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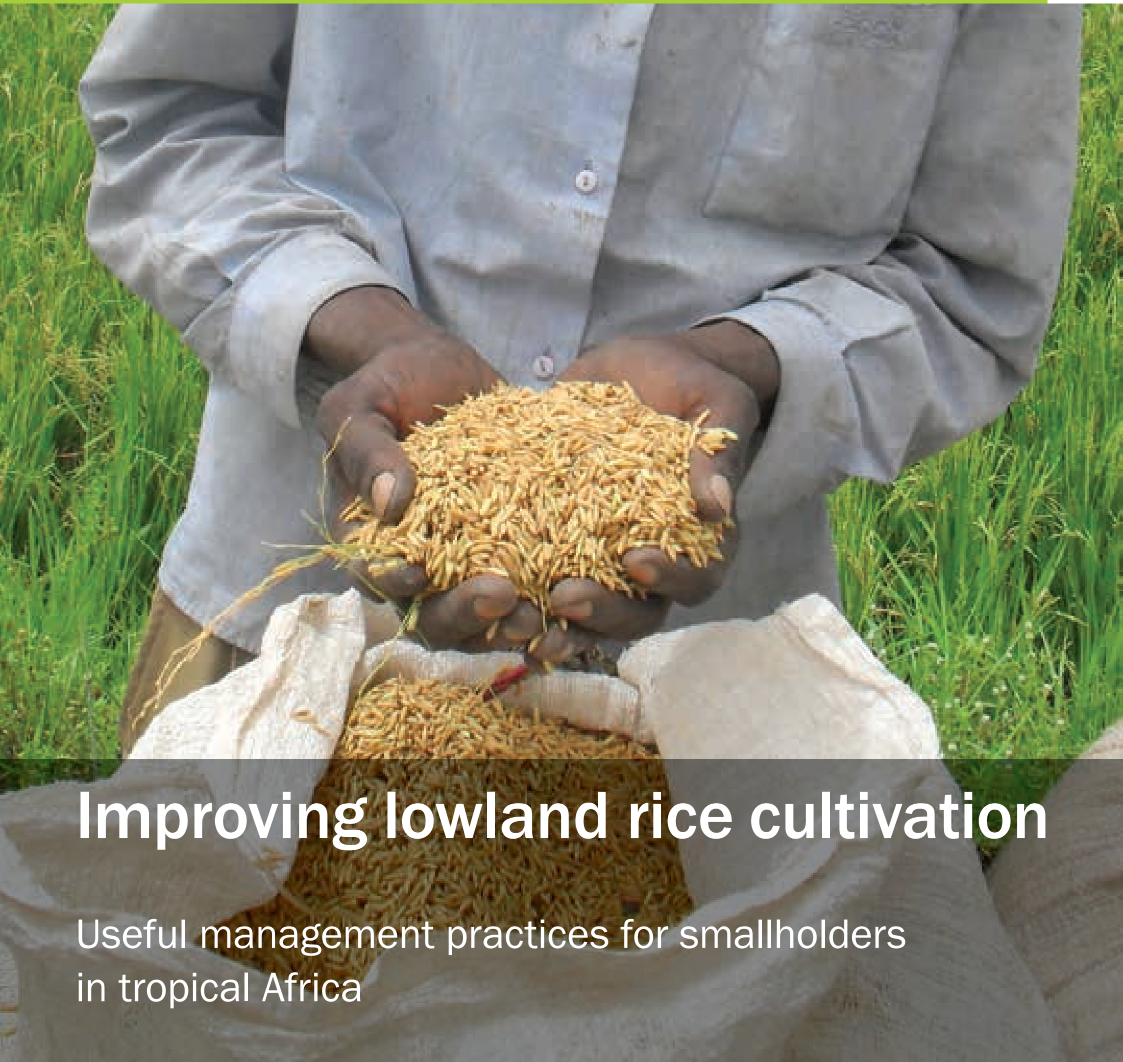

Improving lowland rice cultivation

Useful management practices for smallholders in tropical Africa

51

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Foreword

Lowland rice cultivation is practised in all tropical African countries. Although rice is the main crop and staple food of many African farm families most of the information on the rice cultivation is based on experiences with small-scale rice production in Asia. The aim of this Agrodok is to provide extension workers and smallholder rice farmers in tropical Africa with the practical and up-to-date information they need to increase the profitability and sustainability of their rice farming and rice processing practices.

As authors we have drawn on our experiences with lowland rice research and development in Tanzania, Togo, Guyana, Surinam and the Sahel to show how farmers can improve their yields by following the steps we outline in this Agrodok. Several experienced agriculturalists and organisations have contributed to this handbook and we would like to thank them for sharing their expertise with us. Robert Elmont, Ab Wanders, Paul Belder, Yacouba Séré and Jonne Rodenburg provided us with specific information on harvesting, storage, water management and pest control while Timothy Krupnik's comments on SRI and Roland Buresh's information about the use of the leaf colour chart were particularly valuable. Finally, our special thanks are due to Willem Stoop and Wim Andriesse, who reviewed the entire manuscript.

Bert Meertens and Michiel de Vries

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1 Introduction

This Agrodok on lowland rice is primarily meant for smallholders in tropical Africa, because the advocated cultivation and processing practices reflect the main circumstances encountered by rice farmers on this continent. The aim of this Agrodok is to inform extension workers and smallholder rice farmers in tropical Africa about current views concerning efficient, profitable and sustainable lowland rice farming and rice processing.

Lowland rice cultivation is practised on about half of the total rice area in tropical Africa. On the other half upland rice cultivation is practised. Deep-water rice cultivation occupies only a very small part of the total rice area.

Generally, lowland rice cultivation is characterised by rice fields which are submerged to a maximum depth of 50 cm for almost the complete growing season. Upland rice cultivation is characterised by rice fields which are not submerged most of the time. Deep-water rice fields have a minimum of 50 cm standing water in which the rapid growth of the rice plants' internodes keeps pace with the rising water. Deep-water rice can grow as tall as 5 m.

This booklet cannot cover all the details of lowland rice cultivation and processing in tropical Africa due to its limited size and the many different circumstances in tropical Africa related to climate, soils, pests and water management. We chose to focus on the main rice management practices, especially water management practices, which can be adapted by the farmers themselves and which affect the quantity and quality of the rice yield. Although there are many booklets available on lowland rice cultivation in Asia, this Agrodok is specifically suitable for smallholders who cultivate lowland rice in tropical Africa.

Cultivation systems

Lowland rice cultivation covers a wide range of cultivation systems, including mangrove swamp rice along coastal regions with tidal intrusion, inland swamp rice on flat or saucer-shaped valley bottoms with varying degrees of flooding, rice on river floodplains, and rice on bunded fields under rainfed or irrigated conditions. A very important factor in classifying these cultivation systems is the degree of water control. Without land levelling, bunds or water inlets/outlets, good water control will be difficult. Conversely, optimal water control can be achieved in well constructed and managed irrigated systems with perfectly levelled fields and a secure water supply. A vast range of water management situations exist in between minimal and optimal water control.

The degree of water control has a strong impact on the germination, growth and harvest of the rice plant. The degree of water control furthermore determines the strategies available to farmers for preparing the land, the use of fertilisers and the management of weeds and pests. This booklet presents how small-scale farmers can improve their water management. It further indicates which cultivation methods match good, moderate and weak water control in the rice fields.

2 Rice growth and development

2.1 Introduction

This chapter describes how the rice plant grows, what types of lowland rice occur in tropical Africa and how to recognise different plant parts. For proper lowland rice management it is important to be able to identify the crop's growth stage, and to know which types of rice are available.

The growing cycle of rice can be divided into three successive stages (Figure 1):

1. **The vegetative stage,** from germination to panicle (flower) initiation, during which the plant develops from a stem (tiller) with only one leaf into a plant with multiple tillers and leaves. The duration of the vegetative stage ranges from 35 to more than 120 days.
2. **The reproductive stage,** from panicle initiation to heading (emergence of the panicle tip from the leaf sheath), during which the plant develops panicles. Panicle initiation takes place approximately when the maximum number of tillers have developed. This can be checked in the field by cutting a main tiller at its base to see if a micro-panicle is developing.
3. **The grain filling and maturation stage,** from heading to maturity, which starts about three days after a plant has started heading, and continues until the grains are hard and ready for harvest.

Figure 1: Growth stages: 1 Germination; 2 Emergence; 3 Start of tillering; 4 Maximum tillering and panicle initiation; 5 Flowering; 6 Maturity.

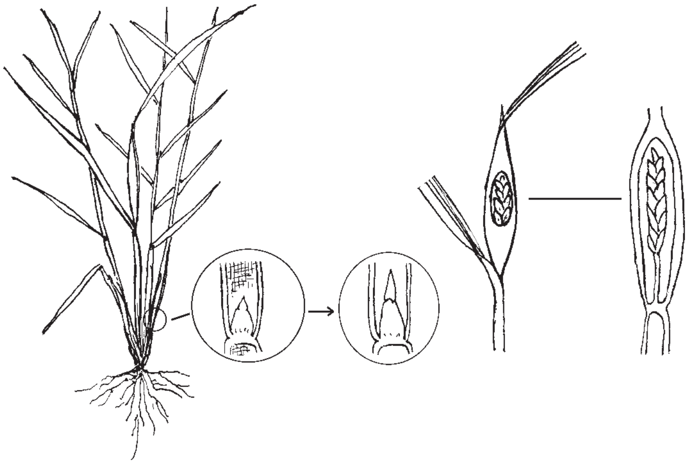

Figure 2: Details of panicle initiation with micro-panicle in base of the main tiller (left) and developed panicle in tiller sheath at heading (right).

Cultivars differ mainly in the length of their vegetative stage.

2.2 The growing cycle

This section describes the different stages of the rice plant in detail, from sowing to maturity.

1. Germination

Once in contact with moisture, rice seed germinates in 24–48 hours. The optimum temperature for germination is 30–32°C. Most cultivars have a short or no dormancy period during which the seed is reluctant to germinate; but for some African rice (*Oryza glaberrima*) cultivars, this period may last up to four months.

2. Emergence

Emergence takes place 4–5 days after sowing. Ten days after germination the plant becomes independent as the seed reserve is exhausted. At that time it has at least two leaves and a 5 cm long root.

3. Tillering

Tillering begins when about five leaves have developed, although in transplanted seedlings it may be a week later. Transplanting causes a shock that delays development for about 10 days. Sometimes leaves of seedlings are cut, to prevent excessive evaporation in the first days after transplanting. Modern cultivars with a medium growing cycle attain the maximum number of tillers around 50 days after transplanting, which coincides with panicle initiation.

4. Flowering

The reproductive stage starts at panicle initiation, and the time between panicle initiation and flowering is around 35 days. It takes around seven days to complete the anthesis (opening of flowers) of all spikelets in a panicle, starting from the top of the panicle and progressing downwards.

5. Ripening

The period from flowering to full ripeness of all the grains in a panicle is usually about 30 days. Total cycle duration is between 105 and 125 days for a short-duration cultivar, 130–160 days for medium-duration cultivars, and more than 160 days for long-duration ones. Low temperatures delay maturity and high temperatures accelerate it; hence the durations can vary between places (e.g. different altitudes) and between different seasons (wet and dry / cool and hot seasons).

Figure 3: Growing cycle of the rice plant: 1 Seed; 2 Germinated plantlet; 3 Vegetative plant; 4 Start of tillering; 5 Mature plant.

2.3 Rice types

The cultivated and wild rice types all belong to the botanical Oryza group. African rice (*Oryza glaberrima*) is indigenous to Africa, but most of the current cultivars used in lowland rice cultivation in tropical Africa are of the Asian rice type (*Oryza sativa*). The major type of *Oryza sativa* used in tropical Africa is Indica. Traditional Indica cultivars are tall, leafy, strongly tillering, and prone to lodging. They produce fair yields under conditions of low management. Modern Indica cultivars are small, and they are less tillering, less leafy, resistant to lodging, insensitive to photoperiod and are early maturing. These modern Indica cultivars have, however, a higher yield capacity than the traditional cultivars.

Rice is almost 100% self-pollinating, but small amounts of cross pollination by wind do occur. Maximum plant height depends on the cultivar and growing conditions; for modern cultivars it is about 90 cm, others may reach 120 cm or even more.

Cultivars of African rice (*Oryza glaberrima*) can cope with specific African pests and diseases (see Chapter 8). In some places African rice has become a weed; in other areas it is valued for its taste and its adaptation to local conditions. African rice is almost exclusively cultivated in West Africa and almost absent as a cultivated crop in Central, Eastern and Southern Africa. African rice has rapid vegetative growth. Vigorous tillering and prolific leaf growth contribute to its high competitiveness against weeds. Consequently its plant stand is wide and open. On the other hand, stems tend to be weak and brittle, making it prone to lodging. Some shattering of seed occurs in many cultivars. It can be distinguished from Asian rice by its reduced secondary branching in panicles, its smaller and less pronounced ligule, and the absence of auricles (see Figures 4 and 5). Asian rice types perform generally better under wet conditions.

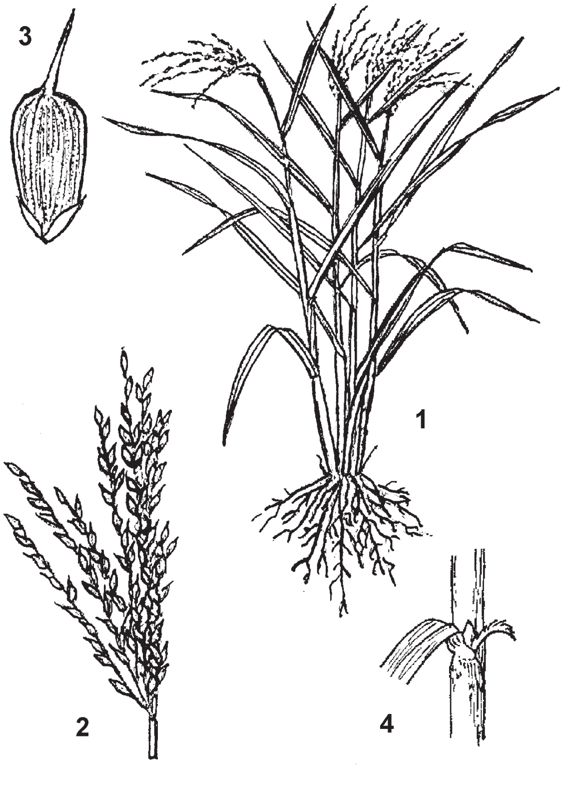

Figure 4: Asian Rice Oryza sativa: 1 Plant with roots; 2 Panicle; 3 Mature grain; 4 Leaf base with typical ligule (tongue) and auricle.

Figure 5: African Rice Oryza Glaberrima: 1 Plant with roots; 2 Panicle; 3 Mature grain.

2.4 Rice cultivars

When selecting their rice cultivars, farmers look at the following list of characteristics:

- grain yield potential
- time to maturity
- straw length and strength
- early vigour
- pest and disease resistances
- cooking and processing characteristics and
- suitability for wet or dry growing conditions.

Although rice per se is not an aquatic plant, it has adapted to wet conditions. As a result, rice roots can grow under both dry and water-logged conditions. However, some cultivars grow better under continuous water-logged conditions, while others are better adapted to alternating wet and dry conditions. Ecological circumstances in a particular field and economical and social factors at the household level determine the choice of cultivars.

Many cultivars have obtained local names, but their origin is often not local. Asian and African development agencies and research institutes such as IRRI and the Africa Rice Center have introduced cultivars from many parts of the world into Africa.

