipment choice must take into account the farmers' socio-economic climate in order to better insert them in their production systems (impact, after-sales service, ergonomics, cost of purchase and maintenance, etc.). During threshing, the shocks the paddy endures lead to grain cleaving and may have consequences on its germination ability.

Beyond its performance (yield threshed per hour), the 'ASI' thresher–cleaner, developed by WARDA and partners, decreases cleaving rates because of its axial flow system. Moreover, it is also equipped with a ventilation system that produces a clean product, which does not require winnowing.

Storing

Correctly storing paddy must follow certain rules in order to:

- Preserve viability and germination ability of seeds.
- Preserve the quality of paddy for processing.
- Avoid losses due to diseases, insects and rats.
- Avoid molding.

This operation, which is often neglected by producers, is one of the main causes of the qualitative depreciation of paddy.

The paddy harvested must be handled like any live biological product, as seeds are live organisms whose growth is temporarily suspended. The quality of paddy can be deteriorated by bacteria and fungi, for which the favorable conditions for development are: high moisture content of paddy, high relative humidity of air, and high temperatures in the store. In order to prevent these risks, the following measures must be observed when storing paddy:

- Correctly dry the threshed paddy in the sun, until a moisture content of about 14% is obtained. This percentage is reached when the paddy is dried in the sun for 24 to 48 hours (with at least 8 hours of sun per day), and if the harvesting has been done at the right time. If too dry, the internal moisture of the grain will fluctuate and lead to high breakage percentages during processing.
- Put the paddy in jute bags (preferably new), to allow good ventilation of the product. If necessary, label the bags, including the variety name and harvest date.
- Clean the store and spray the inside with a solution of malathion 2% or any other appropriate product to protect paddy against insects. Let it dry before storing the paddy.
- Place wooden pallets directly on the ground, so as to allow good ventilation around and under the bags. Leave some space between the bags and the walls.
- Lay the paddy bags one upon the other, taking care to alternate their orientation.
- Never store chemical products (fertilizers, herbicides, etc.) with paddy.
- Check the stock once or twice per week; if insects or rats are detected, treat again, preferably with bio-pesticides like neem.
- When storing for a long time, check the moisture level of the grains; if it increases too much, dry again in the sun. To prevent this problem, once in a while put the stock in the sun for the day.

Transferring paddy to the factory

This step in the rice network is often neglected by producers, although it is one of the main reasons for counter-performance in rice processing. The quality of the paddy, in particular the moisture content of the grain, is a determining factor in the processing yield and for the quality of the processed rice.

When the moisture content of the grain is too high (more than 14%), the milling recovery (weight of milled rice divided by weight of brown rice before milling) will be affected. When the moisture level is too low (below 10%), the percentage of broken grains increases.

To guarantee good yield and acceptable grain size distribution (product essentially made of whole rice grains, intermediate grains and relatively large broken grains), the moisture content at processing ought to be between 12 and 14%. This means that, after respecting all the recommendations about the last draining before harvesting, and about the drying and threshing conditions, the paddy to be processed should be taken to the factory as soon as possible.

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Reference 27 End-of-season evaluation

Summary

The end-of-season evaluation is a very useful tool that helps improve the overall performance of a farm. It consists of comparing expectations and outcome, and analyzing the differences. An end-of-season evaluation analyzes the season's results, but also prepares for the next season. The importance of calculating value/cost ratios in the financial analysis of a new technology is also explained.

Elements required for an end-of-season evaluation

The elements required for an end-of-season evaluation are: the predicted financial balance sheet, the actual financial balance sheet, an analysis of the difference between the two, and recommendations for improvement, leading to a new work-plan and expected financial balance sheet for the next season. The work-plan takes into account timing of crop management interventions as budgeted in the financial balance sheet.

Financial balance sheet

This is a table (Table 27.1 showing an example for an inland valley with good water management) with a number of line items, showing costs of inputs and value of agricultural produce. The actual numbers obtained at the end of the growing season need to be compared with the predictions at the start of the season.

Financial analysis of the performance of a new technology

When introduced to farmers, a new technology has a chance of being considered viable and adopted by the producers if the ratio value/costs exceeds 1.5 or 2. This ratio points at the additional benefit attributable to the technology minus the costs linked to this yield profit (e.g. additional costs for harvesting, threshing, etc.). In this ratio, the costs are the additional costs necessary to apply this technology. A minimum ratio of 2 has been suggested for the use of mineral fertilizers in Africa.

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Table 27.1. Example of financial balance sheet

Items	Quantity	Units	Unit cost	Total cost
Variable costs				
Crop management operations				
Plowing				
Other				
Agricultural inputs				
Seeds				
Urea				
NPK				
Herbicides				
Propanil				
Weedone				
Other phytosanitary products				
Input transport				
Harvest				
Bags				
Human labor				
Harvest				
Handling				
Harvest transport				
Total variable costs				
Other costs				
Dikes, embankments maintenance				
Other				
Total costs (a)				
Production value (b)				
Net revenue (b) – (a)				

Reference 4

Iron toxicity

Photo 4.1. Symptoms of iron toxicity on leaves

Photo 4.2. Symptoms of iron toxicity in the field

Photo 4.3. Oxidised iron spots on soil

Reference 14

Plant nutrients

Photo 14.1. Symptoms of nitrogen deficiency

Photo 14.2. Symptoms of phosphorus deficiency

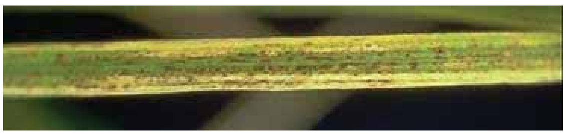

Photo 14.3. Symptoms of potassium deficiency

Photo 14.4. Symptoms of zinc deficiency

Photo 22.1. African rice gall midge; adult

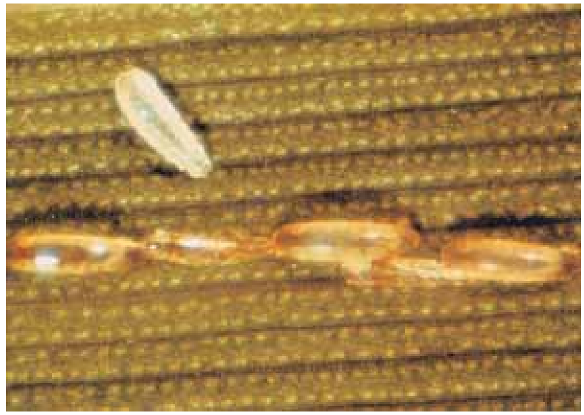

Photo 22.2. African rice gall midge; eggs

Photo 22.3. African rice gall midge; larva

Photo 22.4. African rice gall midge; cocoon

Photo 22.5. Symptoms of the African rice gall midge in the field

Photo 22.6. Symptom of the African rice gall midge on the plant (onion leaf)

Reference 23

Rice stem borers

Photo 23.1. Symptom of stem borer: dead heart

Photo 23.2. Symptom of stem borer: white head

Photo 23.3. Lepidopteran stem borer *Chilo zacconius*

Photo 23.4. Dipteran stem borer *Diopsis thoracica*

Major diseases in rice

Photo 24.1. Pyriculariosis: symptom on leaf

Photo 24.2. Pyriculariosis: symptom on the node

Photo 24.3. Rice Yellow Mosaic Virus (RYMV): symptoms of leaves

Photo 24.4. RYMV: symptoms in the field

Reference 24

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Photo 24.5. Bacterial leaf blight

Photo 24.6. Bacterial leaf blight

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