The increasing popularity of NERICA cultivars (New Rice for Africa), which are crosses between Asian and African rice established at the Africa Rice Center, is noteworthy. Due to the common use of long-term recycling of farmer-saved seeds, almost all cultivars have adapted to local conditions and diverge from the original cultivar. Due to the large number of cultivars used and their local adaptation in different areas, it is practically impossible to supply a list of main cultivars with their specific characteristics.

3 Lowland rice cultivation systems

In tropical Africa, lowland rice cultivation, which comprises mangrove swamps, inland valley bottoms, river flood plains and irrigated perimeters, accounts for 55% of the total rice area. Lowland rice in sub-Saharan Africa is cultivated in a variety of systems and can be found from tropical rainforests up to the semi-arid savannah. In this booklet we restrict ourselves to lowland rice systems with a maximum water depth of 50 cm. This means that deepwater rice is not included. The main distinguishing factors in lowland rice are the degree of water control and the type(s) of water source. In Table 1, a division is made based on these factors with an estimation of the range of yields that farmers attain depending on the crop and soil management.

Often, a formal distinction between these cultivation systems cannot be made and it is better to see them as a continuum. Water control level can change over time and within the same field. Fields may be irrigated in the dry season, but rainfed during the wet season. Within irrigation schemes, head and tail ends of fields may have different levels of water control. Currently, it is estimated that 10% of the lowland rice cultivation area has a high degree of water control.

Table 1: The level of water control, water source and an indication of the yield range for different lowland rice cultivation systems

Cultivation system	Water control level	Water source	Attainable paddy yield range (t/ha)
Rainfed lowland	Low	Rainfall/floods	0.5 – 2
Rainfed lowland with bunds	Low Intermediate	Rainfall/floods/ groundwater	1 – 3
Incompletely irrigated	Intermediate high	Rainfall/floods/ irrigation	1.5 – 5
Irrigated perimeters	High	Irrigation	3 – 8

Rainfed lowland cultivation system

In rainfed lowland without bunds, the main water sources are rainfall and floods from nearby rivers. The lack of effective control over the amount and timing of the water supply, resulting in alternating periods of drought and water excess, or even submergence, makes this cultivation system not very productive. The low degree of water control further complicates proper land preparation and effective weed control. As a result the quantity and quality of rice production from rainfed fields without bunds is generally unsatisfactory.

Rainfed lowlands cultivation system with bunds

In rainfed lowlands with bunds groundwater is an additional source of water in areas with a sufficient slope. Bunds constructed in the rice fields help to keep the water in the confined area. Redistribution of water to adjacent fields can be done through small inlets and outlets. Draining excess water in fields at the lower end of the slope is however often difficult.

Incompletely irrigated cultivation system

There are two types of incompletely irrigated cultivation systems. The first is a rainfed lowland system with bunds in which water control is further improved through land levelling, canals for drainage and terracing. Small dams at an inlet or a water storage reservoir may further enhance water supply. The second type is an irrigated system with malfunctioning irrigation and drainage. This can be due to unsatisfactory water distribution, overdue maintenance of canals and/or inadequate irrigation/drainage structures. However, rice paddy yields of up to 5 tonnes/ha can be reached under these suboptimal irrigated conditions.

Completely irrigated cultivation system

In completely irrigated cultivation systems there is complete control of the water level in the rice fields at any time. This is only possible when the physical and social structures of the irrigated area are both in perfect order. First of all the irrigation and drainage inlets and outlets have to function without problems at any time of the year. Secondly, water user associations must function properly so that water distribution between fields will be fair and equal at any time of the year. Paddy production levels under such circumstances can reach 8 tonnes/ha in areas with high sunshine levels.

3.1 Benefits of better water control

The level of water control is important for:
- *meeting the water requirements of the rice plants at each stage,*
- *the quality of land preparation,*
- *the effectiveness of weed control and*
- *the efficiency of soil fertility strategies.*

Table 1 shows that production levels vary greatly from low to high water control. In line with the production level of the cultivation system, rice farmers choose their rice management practices. For example, in rainfed lowlands farmers may direct-seed to allow germination before flooding, whereas in systems with better water control wet soil preparation can take place and transplanting is practised. Improvement of water control may increase the yield potential enormously and change the cultivation system completely. Under improved water control conditions rice farmers can for example opt to follow the System of Rice Intensification (SRI). Box 1 presents briefly the characteristics of the SRI system.

Ways to improve water control will be explained in Chapter 5. Improved water control can further enable the cultivation of a second rice crop, unless other factors block that opportunity. In the latter case farmers can alternatively grow horticultural crops or legumes in the rice off-season.

If irrigation and drainage cannot be controlled, application of herbicides may be ineffective and mineral N-fertiliser may not be beneficial for the crop. This is explained in detail in Chapters 6 and 7.

Box 1: The System of Rice Intensification (SRI)

The System of Rice Intensification (SRI) was developed in Madagascar during the 1980s for irrigated rice production. SRI was the result of collaboration between rice farmers, an NGO and a French Catholic priest with a degree in agronomy. SRI is based on the premise that through changes in soil, water and plant management rice can produce more fertile tillers and grains than what is normally obtained by farmers.

Crucial aspects of SRI are:

- *early transplanting of one seedling per hill at a wider spacing*
- *no standing water during the vegetative phase*
- *the application of compost*
- *early and frequent weeding*

In general it is advised to use seedlings of 8 to 12 days old; before seedlings develop more than three leaves. Where soils are poor it may be better to use two seedlings per hill. Farmers are advised to start with a spacing of 25 x 25 cm between hills and with a wider spacing such as 35 x 35 cm on good soils. On poor soils it is better to use a closer spacing of 20 x 20 cm. The SRI recommendation is to avoid continuous flooding during the first two months and to drain the fields periodically. Farmers are encouraged to leave their fields dry for 2 to 6 days every 7 to 15 days and then re-irrigate their fields with a small layer (±5 cm) of water. This permits the aeration and warming of the soil during the drains, which contributes to improved root growth. The ideal case is to add small amounts of water daily in the late afternoon or evening and to drain excess water in the morning. A well-levelled field with a proper drainage system would facilitate this water management. Applications of 1 or 2 tonnes high-quality compost per ha (or more if available) are recommended to obtain good yields and improve the biological life of the soil. However, other organic fertilisers and/or inorganic fertilisers can be used as well. For the frequent weeding during early growth, it is recommended to use hand-pushed weeders instead of a hoe.

The reported advantages of SRI are:
higher production (an average yield increase of 2 tonnes/ha), compared to existing practices;

- *increased return to labour*
- *less water use (up to 50%)*
- *lower amount of purchased inputs needed (seeds, inorganic fertilisers, pesticides)*
- *improved soil quality*

In SRI, only 5–10 kg of seeds per ha are needed. This could facilitate the adoption of improved rice seeds by small-scale farmers. The better quality of the soil gives a higher efficiency of both organic and inorganic applied fertilisers so that less is needed. SRI produces well-developed and healthy rice plants, which are more resistant to pest attacks and drought. Consequently fewer pesticides are needed to protect the rice plants. All these advantages give SRI farmers a higher income in comparison to conventional rice farmers.

Preconditions for SRI are:

- *good water control and properly levelled fields*
- *timeliness in implementing the various field operations*
- *availability of more labour and compost compared to existing practice*
- *better skills on the part of farmers*

The drastic changes in rice cultivation practices and the new skills required may make SRI costly in terms of extension and training services. These initial costs do not have to be a problem in rice areas with high SRI potential, such as where there is good water control and households have fewer labour constraints. However, farmers who face constraints with water supply and management and/or labour availability are likely to face difficulties in implementing all aspects of SRI, which initially may lead to disappointing results of the system.

4 Land preparation and crop establishment

4.1 Land preparation

Land preparation is the key to good crop establishment. In lowland rice the land is mostly prepared while it is wet. The primary reason for preparing the land is to control weeds. Land preparation has to be done a few weeks before planting in order to enable the decomposition of the incorporated weeds and other organic material. Another benefit of land preparation is the loosening of the soil, which facilitates levelling and root penetration. Good land preparation makes fields more level, which is a precondition for efficient and controlled use of water. Often the application of fertilisers before planting furthermore requires incorporation through soil tillage operations.

Ploughing

The main wetland tillage method consists of soaking the land until the soil is saturated, and ploughing to a depth of 10–15 cm using a plough drawn by oxen or small machines or by using a hand hoe. In order to reduce power requirement, this primary ploughing operation should preferably be done with a thin layer of water on the land (especially if draught animals or two-wheel tractors are used).

Puddling
After primary tillage, animal-drawn harrows or two-wheel tractor power tillers (see Figure 6) can be used with a layer of water on the field to break down clods and realise a rather rough mud bed suitable for transplanting. This operation is called puddling.

Figure 6: Use of power-tiller for puddling in irrigated rice, southern Togo

Puddling completely breaks down soil structure to decrease water percolation and to bury weeds. It also loosens the soil for greater ease of levelling and transplanting. To finish the puddling operations, a rake or levelling board can be used to further bury weeds and to smoothen and level the mud layer. Floating sediments should be allowed to settle for two to three days before sowing.

The primary tillage operations may be carried out at intervals, which allow for the emergence and successive destruction of weeds. In rice fields with lots of perennial weeds, it is recommended to disc plough the field immediately after harvest to expose the roots to the sun.

Timely land preparation facilitates planting at a more optimal time. Most farmers use the hand hoe, but farmers who are able to use animal traction can prepare the land five times faster. A two-wheel tractor is 2–3 times faster than animal traction and a four-wheel tractor is 4–8 times faster than a two-wheel tractor. However, a four-wheel tractor is expensive to purchase and maintain. Moreover, if the soil is kept wet and soft, then all equipment – especially larger equipment – will tend to sink, creating problems of mobility, soil compaction and tillage depth.

When shifting to machinery, ensure proper use and that spare parts and after-sales services are available.

It is recommended that farmers shift from hand hoeing to animal traction or two-wheel tractors instead of changing immediately to four-wheel tractors. The latter are, in any case, no viable option for very small rice fields.

4.2 Land levelling

Because lowland rice is grown under flooded conditions, it is best produced on land that is nearly level, thus minimising the number of water retaining barriers or levees required. Some slope is required to facilitate proper drainage. Generally, slopes of less than 1% are necessary for adequate water management in relatively large fields. In small fields even more gentle slopes are better for proper water management.

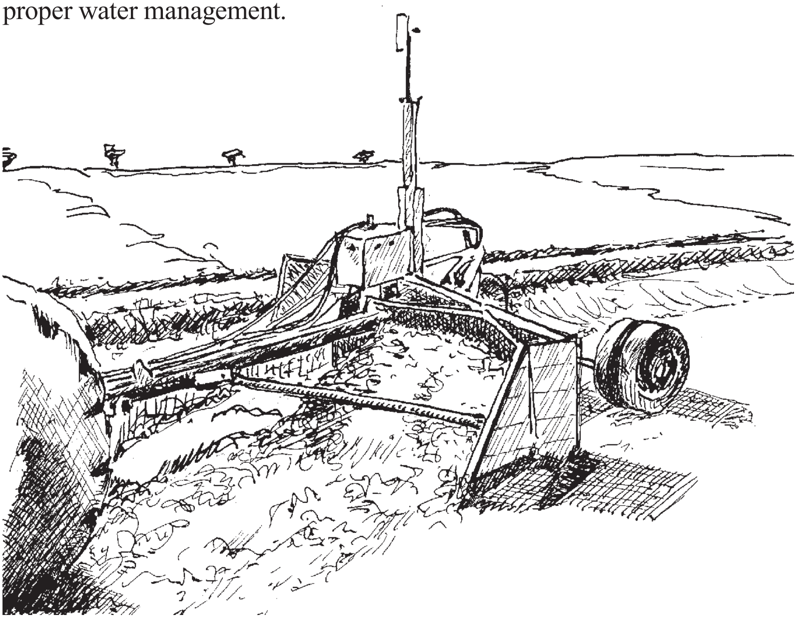

Figure 7: Laser-guided land levelling with a tractor drawn levelling board.

Land levelling helps to improve water management because it reduces the amount of water needed on the field and it facilitates control of the amount of water on the field. This improved water management will improve weed suppression and control, crop establishment, nutrient use efficiency, crop uniformity and maturation, drainage, yields and profits. Therefore care needs to be taken in any ploughing operation to leave the field as level as possible. Generally, high spots emerging above the water develop into areas that are heavily infested with weeds. Before levelling the land, identify first the high and low spots. The objective is to minimise soil and equipment movement. By drawing a figure eight over the length and width of the field, you can identify the high and low spots and estimate the most efficient manner to move soil.

Hand (two-wheel) tractors plus a blade and animal-drawn implements (such as levelling board or bucket) can level areas up to 0.25 ha. For areas up to 0.5 ha one can use four-wheel tractors with blade or bucket. These systems are capable of removing 4-5 cm unevenness from a field. Recent innovations using laser-guided systems have made precision-levelled or graded fields physically and economically feasible. Laser-guided systems are capable of removing 1 cm unevenness from a field.

With land levelling it is important to be aware of the chemical (e.g. acidity, salinity) and physical properties (such as infiltration rates) of the subsoil. It is also important to make sure that the exposed sub-soil will not be problematic. In areas where a large amount of soil is moved and hard pans are removed, excessively high infiltration rates may lead to increased rates of nutrient and chemical leaching. Areas which have received additional soil may require less fertiliser in the first crop as the richer topsoil from other parts of the field is moved to these areas. For areas where topsoil was removed, additional fertiliser requirements might be needed.

Dish effect

Traditional tillage practices using animal traction and tractors have often moved the soil in one direction from the centre of the field to the boundaries. Over time, such soil movement will result in a low spot in the centre of the field (a saucer or dish effect), which often leads to delayed tillage operations and an increased incidence of weeds. In such cases ploughing should begin in the centre of the field, leaving the centre of the field level, and moving toward the field boundary in a continuous pattern with the final run leaving a drainage furrow beside the bund.

4.3 Bund/levee building

Bunds retain water and are an important component of good water management. Bunds can be built manually or mechanically. New bunds will require compacting and additional filling after initial settlement occurs. It is always best to build or at least mark out the bunds before levelling commences. Some farmers decide to make new rice fields through the construction of bunds at the end of the rainy season, when the soils are still moist and workable. For rice fields located in valleys with large catchment areas the bunds have to be higher and wider to withstand the sometimes severe floods. Levelling typically reduces both the number and size of bunds, thus increasing the cropped area. High bunds are often an indication of poorly levelled fields.

Figure 8: Making bunds

4.4 Minimum tillage options

Minimum tillage refers to a system of crop production where the soil is tilled as little as possible. This is done to better conserve the organic matter in the soil and to reduce the costs of land preparation.

Over the past ten years the use of reduced tillage practices has increased in rice production. An excellent seedbed can be prepared on most sandy and silt loam soils with minimum tillage. However, clay soils often need a proper tillage for lowland rice production due to their stickiness. On clay soils where minimum tillage is still possible, it usually improves seed-to-soil contact. Normal tillage practices on such clay soils often produce a cloddy seedbed that does not provide good seed-to-soil contact. Minimum tillage does not produce such cloddy seedbeds.

Unlevel fields and fields with excessive vegetation, hard to control weeds (e.g. wild/red rice), or many (wheel) tracks are not suitable for minimum tillage. Dense vegetation reduces seed-to-soil contact and increases problems establishing adequate plant stand. Rutted fields and unlevel land will experience more water management problems with minimum tillage, which will decrease the rice production.

4.5 Principles of crop establishment

This section provides information on how to plant or seed for the following different forms of crop establishment:

- wet direct seeding
- dry direct seeding
- transplanting

The establishment of a proper plant population is an essential first step in successful rice production. Target plant stands are related to the target panicle counts. The desired number of panicles per plant depends on the tillering capacity of the rice plant, which is primarily driven by cultivar, N management and plant stand. Rice has the ability to tiller or stool and produce several panicle-bearing stems from one plant. The System of Rice Intensification (see Box 1) is largely based on this capacity of the rice plant. However, dense plant populations may lead to reduced tiller production, increased disease pressure and spindly plants that are more susceptible to lodging.

A good crop starts with high-quality seeds. Quality seed has a good germination rate, is pure, full and uniform in size, and is free of weed seeds, seed-borne diseases, pathogens, insects or other matter. Certified seeds *are quality seeds that have a certified purity (normally less than 2–4% impurities such as weed seeds, other rice seeds and dirt) and a certified germination rate (usually at least 80%). However, the germination rate is only guaranteed in the year of testing, which is marked on the label. The cultivar on the label has been compared with a reference sample, and is thus the true cultivar. Seed certification is done by officials at national levels; hence standards can vary among countries. Certified seed can be produced by government agencies or the private sector. In both cases well-trained farmers can collaborate in the production of certified seeds.*

An obvious way to manipulate plant stand is through seed rate. The quantity of seed required to establish a good plant stand varies with the cultivar (due to differences in seed size or weight), the quality of the seed bed, the percentage germination of the seed (which is related to the quality of the seed), the seeding method and the environment. Often less than 50% of seeds emerge. This is especially true in wet direct seeding and minimum tillage. Therefore, a double amount of seed has to be applied to reach the desired plant stand.

4.6 Wet direct seeding

For wet direct seeding the rice seed can be dry or pre-germinated (presoaked). Pre-germinated seed is highly recommended. When the rice is seeded dry, seeds are more likely to drift. If rice is presoaked, the heavy, wet seeds immediately fall into the seedbed.

Pre-germinate seed by soaking it 48 hours before planting. Change the water every four hours if possible. After 24 hours, incubate the drained seed in the shade for 24–36 hours; rinse if possible to prevent the seed from becoming too hot.

Seed must be planted shortly after pre-germination or deterioration will occur. Wait 1–2 days after land preparation (depending on soil texture) to ensure the seed does not sink too deep; deep seed will have problems emerging if covered by mud and water.

For broadcasting use a seed rate of 80–150 kg seed/ha. The higher seeding rates should be used when a low germination rate is expected. For wet sowing in rows use a seed rate of 60–80 kg/ha. Seeds should not be planted deeper than 1 cm.

Wet direct seeding requires good levelling and weed control. However, the seedbed should be left in rougher condition than for dry seeding. The rough seedbeds minimise seed drift and facilitate seedling anchorage and rapid seedling development. After sowing, the water level is preferably kept at 0–5 cm.

To enable replanting of bare patches, start to soak and incubate a sufficient amount of additional seed (e.g. 1 kg/ha) already one day after initial seeding. Broadcast it in problem areas as soon as they become visible (about three days after initial seeding). If required, you can also transplant seedlings to bare patches about 15 to 20 days after initial seeding.

Wet direct seeding is a good practice to suppress red/wild rice and other grasses because the soil's oxygen is replaced with water once the field is flooded and this blocks the germination of the weed seeds. For the best weed control, flood fields immediately after land preparation. This limits the amount of weed seed that might germinate prior to this flooding.

4.7 Dry direct seeding

In dry direct seeding, the seeds are sown in dry soil just before or after land preparation. In the latter case the seeds are then covered lightly with soil. In rainfed lowland fields, the seeds are sown just before the rains begin and germination will occur when the rains have come. This method makes it possible to have initial crop growth from early rains. Where soil moisture is adequate, irrigation may not be necessary. But, when soil moisture is insufficient and rainfall is not imminent, the field should, if possible, be irrigated within four days after seeding to assure uniform emergence. Dry direct seeding can require more water and fertiliser if there is no natural hardpan to limit infiltration and percolation.

The seed rate for broadcasting is 80–150 kg/ha. Surface seeding is vulnerable to problems with birds and rats. Harrow after the broadcast if possible. Another option is to broadcast in furrows. Prepare land with furrows 15 cm apart and 5–10 cm deep. Broadcast and harrow lightly and seeds will emerge fairly strongly in rows. For drilling the seeds in rows use a seed rate of 60–80 kg/ha. The best planting depth is less than 2.5 cm, especially for semi-dwarf cultivars. When rice is to be drill seeded, a well-prepared, weed-free seedbed is desirable.

For replanting bare patches soak and incubate additional seed (e.g. 1 kg/ha) one day after the field has sufficient moisture for germination. Three days after initial seeding, broadcast additional seed in the problem areas. If required, transplant seedlings to bare patches, 15 to 20 days after initial seeding.

Dry direct seeding normally works best on soils in which a well-prepared seedbed is possible and where annual and perennial grasses (including wild/red rice) are not a severe problem. Weed pressure tends to be greater in dry direct seeded systems than in wet direct seeded systems. A well-prepared seedbed will facilitate uniform seeding depth.

4.8 Transplanting

In lowland rice cultivation seedlings are mostly raised on wet nursery beds and sometimes on dry nursery beds. Wet nursery beds are made in the puddled or wet field. Seeds are pre-germinated and spread on the bed, which is kept constantly wet. Dry nursery beds are best prepared near a water source, before land preparation.

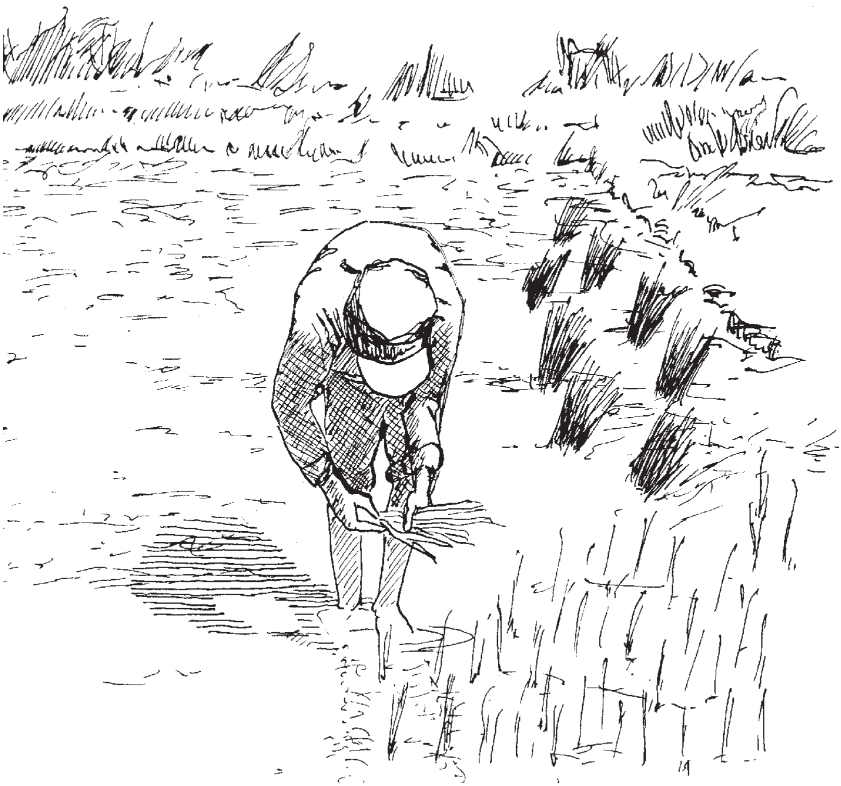

Figure 9: Transplanting

Under lowland conditions rice is generally a sole crop. Hand transplanting requires 15–20 person days per ha. Mechanical transplanters can plant 1–2 ha per day, but require optimal levelling and water control in addition to specialised skills and expertise.

The seed rate for transplanting one hectare is 80–100 kg depending on the quality of the seed used. In general, about 1000 m^2 seedbed nursery is required to transplant a one hectare field. The seeds are sown and then covered with a thin layer of soil and watered until saturation for uniform germination. Further watering is applied as needed. In both wet and dry nursery cases the seedlings are ready for transplanting 20–35 days after sowing.

Good seedlings are taken from the seedbeds and transplanted into well-prepared and saturated fields. Wait 1–2 days after land preparation to avoid plants sinking too deep; deep plants will have problems growing if covered by mud and water. The seedlings are often planted in rows at a rate of 2–3 seedlings per hill, and to a depth of 3–4 cm. Heavy-tillering and late-maturing cultivars in fertile soils are wider spaced (30 cm × 30 cm) than slightly tillering cultivars in less fertile fields (20 cm × 20 cm). The spacing in irrigated rice is normally 20 cm × 20 cm with 2–4 plants per hill (500,000–1,000,000 plants per ha).

In rainfed lowland systems some farmers regard a water depth just above 15 cm ideal for transplanting. Shallower water depths are risky as transplanting can be followed by serious dry spells. However, water depths of more than 15 cm reduce tillering and give poor results when floods wash away the poorly anchored seedlings. Replant seedlings as soon as damage is noted to bare patches within two weeks after the initial transplanting.

The general goal is to obtain a uniform plant stand. Transplanting gives usually a more uniform stand than direct seeding. However, transplanting requires substantially more labour than the other two planting methods. Direct seeding, on the other hand, requires a more uniform land levelling and better water management. Use of clean, uniform and improved seed(lings) is recommended for all planting methods. This in itself may increase yields by 5–20%!

5 Water management

5.1 Water demand and function

Rice plants need ample water to grow properly and to complete their life-cycle and are therefore often grown in basins and paddy fields under submerged conditions. Continuous presence of water in the fields also helps to suppress weed growth and can improve the efficiency of nitrogen fertilisers. Almost all lowland rice cultivars are very sensitive to water stress, which can occur even when the soil is moist.

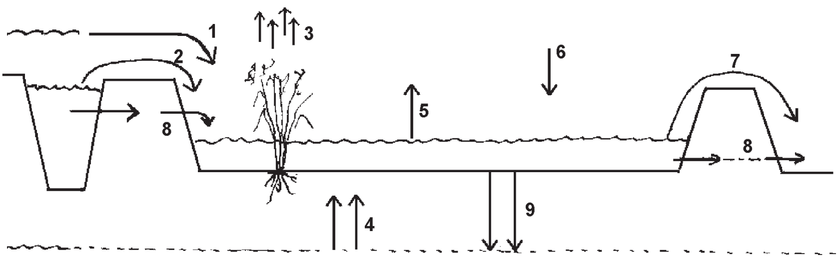

Figure 10: Scheme of water flows in a rice field; example for a flooded, irrigated rice field. Numbers are explained in the text.

Water demand in lowland rice cultivars varies greatly; it ranges from 300 mm to 2500 mm per season, depending on soil properties, climate, type of cultivar and type of cultivation system. While the plants grow, water is transpired through small openings in the leaves (see Figure 10 arrow number 3). Transpiration often represents only a small part of the total water use, but it is through transpiration that the plant produces biomass. A rice crop transpires between 250 and 500 mm per season. The remainder of the water is lost through evaporation from the soil and water surface (nr. 5), percolation to lower parts of the soil (nr 9), seepage to neighbouring fields (nr. 8) and drainage from the rice field (nr. 7).

5.2 Water sources

Water supply to the rice plant can come from different sources. Figure 10 shows that water inputs can be rainfall (arrow nr. 6), seasonal flooding from a river or lake (nr. 1), groundwater (nr. 4), lateral inflow from higher parts (nr. 8) and irrigation (nr. 2). It is important to realise which source supplies water to a field.

Rainfall patterns in tropical Africa are often irregular, but knowledge of local rainfall statistics can give reasonable estimates of total water input over a season.

Seasonal flooding of a river or lake tends to vary annually and may be difficult to predict in advance. The flooding can sometimes be foreseen but the amount of supplied water is often difficult to estimate.

Groundwater is an often overlooked source of water. When groundwater is not too deep, capillary rise can supply plants with water from deeper soil layers. Groundwater levels can fluctuate over the year, and a high water table that can supply the crop through capillary rise at the end of the wet season is an important source to take into account.

Lateral inflow from higher parts of the slope is an important source of water in rice fields with bunds, which enable the trapping of rainfall water.

Irrigation is the artificial supply of water to a crop. It can take many forms, but in rice fields it is commonly the diversion of water into a field until the field has a layer of standing water. In irrigation schemes, a distribution system supplies water to each individual field.

In some cases basins are used for supplementary irrigation. Water for basins may come from rivers, (deep) bore holes or dams. Water is stored in basins, and when needed released to the crop. Furrow irrigation and the associated raised beds are used in some areas with problematic soils (e.g. high salinity or acidity), but due to the labour demand it is not very common. In Africa, sprinkler irrigation in rice is very rare.

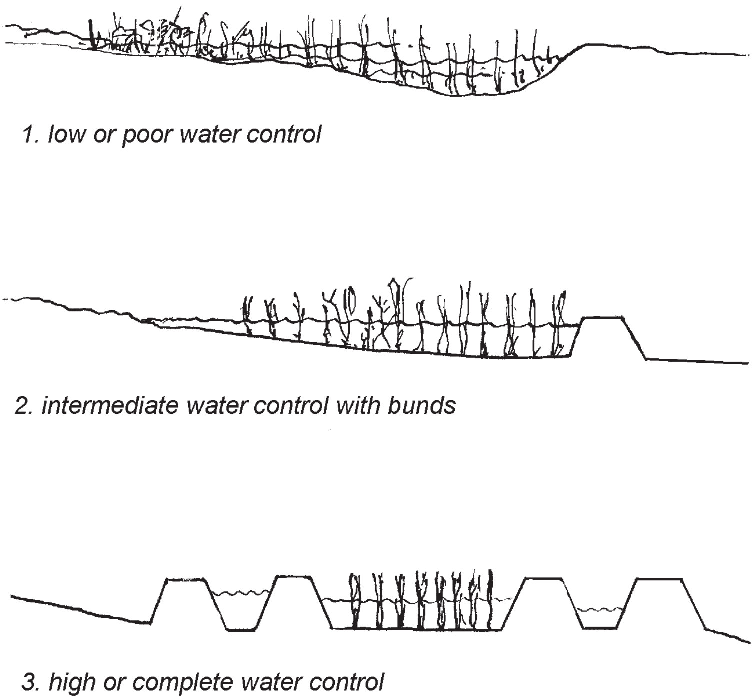

Figure 11: Example of the water control continuum, from the top, a poor, intermediate and complete water control situation, see Table 2.

5.3 Water control

In rice cultivation, the degree of water control in the field determines the attainable yield (see Table 1 in Chapter 3). When farmers have control over the amount of water in their fields, strict water management can be applied. In Table 2 lowland rice is subdivided based on the degree of water control; from poor, with un-controllable water sources and often lacking drainage, to complete control with functioning irrigation and drainage.

Water management consists of two main operations: irrigation, to increase the amount of water in the field, and drainage, to decrease the amount of water. If farmers cannot directly control the water flows in their plots (poor water control), building bunds and land levelling will improve their ability to manage water, and hence increase their attainable rice yield (intermediate water control).

Table 2: The water control continuum for lowland rice systems

	Poor	Intermediate	Complete
Cultivation system	Rainfed lowland	Improved rainfed lowland and Incompletely Irrigated	Completely Irrigated
Water sources	Rainfall, floods, groundwater	Rainfall, floods, groundwater, sometimes irrigation	Rainfall and irrigation
Capacity to drain	Sometimes available	Often available	Always available

5.4 Field water management

Figure 10 shows all water in- and outflows of a lowland rice field. Farmers can improve their water control by managing each of these flows. Below are some suggestions for good water management:

- Land levelling. A levelled plot allows the farmer to maintain a uniform layer of water (although bunds are also needed), and to thereby reduce the total amount of water needed in the field.
- Bunds. The bunds function primarily to keep water in the field, and secondly to prevent overflow into or from other fields. The bunds should be high enough to prevent overflow and tight and thick enough to prevent seepage.
- Well-placed and functioning in- and outlets. The inlets of a field need to be placed at the highest point, and both inlets and outlets should be easy to open and close. Outlets should be placed at the lowest end of the field.
- Puddling. When percolation is a problem, puddling can be an option. See Chapter 4 for details on puddling.
- Type of land preparation. Dry land preparation, e.g. using a disc plough, uses a lot less water than wet preparation.
- Timing of activities. Adequate timing of activities can reduce the time between land preparation and sowing/transplanting. Shortening this interval minimises losses by percolation and evaporation.

- Close spacing. Evaporation losses will be reduced through a close spacing of the rice plants in the field.

5.5 In-season water management

Complete water control

Depending on the crop establishment method, the following water depths in the fields are recommended for lowland rice cultivation systems with complete water control. This means that irrigation and drainage can take place at will, which often is the case in completely irrigated systems.

Field water management in direct-seeded fields

1. For direct-seeded rice, if the field has not been wetted for puddling or levelling, pre-soak the field 48 hours before sowing. At sowing the field should be muddy, with a small film of water on top. As the seedling emerges, increase the water layer gradually to 5 cm after three weeks.
2. Drain the field before application of herbicides and N-fertiliser, which is around three weeks after sowing. Re-irrigate to a layer of 5 cm.
3. Repeat the drainage for a second top-dressing of fertiliser after nine weeks, and irrigate to obtain a layer of 10 cm.
4. Two weeks before harvest, drain the field to ensure a uniform ripening and easy access to the field.

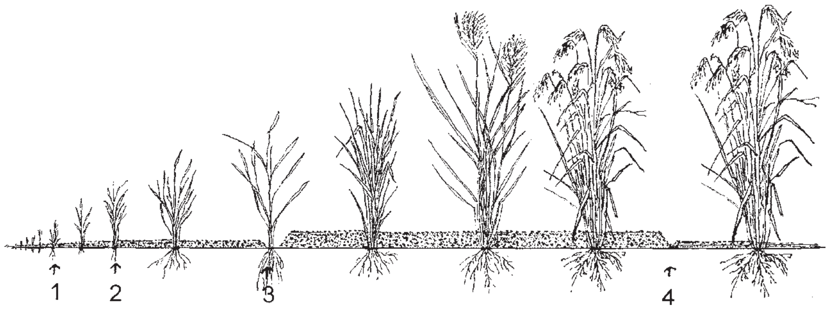

Figure 12: Field water management in direct seeded fields

Nursery water management

In the nursery, seeds are sown densely, and the seedbed is kept moist at all times. As the nursery plots are relatively small, irrigation can often be done with a watering can. In hot and dry climates daily irrigation is required.

Field water management in transplanted fields

1. While the seedlings are growing in the nursery, the field can be prepared for transplanting. To this end, the field is flooded at least three days before transplanting.
2. When the seedlings are ready to be transplanted (after three to five weeks), the field should be flooded with a layer of 3–5 cm water.
3. Around three weeks after transplanting, drain the field before application of herbicides and/or N-fertiliser. Re-irrigate to a layer of 5 cm.
4. Repeat the drainage for a second top-dressing of fertiliser after about nine weeks, and re-irrigate to obtain a layer of 10 cm.
5. Two weeks before harvest, drain the field to ensure a uniform ripening and easy access to the field.

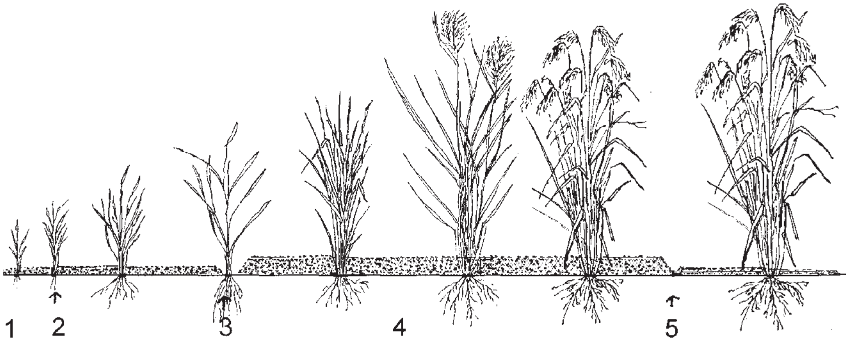

Figure 13: Field water management in transplanted fields

Intermediate water control

The above-mentioned schemes are valid if a farmer has full control of the water in his or her field. In the case of improved rainfed lowlands, the depth of water in the field cannot be controlled with precision. Although in these cases water management is very case specific, we would like to give some general suggestions for improvement of water management.

The applicability of the proposed techniques depends on the personal goal and resources of the farmer, the resources of the water user group (if present), and the specific water in-and-outflow characteristics of the lowland rice cultivation system.

If inflow of water cannot be controlled, but outflow can be controlled (rainfed with drainage):

- Make bunds. It helps to create plots that have similar water depth through redistribution of water between fields. Plots need to be levelled. Bunds enable the collection of a layer of standing water that can be used as a buffer in times of drought, or when the on-set of the rainy season is irregular.
- However, do not keep too much water in the field as a way to conserve water. If the water is more than 20 cm deep, tillering and leaf development will be less for most types of lowland rice cultivars, and final yield will decrease. Also, application of fast-releasing mineral N fertilisers (e.g. urea) in too much water is often not effective when rice plants are still small; the fertiliser is diluted and lost before it reaches the roots.
- The construction of a basin, pond or small dam will help to secure a desired water supply throughout the season.

If only inflow can be controlled (irrigation without drainage).

- Irrigate frequently, but apply small amounts.
- Maintain level plots; if necessary sub-divide fields into smaller plots.
- In some cases a raised-bed technique, in which rice is grown on beds that are higher (10–40 cm) than the soil surface can help to avoid deep water. This is a labour-intensive technique, but beds may be used for more than one season. Be careful in hot and dry climates, as salinisation can occur.
- Bunds should be of good quality, i.e. high enough to prevent overflow and tight and thick enough to prevent seepage through the bund.
- In valley bottoms, construction of small dykes that can regulate drainage is possible. The dykes can retain water behind them, and outlets in the dykes allow drainage of the area behind the dyke. Be alert to the risk of flash floods after rain storms.

5.6 Water management infrastructure

A vast range of infrastructures has been developed to manage water at landscape level. They can be divided into three categories: water pumping, transporting and drainage structures. Irrigated systems with complete water control have the most sophisticated infrastructures, including water dams, diversion dams and channels, pumps, irrigation and drainage canals that may be concrete lined, and inlet systems at the level of individual plots. Inland valleys can have simple earthen dams to retain water that floods a valley bottom. The dams usually have a drainage outlet to prevent high flood water levels. Alternatively, water can be collected in a basin or pond, and released to irrigate lower-laying rice fields.

Water user groups

Water management at landscape/system level is only effective when it is well organized between fields belonging to different farmers. It is important to realise that rice fields are connected irrigation and drainage systems. Water that drains from one field may be used to irrigate another. Percolation to the groundwater from one field is used as a water source down the slope. How water is managed in one field has consequences for other fields.

The magnitude of some large irrigation schemes makes it necessary to form some sort of hierarchical decision-making tree. Often, expert knowledge from outside the group of direct users is needed to facilitate decision making. Experts can help to design the most efficient irrigation sequence of the fields in an irrigation scheme, but the individual field owners should agree and ideally write down the procedures at the level of the water user group or association. In small catchments, decisions can be directly taken by the users. Although the situation in small valleys is relatively simple, most potential problems can be avoided by writing down the procedures of water management before the actual infrastructure is placed. Historic land and water claims of different user groups (e.g. herders vs. farmers) should be taken into account before conflicts arise. It is crucial to start drawing the rules and responsibilities before changes in the water management system take place, and they should be reviewed every few years, because water management systems can change rapidly over time.

The implications are that farmers need to organise themselves in so-called water user groups or associations to discuss how water management decisions should be taken.

The goal of a water user group is to distribute the available water in a fair and sustainable way among its members. A sustainable supply is guaranteed if the water infrastructure (consisting of canals, inlets/outlets, basins, ponds) is maintained in a proper way by the water user group. Members of the group should be all those who use the water resources. Members are for the most part farmers, but they can also be fishermen, or families that use the water for their household activities. To avoid conflicts, rules for water use and responsibilities for maintenance should be agreed upon by all users involved.

5.7 Water-related diseases

The prevalence of water-based diseases often increases when dams are constructed, because stagnant water behind dams is ideal for snails, the intermediary host for many types of worms. Water-based diseases include Guinea worm disease, filariasis and bilharzias/schistosomiasis. These diseases are caused by a variety of flukes, tapeworms, roundworms and tissue nematodes, often referred to as helminths, that infect humans. Although these diseases are not usually fatal, they prevent people from living normal lives and impair their ability to work.

Millions of people suffer from infections transmitted by insects (mosquitoes, flies) such as malaria, yellow fever, dengue fever and sleeping sickness. The incidence of these diseases appears to be increasing, partly due to the increase of stagnant water sources.

In general, one has to avoid standing water as much as possible in fields, canals, ponds and puddles.

The following environmental control methods can be implemented to reduce the risk of water-related diseases:

- Prevent the growth of or remove aquatic vegetation.
- Line canals with cement or plastic.
- Regularly fluctuate water levels.
- Allow periodic rapid drying of irrigation canals.
- Increase flow velocity in canals.
- Prevent contamination of water bodies with faeces.
- Ensure a supply of safe and clean drinking water.
- Ensure appropriate placing of housing.

6 Weed control

6.1 Introduction

Weeds are all plants that occur in a field other than the crop a farmer wishes to grow. In lowland rice cultivation in south and southeast Asia, weed infestation is a very important constraint. Weeds compete with the rice crop for light, moisture and nutrients, thus reducing the yield of the crop. Although rice fields are often flooded to suppress weeds, adapted weed species can still compete fiercely with the rice crop. Timely control is required to avoid yield losses in the present season and avoid the production of seeds that could threaten production in subsequent seasons.

What makes weeds such a persistent problem?
- They produce a lot of seed.
- These seeds can survive in the soil for a long time.
- The seeds germinate easily.
- Their growing cycle is short.

Weed management is becoming increasingly important as more farmers move to direct seeding and as water becomes more scarce. Integrated weed management relies on a range of practices to decrease weed pressure, including, good and timely land preparation, good land levelling, good water management, good crop establishment, healthy clean seeds (free of weed seeds), cultivars with good early vigour and, where necessary, sound and appropriate use of agrochemicals.

Crop rotation and weed control practices will decrease weed build-up. Furthermore, it is important to prevent weeds from growing along bunds and irrigation canals as weed seed can pass along the irrigation system to your field. Each type of weed requires a specific control method.

6.2 Weed types and their biology

Before farmers can control weeds, they need to know what types occur in the field as well as how these weeds grow, and when and how they compete with the rice plants.

Weed species differ depending on the ecology of the rice crop: for example, intensively used irrigated perimeters in semi-arid areas have different weeds than flooded valley bottoms in the humid rainforest. Weeds also differ between sites, and are often adapted to the local environment. Weeds can be divided into types based on growing cycle length and appearance (plant type).

Growing cycle length

Annual weeds

Annual weeds produce seed and die within one year, often even within one growing season. Some can produce seeds in 40 days, and are able to have two generations in one year. Often, annual weeds can produce large amounts of seed. *Echinochloa colona*, for example, produces up to 20 000 seeds per plant, and these can survive for years in the soil. Therefore, it is important to control weeds before they set seed, otherwise the seed bank in the soil will become very large.

Perennial weeds

Perennial weeds are those whose vegetative parts survive for more than one year in a similar way as tubers or rhizomes. They can spread either through seed or through dispersal of (underground) plant parts. Once a field has become infested with these weeds, they are often hard to eradicate.

Differences in appearance

Broad leaves

Plants with broad leaves have two leaflets when they germinate, contrary to rice, grasses and sedges, which appear with one leaflet. There is a very large variation of broadleaved weeds adapted to the lowland ecologies. Not one single family of weeds can be named as the most important in this group. In general, broadleaved weeds outgrow the rice crop towards the end of the season, and are often found near the edges of the fields and in gaps, where rice plants are missing. Many broadleaved weeds can develop into tall plants of over 1 m. In places where rice is less dense or delayed in germination, this type of weed can thrive and dominate the field.

Sedges

Sedges are aquatic plants. Most of the species occurring in lowland ecologies form bulbs, which survive for long periods in the soil, overcoming drought and flooding. They often grow between 10 and 70 cm tall. Within the *Cyperus* family, the species *C. esculenthus*, *C. difformis* and *C. rotundus* are among the most common found in lowland rice. They multiply rapidly, and infest intensively cultivated fields within a very short time, because they prefer the same ecology as rice.

Grasses

Rice itself is a grass, hence it is logical that its closely related species have become a nuisance to farmers. Notably *Oryza longistaminata*, *Oryza breviligulata*

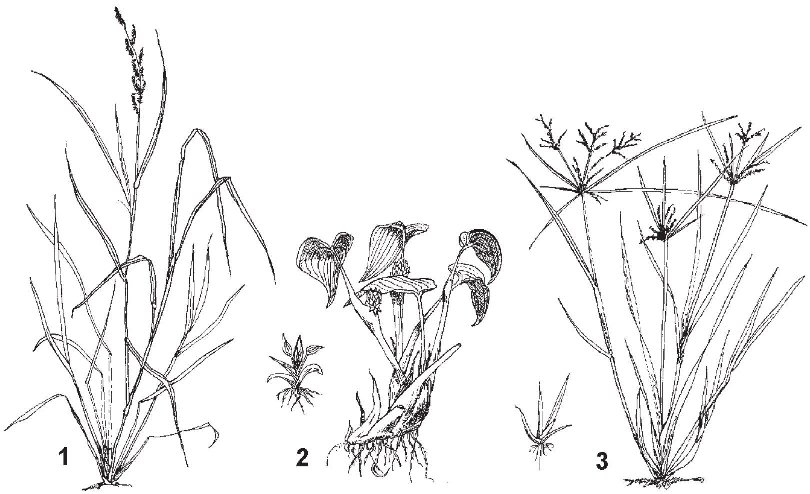

Figure 14: Examples of common weeds 1. Echinochloa colona – a grass, 2. Heteranthera callifolia – a broadleaf weed, 3. Cyperus difformis – a sedge.

and *Oryza barthii* are often called 'wild rice'. Also 'red rice' (*Oryza rufipogon*), of which the seeds have a red pericarp, is closely related to cultivated rice and crosses with it. In the seedling stage it is hard to distinguish the wild rice, red rice and other grasses such as *Echinochloa* species from the crop. Later, and certainly after heading, wild rice is taller, but by then the damage to the crop has already been done. Red rice typically shatters its seed before the rice crop is harvested. One has to avoid this at all cost because these dropped seeds remain viable in the soil for several years. *Oryza longistaminata* is a grass weed that is difficult to remove, as it propagates vegetatively through rootstocks.

Making a false seedbed, when possible, can be a management option. A false seedbed is made by wetting the soil and sometimes even preparing the soil without sowing a crop, to let the weeds germinate. The weeds can be removed, and a new seedbed can be made to sow a crop.

Another option is chisel ploughing (turning the soil) immediately after the harvest to let the weed roots dry out. The costs of this intervention are often too high, however, and farmers have sometimes had to abandon heavily infested fields.

6.3 Weed management

After the weed type has been identified, the next step is control. Control is critical during the first 15 to 20 days after seeding or transplanting. There are many weed control methods, but water control is often the most determining factor. Poor water control will often lead to serious infestations with broadleaves, sedges and grasses. Weed control methods are therefore discussed below in order of increasing water control.

Low water control

In lowland rice cultivation systems with low water control, where rainfall and natural drainage are the major water flows, hand weeding is the main weed control practice. The first hand weeding has to be done 14–21 days after planting or transplanting. The second hand weeding follows normally 14–21 days after the first one. A third weeding is sometimes necessary in heavily infested fields. Any delay in weeding will lower the rice yield substantially. Weeding in flooded rice plots can be relatively easy, as plants are easy to pull out, compared to those in dry soils. However, perennial weeds can re-grow within a week if not completely removed.

Transplanting is a very powerful option to reduce weed pressure. As the rice has a head-start, it will outgrow weeds that emerge later. The water level in the field can be deeper after transplanting than after direct seeding, hence weeds can be suppressed more effectively. Planting or sowing in rows also eases weed control: rice and weeds can then be easily distinguished, and the rows allow the farmer to move between the rice plants.

Intermediate water control

If locally available, weeders and treatment with herbicides can be used in addition to hand weeding. A multitude of tools have been developed to ease the weeding burden of the farmer. A hand-held hoe is often used to dig out larger weeds and to eradicate weeds after the harvest.

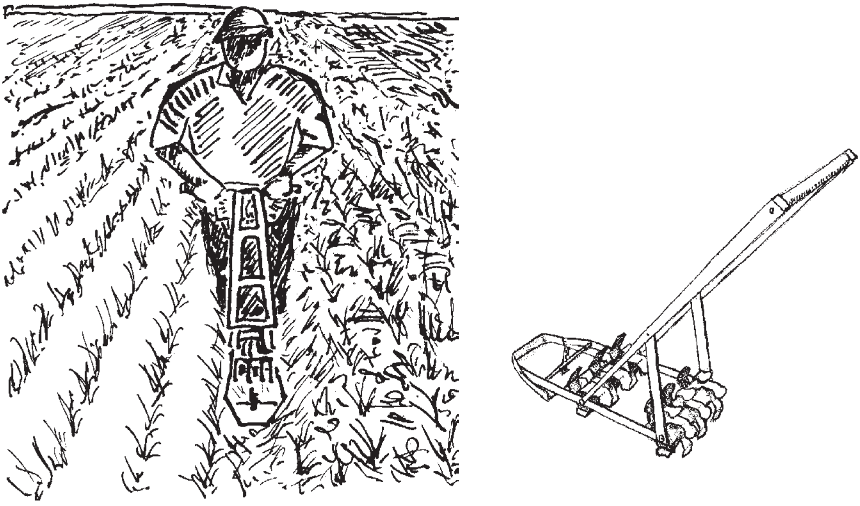

Figure 15: Rotary weeder

Another apt tool is the rotary weeder (see Figure 15 with a detail of the rotary end of the weeder). Rice has to be planted/sown in neat rows to allow the rotary weeder to pass. While moving it up and down the rows the weeds are uprooted, and as an additional benefit the soil is aerated. The water level in the field has to be lowered for each weeding.

In deep water, the weeder does not function. Hence a certain level of water control is necessary.

In some instances disc ploughing after harvest or before planting is done to cut the weeds up in pieces. If sedges and perennial grasses are present, this should not be done, because the plough will only spread the bulbs and rhizomes of the weeds and increase the weed infestation for next season.

To suppress the population of rhizomes, it may help to chisel plough after harvest and leave the soil to dry for at least two months.

Complete water control

In cropping systems where water control is complete or close to optimal, chemical control can be used. This is mainly the case in irrigated perimeters. Often the price of labour for hand weeding is high, and favours the application of chemical herbicides.

Many different herbicides are used for rice crops (see Table 3). Some may also affect the rice crop and are therefore used before the rice plants emerge, while others are selective and can be used after emergence. Timing of post-emergence herbicide application is crucial: an herbicide applied too early will damage the rice crop, but if applied too late it will not kill the weeds. In most cases optimal timing lies between 21 and 35 days after sowing in direct-seeded rice, and 15–28 days after transplanting. Application of herbicides demands a specific water level, depending on the type of herbicide used; often the field has to be drained before application. Some herbicides are sold in dry formulas that can be applied in the irrigation water.

Application of herbicides should be well thought out and chemicals should be handled by a responsible and trained person (see Box 2 for safety precautions). In small fields, herbicides can be applied using a rucksack sprayer. Pressure is regulated by the operator and heavily infested spots can be sprayed intensively, while not infested spots can be left un-sprayed. The operator should be a qualified person.

Before application the sprayer should be checked for irregular spraying. This can be done by using it to spray water on a dry surface and then checking whether the surface is homogenously wetted. Spraying nozzles wear off easily and should be checked before spraying. Fan or flood nozzles are best for herbicide treatments. Applying the right dosage is very important. Use a can or water bottle with a known volume to prepare the doses.

Box 2: Safety precautions while dealing with herbicides

- *Herbicides, like other agrochemicals, are often very toxic in their undiluted form; so do not ingest any and avoid direct contact with skin.*
- *Use protective clothing: rubber boots, gloves and a mouth piece.*
- *Use reliable and well-serviced equipment.*
- *Respect the dosage as recommended by the manufacturer.*
- *Wash equipment and body with ample water after application.*
- *Store the herbicides in a cool, dry place that can be locked and is out of the reach of children.*
- *Dispose empty containers by bringing them to an official disposal site – never dump them carelessly.*

The following measurements need to be known in advance:
a: the surface area, in hectares, to be sprayed;
b: the dilution of the herbicide (how many litres water per litre herbicide);
c: the dosage of the herbicide (litres) per ha;
d: contents of the rucksack (litres).

The volume of herbicide needed is a x c. This number multiplied by b results in the total volume of water to be added to the herbicide to spray the field. The total volume of water divided by d gives the number of times the rucksack needs to be filled.

Some of the most popular chemical herbicides are based on (mixes of) 2,4D-amine. This is an excellent selective herbicide, but in the USA several cases of herbicide-resistance have been reported, notably in *Echinocloa colona*. Farmers should be vigilant to prevent resistance build up by avoiding excessive use and sub-recommended dosages.

Agromisa promotes sustainable agriculture and discourages excessive use of agrochemicals. Agromisa does not recommend any of the above specific products.

Table 3: Examples of herbicides and their use in rice

Active Ingredient	Application*	Weed types controlled **	Example of brand name***	Dosage (L/ha)****
2,4 D-amine	Post	Bl, S	Weedone	1–1.5
Bensulfuron (dry)	Pre/early post	Bl, S	Londax 60DF	80 g/ha
Bentazon	Post	Bl, S	Basagran PL2	6–8
Butachlor	Pre/early post	Bl, G	Machete	0.75–1.0
MCPA	Post	Bl, S	Agroxone	1.0
Molinate	Post	G, S, some Bl	Ordram 960	5–10
Oxadiazon	Pre	G, S, Bl	Ronstar 12L	6
Pendimethalin	Pre	G, Bl, S	Stomp SC	2–3.5
Piperophos	Pre/early post	G, S	Rilof H	1.0
Pretilachlor	Pre	S, G, Bl	Sofit 500	1.0
Propanil	Post	G, some Bl	Stam F34	5-8
Quinclorac (dry)	Pre/post	G	Drive	1.1 kg/ha
Thiobencarb	Pre/post	G, S, Bl	Saturn	1.5
Glyphosate	Pre	Bl, S, G	Round-up	1–4

* *Application pre, post or early post emergence of the rice crop*

** *Weed types controlled are: Bl = broadleaf, G = grasses and S = sedges.*

*** *These are some examples of common product names; these can vary by country and over time.*

**** *Dilution factors are not given because they vary with brand name and package.*

7 Integrated nutrient management

Rice plants need various nutrients to grow . Relatively large amounts are needed of nitrogen (N), phosphorus (P), and potassium (K). Less is needed of nutrients like zinc (Zn), iron (Fe) and sulphur (S). If not enough of all these nutrients are available to the rice plants it will cause a reduction in yield. Nutrient deficiencies in rice are most common with increased intensification of rice cropping. However, too high, toxic levels of certain nutrients in soils and rice plants can also lead to lower rice yields.

The key principle of nutrition is to provide nutrients to the plant in the amount and at the time required. Nutrients vary in their mobility in the soil, and this affects their availability to the plant and their loss from the system. N is highly mobile, P is immobile and K is intermediately mobile. N is generally the most limiting nutrient due to its high mobility. N is quickly lost as a gas (volatilised) or easily lost by leaching (washing out the bottom of the soil). K is predominant in the straw, which means that straw management greatly affects the K balance. The availability of nutrients depends further on the acidity (pH-level) of the soil. Fortunately, flooded rice fields have pH-levels near to neutral (pH of 7.0), which makes most nutrients more available, particularly phosphorus.

For high yields one normally has to add nutrients in the form of mineral or organic fertilisers. The amount needed depends on the actual fertility status of the rice field, the type of cultivar grown, the season (rainy or dry), the degree of water control in the rice field, the amount of nutrients in flood or irrigation water, and the amount of rice straw remaining in the field. Therefore no uniform fertiliser recommendation exists for all lowland rice conditions.

7.1 Key principles of N management

Sufficient nitrogen is particularly important during establishment and tillering to ensure adequate tillers/unit area; just prior to and during panicle initiation to ensure adequate panicle size; and during grain filling to ensure proper filling of the grains. However, most of the plants' N should be applied prior to or around panicle initiation. To reduce the risk of lodging and pests, do not apply excessive amounts of N fertiliser between panicle initiation and the flowering stage, particularly in the wet season.

Divide recommended N fertiliser rates of more than 60 kg N/ha per crop into 2–3 split applications. Use more splits especially with long-duration cultivars, when yellowish leaf colours indicate N shortages and in the dry season when crop yield potential is greater. Avoid large basal N fertiliser applications (i.e. >50 kg N/ha) in transplanted rice where growth is slow during the first three weeks after transplanting. Incorporate basal N into the soil before planting or sowing.

A large percentage of the nitrogen required can be incorporated before planting in wet-seeded rice. In dry-seeded rice, alternating wet and dry cycles before the permanent flood lead to high losses of nitrogen; nitrogen applications prior to planting should therefore be kept minimal.

Recovery of top-dressed N fertiliser is at its lowest during the early growth stages, mainly due to the incomplete root growth during that time. Ammonium N fertilisers such as urea and sulphate of ammonia are mostly used in lowland rice cultivation due to their relatively lower cost and faster effect on rice growth.

7.2 Improving N fertiliser efficiency

Due to the high mobility of N, special care has to be taken during the application of N fertilisers, especially urea, which is highly susceptible to volatilisation losses. Water management forms a crucial aspect in improving the efficiency of N fertilisers.

The best thing to do is to lower or remove the floodwater in the rice fields before applying top-dressed N and then re-irrigate to enhance movement of N into the soil. Keep the water level at 5 cm when making mid-season applications and raise drains to reduce losses due to run-off. To reduce volatilisation losses, do not apply urea onto standing water under windy conditions before canopy closure, nor at midday when the water temperature is highest. Keep the soil continually saturated when using urea as N fertiliser to avoid N losses.

For N applications in the first weeks after sowing and transplanting water levels must not be higher than 5 cm. For N applications at mid-tillering and panicle initiation, water levels must not be higher than 15 cm. For farmers who cannot fully control the water level in their rice fields it is important to at least avoid too-high water levels in their fields during N fertiliser applications.

Yellowing of rice leaves indicates a deficiency of N. The so-called Leaf Colour Chart (LCC) can be used by farmers to determine timely and efficient use of N fertiliser top-dressing in modern semi-dwarf, high-yielding rice cultivars. The LCC is not useful for traditional, tall, low-yielding cultivars due to the relatively low nitrogen top-dressing requirements. The LCC monitors leaf N status from tillering to panicle initiation or later. Start monitoring from the beginning of tillering and take readings once every 7–10 days. Use the uppermost, fully expanded leaf, which best reflects the N status of rice. Compare the colour of the middle portion of the leaf with the LCC. Take the readings of 10 leaves from randomly selected hills in the field. The LCC contains four gradients of green colour from yellowish green to dark green. If the average colour is like in the upper situation of the image shown here then N fertiliser has to be applied immediately. If the status corresponds with the middle situation then N fertiliser has to be applied soon. In the lower situation no N fertiliser is required yet.

The critical LCC values can be determined after 1–2 seasons of testing for locally important cultivars and crop establishment methods. For more details on the LCC we refer to IRRI.

7.3 Recommended N applications

As already stated, N fertiliser recommendations have to be adjusted to the specific situation of each lowland rice field. N requirements are relatively low in rainy season crops (less sunshine, lower potential yield) and relatively high in dry season crops (more sunshine, greater potential yield). The N fertiliser requirement is accordingly lower in humid forests than in semi-arid environments. Table 4 presents the recommended N applications at different growth stages in wet and dry seasons. These applications refer to semi-dwarf indica cultivars. For taller indica cultivars the N applications should be reduced to 30–60 kg N/ha to avoid lodging and consequently serious yield losses.

Table 4: Recommended N applications at different growth stages in wet and dry seasons.

Transplanted and direct-seeded semi-dwarf indica rice	Wet season (cloudy)	Dry season
Early growth stage: 14–28 DAT / 21–34 DAS	20 kg N/ha	30 kg N/ha
Rapid growth stage: 29–48 DAT / 35–55 DAS	30 kg N/ha	45 kg N/ha
Late growth stage: 49 DAT / 56 DAS (= at flowering)	20 kg N/ha	30 kg N/ha

DAT = days after transplanting, DAS = days after sowing

In order to calculate how many bags of a certain type of N fertiliser one has to apply to a specific rice field one has to know the N percentage of that fertiliser and the surface area of the rice field. Urea, the most common N fertiliser, contains 46% N. One 50 kg bag of urea contains therefore 23 kg N. This is enough for the early growth application on one hectare (or 2.5 acres) in a wet season (see Table 4). Three bags of urea (69 kg N) will cover the whole wet season.

7.4 Recommended P and K applications

Phosphorus (P_2O_5) deficiency is difficult to detect unless it is severe. In such cases one may observe that roots are weakened, tillering is reduced and plants are stunted with dark green leaves and possibly a purplish colour.

In the case of a severe potassium (K_2O) deficiency one may observe that roots are rotten, plants are slightly stunted and older leaves show leaf tip and leaf margin burning (yellowish/orange to brown discolouration starting at the tip and moving toward the base). At grain formation the grain size and weight may be reduced. However, these K deficiency symptoms are not so easy to recognise.

The need for P and K applications can be guided by the results from soil chemical analysis of soil samples. When the amount of plant-available K in the soil is less than 0.2 mEq K/kg soil, a response to K fertiliser is certain. On acid soils (pH < 7.0), less than 5 mg P/kg points to a deficiency; and a response to P fertiliser is certain. On calcareous, alkaline soils (pH > 7.0) this critical level can go up to more than 25 mg P/kg. In the absence of a soil analysis, observations of your rice crop are needed to detect any P or K deficiencies.

P and K are typically applied as a basal application, although P application at 10 days after sowing (DAS) in direct-seeded crops may increase the efficiency. K can also be split with half applied as basal and half at mid-tillering, especially when higher doses (>30 kg K_2O/ha) are needed or the soil is sandy. In direct-seeded plots it is recommended to apply the first dose of K 10–15 days after planting. K application at flowering increases the resistance to lodging and diseases in dense canopies. Recommended application rates for P and K deficient soils are given in Table 5.

Table 5: Recommended P and K applications in wet and dry seasons in case of deficiency.

	Wet Season	Dry Season
P application rates	25 – 40 P_2O_5 (kg/ha)	40 – 60 P_2O_5 (kg/ha)
K application rates Low rice straw return	30 – 60 K_2O (kg/ha)	60 – 90 K_2O (kg/ha)
K application rates High rice straw return	0–30 K_2O (kg/ha)	30 K2O (kg/ha)

Superphosphate is usually the best type of P fertiliser, except in very acid soils. Triple superphosphate (TSP), which contains 46% P_2O_5, is most commonly used. One 50 kg bag of TSP provides 23 kg P_2O_5. KCl (muriate of potash) and K_2SO_4 (potassium sulphate) are the most common K fertilisers. One 50 kg bag of KCl contains 30 kg K_2O and one bag of K_2SO_4 contains 25 kg K_2O.

Application of P fertiliser has a residual effect that can persist for several years. Normally one application every other year is enough. The amount of K application depends mostly on the type of soil and the management of rice straw, which contains a relatively high amount of K. A low return of rice straw to the field will therefore increase the need for K fertiliser as Table 5 shows.

7.5 Zinc, iron and sulphur

Generally, less than 1 mg Zn/kg soil is considered critical. The symptoms of Zinc (Zn) deficiency are the appearance of dusty brown spots on the upper, younger leaves, stunted plants and leaves that turn yellow and start to die within

3–7 days after flooding. Rice plants can recover from Zn deficiency soon after the field is drained because a dry fallow increases the amount of available Zn.

Sulphur (S) is not required if there is more than 9–10 mg S/kg soil and/or when potassium is being applied as potassium sulphate. The symptoms of S deficiency are pale green plants and light, green-coloured young leaves.

Iron (Fe) deficiency is most likely when there is less than 2 mg Fe/kg soil. The symptoms of Fe deficiency are interveinal yellowing of emerging, young leaves and stunted plants with narrow leaves. Flooding increases the availability of Fe. A deficiency of Fe is difficult to correct with fertilisers as repeated foliar sprays might be necessary.

The most common nutrient toxicity in rice is iron toxicity. This is fairly common for the inland valleys in West Africa, where it is most severe in areas where the adjacent uplands are strongly leached, reddish, clay-rich, acidic soils. Iron toxicity occurs at the beginning of the rice growing season when the plants are still small and the fields are flooded partly by iron-rich groundwater from the uplands. High iron content can be detected as an oil-like film on the flood water. Plants show a stunted growth and express bronzing or yellowing of leaves due to iron toxicity. Plants can furthermore not take up enough of the other nutrients, and it is thus recommended to increase fertiliser levels. The most effective way to combat iron toxicity is to drain the fields thoroughly, if abundant water is available and re-fresh flood water.

Other toxicities of aluminium, boron, manganese and sulphide may be locally important.

7.6 Use of organic fertilisers

Organic fertilisers include biological N fixation sources (e.g., green manures, azolla and blue green algae), compost, animal manures and crop residues such as straw. Each of these sources varies in their composition. One advantage of organic fertilisers is that they can provide a wide range of nutrients. In addition, organic sources contain ingredients that can be important in the maintenance of soil organic matter, which indirectly also improves the efficiency of mineral fertilisers. Organic matter helps, for example, in retaining nutrients like K, calcium (Ca), and magnesium (Mg). Furthermore deeper-rooting green manures can draw nutrients from deeper in the soil profile; nutrients that would otherwise not be available to a relatively shallow rooting cereal such as rice.

The main disadvantage of organic fertilisers is that due to their relatively low nutrient contents large quantities are required, which tend not to be easily available. Secondly, labour requirements increase with the need to collect, cart and spread this material. Thirdly, the often relatively short time span available for green manure growth before or after rice cropping hinders its use. As a result, practicalities often limit the adoption of organic fertiliser application by farmers.

The use of rice straw is less complicated because this bulky organic fertiliser is already in the field as a by-product of the harvested rice crop. Incorporation of stubble and straw into the soil returns most of the nutrients taken up by the crop and helps to conserve soil nutrient reserves in the long term. Organic matter turnover is higher in aerated systems relative to continuously flooded systems. Straw breaks down fastest when the soil is moist – thus neither wet (saturated) nor dry. A shallow dry incorporation two weeks after harvest can give 50% decomposition of straw in a normal fallow period of two months between two crops without any additional water. This early tillage and aerated decomposition of rice stubble and straw leads to improved nutrition of the subsequent rice crop due to enhanced N availability and P release. Incorporation of stubble and straw under wet conditions will lead to a temporary use of N by soil microbes involved in the decomposition process.

To avoid N deficiency during the early stages of crop growth, direct sowing or transplanting of rice will have to be done at least 2–3 weeks after this wet incorporation of stubble and straw.

The spreading and incorporation of straw is labour intensive and rice farmers often prefer to burn the straw in their rice fields. However, burning results in the loss of almost all N, about 25% of P, an indirect loss of 20% K due to leaching and 5–60% loss of S. Rice straw is also an important source of Zn and silicon (Si). Total removal of rice straw (e.g. as thatching material) or partial removal (e.g. due to animal feeding) will decrease the total stock of nutrients in the soil and can endanger the long-term sustainability of the rice cropping system.

8 Pest control

Rice pests are all types of bio-organisms that cause reduction in the quantity and quality of rice. Pests can be insects, birds, rats, snails, crabs, worms, nematodes (resembling worms), fungi, bacteria and viruses. This chapter will deal with the description and control of all pests which cause widespread economic losses in the lowland rice fields of tropical Africa.

8.1 Pest control methods

The first step toward pest control is identification, followed by careful field inspection. Early foliar damage is rarely a problem because the rice plants can compensate for this later on in the season. However, very heavy leaf loss (>50%) may delay development and maturity.

Pests can be controlled by cultural, biological and chemical methods. It is important to use various crop protection methods in an integrated way to develop an integrated pest management (IPM) system for rice that is sustainable, inexpensive and environmentally safe. IPM combines the use of resistant cultivars, cultural methods, biological control and, finally, chemical control when pest damage threatens to exceed the economic injury threshold. Cultural methods include sanitation (the destruction of infested crop residues of alternative hosts including weeds, and of pest habitats), tillage and flooding of fields, crop rotation, intercropping, proper timing of planting and harvest, use of trap crops, the judicious application of N fertiliser and proper water management. Biological control includes exploiting biodiversity, beneficial insects, parasites and pathogens.

8.2 Examples of biological control

Exploiting biodiversity for sustainable pest control involves the within-field planting of cultivars differing in susceptibility to the relevant diseases or insect pests. The principles behind biodiversity for plant disease management are that diverse cultivars can provide complementary disease resistance, can reduce disease spread and may lead to induced resistance. These factors can lead to reduced spray requirements and increased yield.

Not all bio-organisms are pests. In fact there are many beneficial insects, spiders and diseases that attack insect pests of rice. Without these so-called predators, insect pests can multiply quickly and wipe out the rice crop. Unfortunately some farmers tend to spray everything that moves in the rice field. The negative effect of this is that many beneficial insects are killed at the same time.

Pests typically are more mobile and multiply more quickly than beneficial insects. Therefore, early pesticide applications will generally benefit pests, which will lead to higher pest infestations and consequently more spraying with pesticides. As a result the farmer is trapped in a vicious circle of spraying against pests and diseases. Thus, although pesticides may be needed in some cases, they must be used judiciously (e.g. not too early) in order to maximise the effect of the natural control agents.

Beneficial insects should be conserved by applying insecticides which are selectively toxic to pests but not to predators. It is important to realise that a few insect pests occurring at levels which cause no economic damage are helpful because they provide food to maintain populations of beneficial species at levels which can prevent damaging pest outbreaks. Examples of predators include lady beetles, ground beetles, crickets, grasshoppers, water striders, assassin bugs, damselflies, earwigs, ants, wasps and spiders.

Parasites are generally more host specific than predators. Parasites lay their eggs either in or near the host. When a parasite egg hatches and the immature parasite develops, the host usually stops feeding and soon dies. Unlike predators, parasites can find their hosts even when host density is low. In general, most rice fields have a rich community of parasites that help keep pest populations at economically insignificant levels. Examples of parasites include big-headed flies, wasps and some other species of flies.

Various pathogenic microorganisms can infect and kill insect pests of rice. Examples of pathogens include fungi, virus diseases and bacteria. Of the pathogens, fungi are by far the most important.

8.3 Main insect pests

Rice stem borers such as the white stem borer, pink stem borer and striped stem borer are the most serious insect pests of rice in tropical Africa. They are internal stem feeders, and larval feeding causes damage to rice tillers. Dead heart is the destruction of the growing point of the tiller before flowering, which causes the drying up of the central shoots. White head is the attack of plant-bearing panicles at the flowering stage, which results in a white and dry empty panicle.

Burning, ploughing and flooding of the stubble after harvest destroys the larvae of rice stem borers that survive in the field. Synchronised planting over a large area helps to let the most susceptible stage of rice escape from stem borer damage. One can also plant cultivars which are more resistant to stem borer attacks. Dragonflies and spiders are known predators of rice stem borers. Stem borer eggs and larvae are parasitised by wasps.

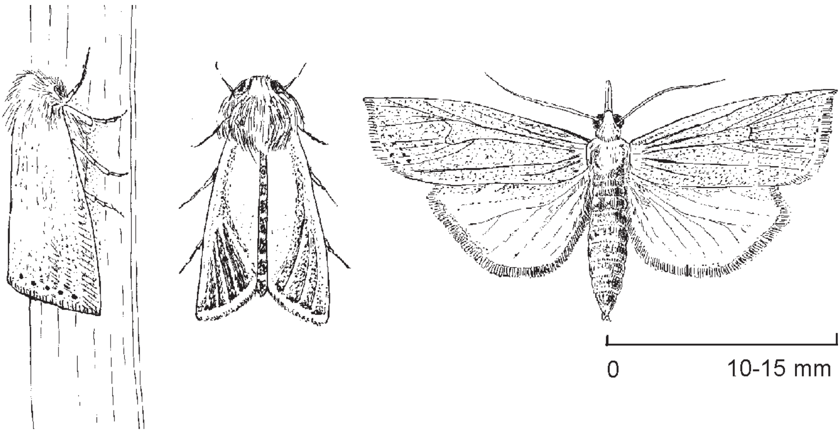

Figure 16: Adult of the stem borer moth

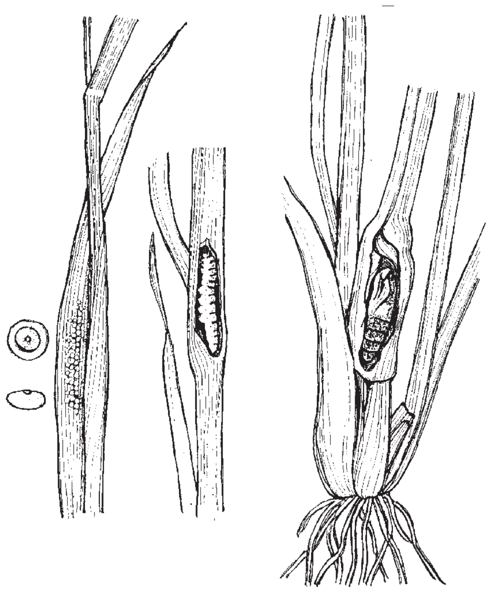

Figure 17: Larvea and eggs of the stem borer and their position in the rice plant

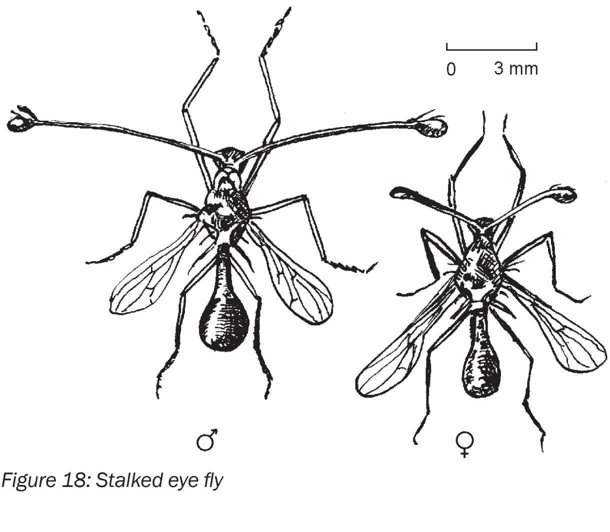

Figure 18: Stalked eye fly

In some humid parts of Africa the greatest damage to rice is caused by the stalk-eyed fly. Adults are easily recognised by their characteristic eyes borne on the end of stalks. The damage from the stalk-eyed fly resembles the dead heart damage from stem borers, as the larvae generally attack the rice plant at the early tillering stage. Cultural practices such as early sowing, narrow spacing of plants and maintaining weed-free fields should be observed to minimise stalk-eyed fly infestation. Synchronised planting over a large area allows the most susceptible stage of rice to escape from stalk-eyed fly damage. Use of cultivars with highly hairy leaves can trap stalk-eyed fly larvae.

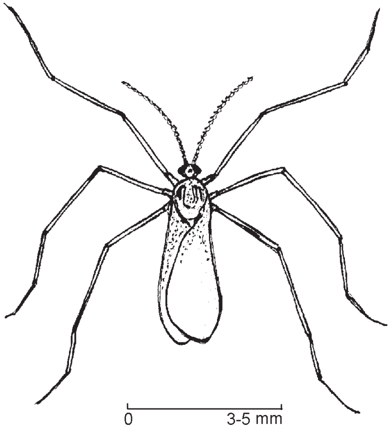

Figure 19: African rice gall midge

The African rice gall midge (AfRGM) is a serious insect pest of rainfed and irrigated lowland rice. It is a bud/stalk borer and larval feeding causes severe damage to rice during the vegetative stages. The larvae attack the growing point of rice tillers and cause the leaf sheath tissues to form a tube-like structure called a 'silver shoot gall' that resembles an onion leaf. Early gall infestation results in stunting and a bushy appearance of the rice plant, with as many as 50 small tillers per hill. Tillers with galls do not bear panicles. AfGRM can be controlled through early and synchronised planting, by destroying alternative host plants, applying moderate levels of fertiliser (e.g. 60 kg N/ha) in split doses, avoiding the exchange of seedlings between farmers and avoiding close plant spacing. Some types of wasps attack AfRGM and should be protected in the field. AfRGM-tolerant cultivars could be used.

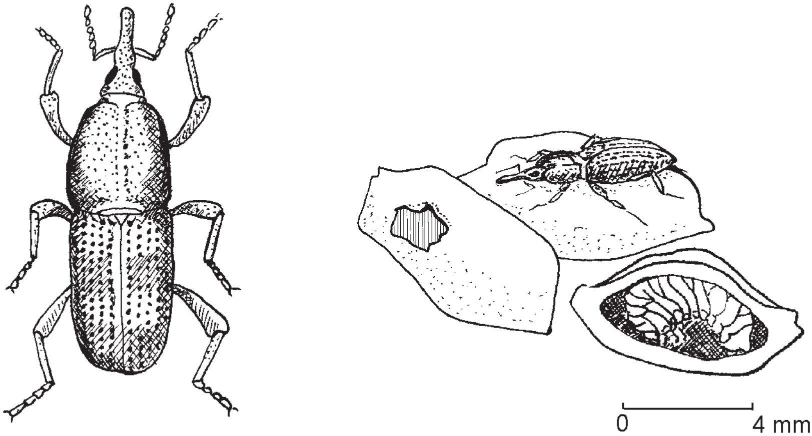

Figure 20: Rice weevil (left) and lesser grain borer (right)

The most serious insect pests of stored rice are the rice weevil and the lesser grain borer. These insects can completely destroy the grain. Rice storage pests can be controlled by using airtight containers for grain storage, applying dried chilli pepper or ash to the stored grains, and by using appropriate pesticides. Wear protective gloves and nose masks when handling pesticides!

8.4 Main rice diseases

Rice yellow mottle virus

The rice yellow mottle virus (RYMV) is one of the most economically damaging diseases of rice in tropical Africa. It gains entry into rice plants through injuries. The possible paths of entry are root damage caused by insects (short-horned grasshoppers and flea beetles) or during transplanting, weeding operations with hoes or harvesting with sickle. RYMV is characterised by pale, yellow mottled leaves, stunting, reduced tillering, non-synchronous flowering and yellowish streaking of rice leaves. Malformation and incomplete emergence of panicles and sterility are observed on infected rice plants.

RYMV outbreaks can be controlled by using pesticides against the insect vectors, transplanting early with reduced spacing of plants and destroying after harvest the rice residues and ratoons that harbour the virus and insect vectors. Other control methods are synchronous planting, diversification of cultivars on a single plot, change of site for nurseries, roguing of infected plants and immediate replanting, reduction of nitrogen application on attacked plots, and reduction of the weed reservoir for the virus and insect vectors. Cultivars that are resistant to or tolerant of RYMV could be used.

Rice blast

Rice blast is a serious problem in African rice production. It is caused by an airborne fungus that survives between crops on infected rice straw or on seed. The blast fungus can infect rice leaves, nodes and floral parts, particularly the basal part of the panicle. Leaves and whole plants are often killed under severe conditions. At heading, spores can infect the node below the panicle, resulting in neck blast, the most damaging type of blast. If the panicle does not fall off, it may turn white to gray, or the florets that do not fill will turn gray.

The disease can be reduced by planting resistant cultivars, using clean healthy seeds, maintaining a 10–15 cm flood, avoiding high nitrogen fertiliser doses, avoiding late planting and by applying a preventative fungicide if leaf blast is present.

8.5 Other rice pests

Nematodes

Nematodes are very tiny creatures resembling worms which live in the soil or as parasites in animals or plants. In tropical Africa serious losses can be caused by nematodes which feed on the stems and leaves of seedlings. Symptoms are shortened and curled leaves with white tips. Eventually nematodes enter the grains, where they can stay for two to three years. Infected seeds are the main cause of distribution of nematodes. Nematode infection can be controlled by submerging rice seeds in water of 55–61°C (not higher!) for 10–15 minutes.

Birds

Birds eat broadcast seeds, disturb young transplanted seedlings and eat rice grains. Losses can be very high. Birds can be best controlled by using different bird-scaring devices (catapults, bird nets, scarecrows). In direct-seeded fields the seed should be covered with soil upon seeding. Avoid planting or harvesting rice fields out of season as these will become focal points for attack.

Rodents

Indigenous rat-like rodents attack rice at all stages of growth and also stored grain. Losses due to rodents are often high. General hygiene in and around the fields and buildings is probably the most important in controlling rodents. In order to limit habitat and food sources for rodents one has to clean bunds, levees, irrigation and drainage canals, cover burrows and reduce food supplies and tall weeds around buildings.

Snails

Snails can eat the germinating seeds in wet-seeded rice fields and the young transplanted rice plants, which will reduce plant stand. The critical times for snail control are the first 10 days in transplanted fields and the first 21 days in wet-seeded fields. Snails can be controlled by draining the field during the first weeks.

9 Harvest and post-harvest operations

9.1 Harvesting

Timing

Before harvesting, fields have to be drained. It is important to harvest at the right moisture content. Grain moisture content at harvest is crucial in preserving grain quality and reducing grain loss. The rice grains should be harvested before they are fully mature (around 20–25% moisture), which is usually about 30–45 days after flowering, or when almost all grains are turning yellow/brown. Grains should be firm but not brittle when squeezed between the teeth. Correct timing of harvesting reduces damage (cracks) to the grain during threshing.

Delaying the harvest increases the shedding of too-dry grains through lodging. Late rains can also cause damage when fungi develop on wet grains remaining in the fields. If the crop is too dry, fissures will form in the interior parts of the dry grains; and if these are rewetted, they will break during milling. If the crop is harvested too early, there will be many immature grains and thus an excessive amount of bran and broken grains.

Methods

Harvesting by hand, the commonest method, is very labour intensive. In some areas a small knife is used to cut each head separately, but in many areas farmers prefer the less laborious method of using a sickle to cut the panicles plus some or all of the culms. This latter method necessitates threshing in or near rice fields. Place the harvested rice plants in an upright position for drying before threshing. Mechanical harvesters such as combine harvesters are seldom used in tropical Africa due to the dominant small sizes of the rice fields.

Yield

Rice yield is influenced by the number of plants per unit land area, the number of panicles per plant, the average number of grains produced per panicle and the average weight of the individual grains. These grain yield components can compensate each other; e.g. fewer panicles per plant can be compensated by a high grain weight.

Chapter 3 presented paddy yield ranges for the different lowland rice cultivation systems on the basis of the water control level. Rice yields are generally higher for dry season crops than for wet season crops due to more sunshine.

9.2 Threshing

Threshing separates the rice grains from the straw. Threshed rice is called rough rice or paddy. Threshing is generally done by hand, by beating the bundles on a stone or drum, or by beating the panicles with wooden sticks on a canvas. However, motorised and pedal-driven threshing machines are becoming more popular in tropical Africa. Avoid threshing on a bare floor to prevent the introduction of sand, pebbles and other foreign matter. Thresh carefully and avoid de-husking the grains.

Thresh immediately after harvesting and drying to avoid losses. Immediate threshing reduces exposure of the crop to insects, birds, rodents, diseases and fungi. Piled crops over a period of time generate heat that serves as an ideal medium for growth of fungi and other pests. Discolouration increases dramatically when the plants are stacked for 3–4 days. Germination and spoilage can also occur.

While piling can lead to problems, field drying prior to threshing can lead to a rapid reduction in moisture content to below 20%, and can lead to high shattering losses. This moisture content is too dry for mechanical threshing, which needs 20-25% moisture content. However, a moisture content of below 20% is still appropriate for hand threshing.

Figure 21: Hand threshing using a drum

9.3 Winnowing

Winnowing is done to clean the grain thoroughly after threshing to remove straws, chaff, unfilled grains, weed seeds, soil, rubbish and other non-grain materials. Cleaning the grain will improve its storability, reduce price penalties at the time of milling and improve milling output and quality. It can also reduce damage by disease and improve yields.

The simple traditional winnowing method uses wind or a fan to remove the light elements from the grain. Winnowing is usually done by shaking and tossing the grain up in the wind on a basketwork tray with a narrow rim. Sometimes less laborious hand-driven or motorised machines that incorporate a fan and several superimposed reciprocating sieves or screens are used. Smaller materials can be removed by sieving the grain through a smaller-sized screen. If the crop is machine threshed, adjusting the blower to the correct speed will provide good initial cleaning.

9.4 Drying

Rice grains should be dried to about 14% moisture content directly after threshing and winnowing. Proper drying of the rice grains prevents germination and rapid loss of quality, provides preliminary control against insect infestation and reduces losses from natural respiration. Proper drying procedures ensure paddy with good milling quality.

The most common and economical drying procedure is sun drying by spreading the grains in a thin layer (2–4 cm thick) on clean concrete floors, mats or tarpaulins. Avoid drying on bare floors or on roadsides, because this will certainly contaminate the rice with sand pebbles, stones and other foreign matter. Keep animals off the grains. Turn or stir the grains at least once per hour to achieve uniform moisture content. Differences in moisture content within the grain cause rewetting and subsequent cracking of drier grain.

Sun-dry slowly for 2–3 days to reduce breakage during milling. On clear bright days, sun-dry for one day (about 9–10 hrs) only. Avoid overheating on hot days, when the grain temperature can rise above 50-60°C, by covering the grain during mid-day. Overheating of grains can result in low milling quality as a result of cracks developing in the grains. Cover the grain immediately if it starts raining to avoid rewetting of the grain. Avoid over-drying to less than 14% moisture content because then the grain will reabsorb moisture from the atmosphere and crack.

For seed production the grains should be dried below 13% moisture content. However, air temperatures above 43°C will affect seed viability negatively. The lower the moisture content of seed at the beginning of storage, the longer the seed remains viable. For successful storage of seed in airtight, sealed bags, pots, or containers, the grains should be dried down to 10–12% moisture content to provide long-term seed viability and minimize insect damage. Malformed, discoloured, germinated, broken or mouldy grains in seed lots can severely impact seed quality, viability and vigour. Visually inspect the seed prior to storage and remove poor grains from the seed lot.

For commercial seed processing, seed grains should have uniform size and weight. A variety of commercial equipment can be used to achieve uniformity in seed size and shape. Maintain seed purity by preventing mixing with other cultivars, and contamination with other species.

9.5 Storage

Storage is a very important aspect of the post-harvest rice operations as losses through insect and rodent infestation may be very considerable. Safe storage of grain for longer periods is possible if the grain is dried down to 14% moisture content or less and the grain is protected from insects, rodents, and from rewetting by rain or the surrounding air. The longer the grain needs to be stored, the lower the required grain moisture content. For 8 to 12 months a moisture content of 13% or less is needed; for more than one year 9% or less is required. Grains stored at higher moisture contents than 14% may become moulded and rapidly lose viability.

A well-designed and properly operated storage system with adequate aeration capacity has to maintain a uniform rice moisture content and temperature.

After drying, rice grain is usually stored in 40–50 kg sacks made of jute or woven plastic. However, the grain moisture content in these bags will fluctuate as moisture in the air can freely transfer through the bag. A combination of high temperature and high relative humidity will lead to insect infestation in these bags, even if the grain was properly dried before storage. The use of wooden pallets to lift the bags from the floor in tidy stacks will increase aeration, lower the temperature in the bags and avoid the possibility of absorbing moisture from the floor. Bags are usually stacked under a roof or in a shed and will likely need periodic fumigation to control insects. Some farmers use granaries, which are made from timber or mud/cement or large woven baskets, and these also suffer from insect and rodent damage.

Rice for home consumption is stored unhusked, as the husk provides some protection against insects and helps prevent quality deterioration.

For longer-term storage of grain and seed, sealed or airtight storage is an alternative. Sealed storage containers range from small plastic containers to sealed 200-litre drums. Recycled oil drums and PVC containers can be used as low-cost sealed storage devices for grain and seed. In such storage, carbon dioxide builds up and oxygen is reduced. The seed remains viable but insects cannot survive.

No bags or containers can protect seed from the detrimental effects of high temperatures. For each 5°C increase in temperature, seed storage life will be reduced by half.

Hygiene in the grain store or storage depot is important for securing grain and seed quality over time. First of all keep the storage areas clean at all times. After the storage rooms are emptied consider spraying against insects before using them again. Inspect the storage room regularly to keep it rat and bird proof. Inspect the stored grains once a week for signs of insect infestation.

9.6 Milling

The structure of the matured rice grain is illustrated in Figure 22. The rice grain mainly consists of starchy endosperm and is protected by the inner (bran) and the outer seed cover (husk or hull). The bran contains most of the nutritional value of the rice grain. The husk helps to protect the interior part of the grain, the kernel, from insect and fungal attack.

Milling is the process of removing the husk or hull from the grain and the bran from the kernel. In rice milling the aim is to avoid breaking the kernels because whole kernels command a higher price. Broken grain has only half the market value of head rice (head rice = 75–100% of the whole kernel). Normally milling the grain by machine gives approximately: husk 20%, whole kernels 50%, broken kernels (brokens) 16%, bran and meal 14%. Long slender grains normally have greater breakage than short, bold grains. The husked or hulled rice is usually called brown rice, and this is then milled to remove the outer layers, after which it is polished to produce white rice.

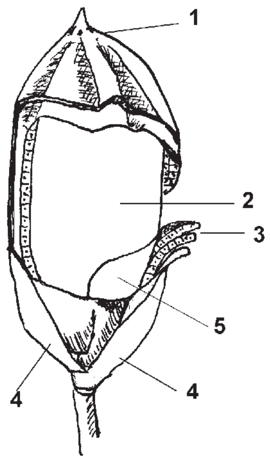

Figure 22: Mature rice grain 1 Husk or hull; 2 Starchy endosperm; 3 Bran; 4 Sterile glumes; 5 Lemma

During milling and polishing some of the protein and much of the fat, minerals and vitamins, which prevail in the bran, are removed. This increases storability and reduces the cooking time, but also reduces the nutritional value.

Parboiled rice

In some countries of West Africa parboiled rice is popular. Parboiling is a treatment with water and steam of paddy before milling, which moves nutrients from the outer husk into the grain itself. This is done by soaking paddy in water to increase its moisture content to about 30% followed by a heat-treatment using steam. The traditional method involves soaking the paddy in cold water in large concrete tanks and then steaming it in small kettles or containers. The modern methods consist of soaking paddy in warm water in batches in large metal tanks and then steaming it in large cookers or in a continuous process. The parboiled paddy is then dried to a moisture content below 14% for safe storage and efficient milling. Rice can be parboiled immediately after harvesting or dried and parboiled at a later date. Parboiled rice can be milled as usual or used as brown rice.

The taste and smell of parboiled rice produced with the traditional process is stronger and preferred in the local market. The parboil process makes the grains translucent, hard and resistant to breakage during milling. During milling it is easier to remove the husk but more difficult to remove the fatter bran. The colour of the milled grain changes from white to yellow. Milled parboiled rice is nutritionally superior to standard milled rice. Parboiled rice swells more during cooking but does not stick to the pan, as regular white rice does.

Methods

Milling by hand is still practised in many parts of tropical Africa. Hand pounding of paddy in a mortar with a pestle induces upward and downward forces on grain against grain that removes the husk and some bran layers. The pounding also results in a high percentage of broken kernels. The final cleaning is done by winnowing and gravity separation by hand. Rice milling by hand is laborious and does not produce milled rice which will fetch a good price in the market. Hand pounding is therefore mainly used for milling small quantities for home consumption.

Greater efficiency in the milling process is achieved by using well-maintained milling machines operated by skilled operators, which results in whole kernels with minimal broken kernels. Insufficiently cleaned paddy contains impurities and unfilled grains that lower the milling recovery. If the moisture content is too low, high grain breakage will occur resulting in low head rice recovery. Grains with high moisture content are too soft to withstand hulling pressure and may be pulverized.

Do not mix cultivars prior to milling. Different cultivars have different milling characteristics that require individual mill settings. Mixing cultivars will generally lead to excessive breakage, non-uniform whitening, and lower quality of milled rice.

Figure 23: Milling by hand

The Engelberg-type mill (see Figure 24) is widely used for milling paddy in many African countries as it is relatively inexpensive, robust and readily repaired. It has few moving parts to wear out, and the skills to operate and maintain this machine can be learned quickly. However, the iron hullers of this type of mill are notorious for breaking the paddy grain. Because of the high breakage, the total milled rice recovery (head rice and all sizes of broken kernels) is 53–55%, and head rice recovery is in the order of 30% of the milled rice. In many rural areas, Engelberg mills are used for custom milling the rice requirements of households.

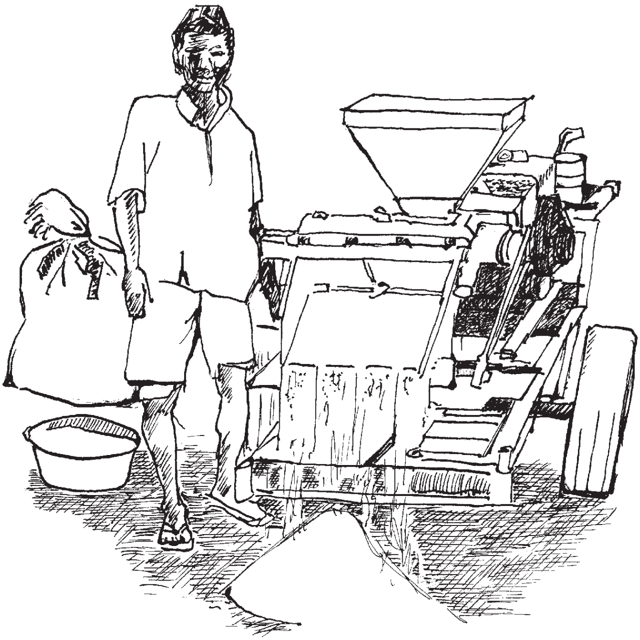

Figure 24: Engelberg-type mill

In single-pass rural mills paddy is husked with a small rubber roll husker. The brown rice is polished in one pass to white rice. An example of a rubber roll mill is the compact 2-stage rice mill (see Figure 25), which has 0.25 to 1 tonne per hour paddy input. Paddy should be continuously fed to the rubber rolls. The rated husking life of the rubber rolls can vary from 40 to 100 tonnes. The milling performance of the compact rice mill is superior to the single pass Engelberg huller. Milling recoveries are normally between 60–65%.

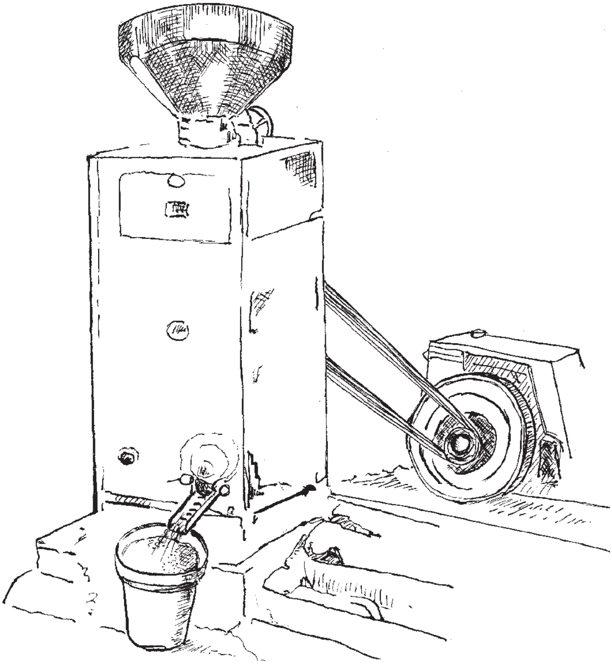

Figure 25: Compact two-stage rice mill

The best-quality milled rice is attained from a multi-stage milling operation. Multi-stage mills have separate rubber rollers to remove the husk, two separate whiteners and one polisher, and a grader for the polished white rice. The husked rice and husked brokens are whitened and polished in two or three passes. Having at least two stages in the whitening process (and a separate polisher) reduces overheating of the grain and allows the operator to set individual machine settings for each step. This ensures higher milling and head rice recovery. Milling recoveries are normally between 65–70%.

Defining quality of milled rice

Quality of milled rice is not always easy to define as it depends on the consumer preferences concerning taste, appearance and smell. In defining the quality standards for milled rice one looks at the percentages of head rice, brokens, damaged and discoloured grains, chalky and immature grains, red (streaked) grains, cultivar purity, foreign matter and brown rice in the rice lot. The amount of immature grains in a sample has a major effect on head rice yield and quality. Immature rice kernels are very slender and chalky and this results in excessive production of bran and broken grains.

9.7 Rice by-product utilization

Rice produces many by-products such as rice straw, rice hulls, rice bran, and small brokens. With increasing crop yields and cropping intensities, the management of rice by-products is becoming increasingly important.

- Rice straw can be used for animal feed and bedding, for the manufacture of straw board and pulp for paper, for composting, as a mushroom-growing medium, for mulching vegetable crops, for making ropes, sacks, mats and hats, for roof thatching, as a plastering material (mixed with clay mud) for the construction of houses and for incorporation into the soil or burning on the field as a way to maintain/improve soil fertility.

- The husk or hull can be used as fuel, bedding, briquettes, poultry feed, absorbent, packing material and building board. Charred hull can be used for water filtration and manufacture of charcoal briquettes. Rice hull ash can be used as a substitute for cement.

- Rice bran or meal obtained in the polishing process is a valuable livestock and poultry feed. Extracted crude rice bran oil can be processed into solidified oil, glycerine and soap. Processed bran oil is used for cooking. Rice bran, polish and flour are used as a (partial) substitute for wheat in bread, cookies, cakes and pies. In hand-pounded rice or rice that is milled in primitive hullers, bran and polish are mixed thoroughly with hulls. They are then generally not suitable for most feed or food uses.

- Small brokens are used as flour.

10 Economics and marketing

This chapter takes a closer look at the economic aspects of lowland rice cultivation in tropical Africa. The aim of rice farmers is not only to produce the highest possible amount of rice but also to do this in the most cost-efficient and risk-avoiding way. The costs involved and possible benefits depend mainly on the agroecological conditions, the type of management applied, and the farmgate prices of rice paddy and of the inputs involved.

10.1 Costs and benefits of different cultivation systems

Table 6 presents these costs and benefits for three lowland rice cultivation systems in tropical Africa during one particular representative season. One system is completely irrigated, one incompletely irrigated, and one is rainfed with bunds.

Table 6 shows that there are huge differences in total costs and benefits per unit land between the three lowland rice cultivation systems. The differences in net benefits are, however, less pronounced. This is due to the fact that the irrigated cultivation system in Mali involves higher total costs to realise its higher rice paddy yields and higher total benefit. The irrigated rice cultivation in the Mali example involves high costs due to high applications of mineral fertiliser, hired labour for transplanting and harvesting, mechanised threshing, payment for rented land, and a high irrigation fee. The relatively high irrigation fee covers the reliable supply of water and the maintenance of the irrigation structures.

Table 6: Costs and benefits (US$/ha) of one representative season in three different lowland rice cultivation systems with high to low water control

Costs (US$ per ha)	Completely Irrigated Office du Niger (Mali)	Incompletely Irrigated Sapu (The Gambia)	Rainfed with bunds Sukumaland (Tanzania)
Renting land	51	0	0
Land preparation	42	17	22
Seed	17	6	13
Transplanting hired labour	34	7	0
Weeding (chemical and/or manual)	17	6	7
Fertiliser	124	33	0
Irrigation fee	108	11	0
Harvesting, threshing, winnowing	188	28	0
Bags	68	20	44
Transport of paddy	8	1	7
Total costs (US$ per ha)	**657**	**129**	**93**
Paddy yield (tonne per ha)	5.5	3.1	2.8
Paddy price (US$ per kg)	0.21	0.25	0.17
Total benefits (US$ per ha)	**1155**	**775**	**476**
Net benefits (US$ per ha)	**498**	**646**	**383**
Total family labour days involved	85	191	230
Gross return to labour (US$ per day per ha)	13.6	4.1	2.1
Gross return to capital (US$ per US$ per ha)	1.8	6.0	5.1

The total costs in the incompletely irrigated system in The Gambia are much lower due to lower fertiliser applications, less hired labour, a lower irrigation fee and no costs for renting land. The rice yield in the Gambia example is considerably lower than in Mali due to poorer water control, lower fertiliser use, and a lower management level of the rice operations in general. Still net benefit in the Gambia case is higher than in Mali. This is due to the higher farmgate price for paddy rice. Farmgate prices between countries can differ considerably due to national price settings and rice import tariff regulations.

The total costs involved in the rainfed cultivation system with bunds in Tanzania are even lower than those in The Gambia. This is due to the near absence of hired labour, complete nonexistence of mineral fertiliser use, and no payment for irrigation. The average rice yield in the Tanzania example is only slightly lower than in the Gambia example. The net benefit is, however, considerably lower due to the much lower farmgate price for paddy rice. One explanation for the lower farmgate paddy price in Tanzania is the loss of quality due to poor threshing. In this part of Tanzania it is still common to beat the harvested panicles with sticks in the fields, which leads to many stones and other unwanted elements in the paddy.

Apart from the net benefits obtained per unit land one can also look at the return to capital and to labour. In Table 6 these gross returns are obtained through dividing the total benefits by the total capital costs involved (return to capital), and by the total number of family labour days (return to labour). Table 6 shows that the return to labour is the highest in the Mali example and the lowest in the Tanzania example. The reason for this is that the farmers in Tanzania use almost three times as many family labour days than those in Mali, where family labour has been replaced considerably by capital inputs. The more secure rice cultivation system in Mali due to reliable irrigation and drainage encourages farmers to use more capital inputs. Credit facilities and cooperative farmer organisations further stimulate these higher capital inputs (fertilisers, mechanized threshers, etc.). Table 6 shows further that the highest capital input (Mali) caused the lowest gross return to capital among the three systems. In The Gambia the amount of capital inputs resembles that in Tanzania due to the less secure water control. The higher farmgate price for paddy rice in The Gambia explains why lowland rice cultivation here has the highest gross return to capital.

In general Table 6 shows that completely irrigated lowland rice cultivation systems are profitable due to an optimal use of labour and rainfed systems are profitable due to an optimal use of capital. Incompletely irrigated systems taking an intermediate position between the other two.

Marketing

If rice farmers want to sell their paddy rice or milled white rice they will have to make sure that the quality of their product meets the standards of the consumers. Individual farmers can obtain information on prices through communication with traders. Farmers may increase their bargaining position if they form farmer associations. Farmer associations can organise post-harvest operations for their members to receive better prices. Farmer associations can also buy inputs cheaper on the basis of relatively large orders. All of this will increase the net benefits of rice farming for their members. Farmer associations can function properly particularly if the members are the principal instigators. However, it is also important that the founding members be well trained in how such organisations should be organised and managed.

Further reading

IRRI Rice Knowledge Bank, providing information on Rice Growth and Development, Lowland Rice cultivation systems, Land Preparation and Crop Establishment, Water Management, Weed Control, Integrated Nutrient Management, Pest Control, Harvest and Post-Harvest Operations and Economics and Marketing. W: http://www.knowledgebank.irri.org/

Piggin, C. et al,. **The IRRI Rainfed Lowland Rice Research Program; Directions and Achievements.** 1998, IRRI Discussion Series Papers No. 26 W: http://www.scribd.com/doc/35338779/The-IRRI-Rainfed-Lowland-Rice-Research-Program

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AfricaRice. **Innovation and Partnerships to Realize Africa's Rice Potential.** 2010. Report of the Second Africa Rice Congress, Bamako, Mali, 22–26 March 2010. W: http://www.africarice.org/warda/arc.asp

CTA Practical Guide Series, No. 17. **Intensive Rice Cultivation**. 2011, 8 p. CTA, Wageningen. ISSN 1873-8192

For information about NERICA cultivars look at the NERICA compendium available on their website:
http://www.africarice.org/warda/guide-compend.asp
For videos about rice production in Africa:
http://www.africarice.org/warda/guide-video.asp

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Glossary

Auricle	A pair of small ear-like lobes at the base of the leaf blade.
Bran	The outer layers of a rice grain, which are removed in milling.
Broadcasting	Applying seeds randomly by hand over a field.
Brokens	Grain that has broken during milling.
Bund	An embankment or levee used to control the flow of water; a division between fields.
Chisel plough	A narrow ploughing tool that is used to break up soil.
Culm	The stem of a grass or sedge.
Cultivar	A cultivated variety.
Disc plough	A round ploughing tool that cuts the soil, but does not turn it (see also Moldboard).
Drilling	Sowing seeds in furrows or holes by hand or machine.
Foliar	Referring to leaves of a plant; application of chemicals to the leaves.
Fungicide	A pesticide used to treat or prevent diseases caused by fungi.
Hardpan	A physically compacted soil layer that restricts root growth and water movement through it.
Harrow	A cultivation tool usually with spikes or teeth used for secondary tillage to pulverise and smoothen the soil, and to mulch, cover or remove weeds.
Head	The panicles and flowers of rice.
Head rice	The whole grains of milled rice that can be obtained from a given quantity of clean rough rice (paddy). It is usually expressed as a percentage of rough rice. Broken rice larger than 3/4 of a

	grain is also considered as head rice. Head rice may vary from as low as 25% to as high as 65% of total rough rice.
Heading	Growth stage of the rice plant marked by emergence of the panicle from the boot.
Hectare (ha)	A measurement of land area equivalent to 10,000 m^2 (e.g. 100 x 100 m or approx. 2.5 acres).
Hill	A group of rice plants close to each other. A hill may also consist of only one plant.
Husk or hull	The outermost covering of the rice grain, which provides protection for the inner grain parts.
Levelling	Land preparation involving moving soil from high to low spots in the field to achieve a flat horizontal surface so that irrigation water will be evenly distributed throughout the field.
Ligule	A thin, upright, leaflet at the top of the leaf sheath. It is attached to the base on the inside of the leaf collar of the rice plant.
Lodge, lodging	The falling down of rice plants in the field due to wind, rain, flooding, pest damage or because the stems are too weak to sustain the plant during the grain-filling stage. Usually causes yield loss.
Mulch	Any material, such as straw, sawdust, leaves, plastic film, loose soil, etc., that is spread upon the surface of the soil to protect it and plant roots from the effects of raindrops, soil crusting, evaporation, etc.
Organic fertilisers	Fertiliser materials derived from plant and animal parts or residues.
Organic matter	The fraction of the soil that includes plant and animal residues at various stages of decomposition.
Paddy	1) Wetland rice. 2) Bunded and leveled field used for cultivation of rice. 3) Threshed, unhulled rice

	(original meaning from the Malay padis).
Panicle	The terminal shoot of a rice tiller that develops into a main axis with branches of rice flowers, which eventually produce the grain.
Panicle initiation	The growth stage of the rice plant which starts when the panicle becomes visible in the base of the main stem of the plant. It can be checked by cutting the main stem open.
Pathogen	An organism that causes a disease. Examples are pathogenic viruses, fungi, bacteria, and nematodes.
Pericarp	The outer layer of the grain, which protects the seed.
Pest	An organism, such as a weed, which competes with other organisms for food or threatens their health.
Photoperiod sensitivity	How much the rice plant responds to a short day length (=photoperiod).
Plough pan	A hard layer of soil at 15–20 cm depth developed through continuous ploughing at the same depth. This layer reduces downward water loss during flooding and prevents penetration of roots. See also Hardpan.
Puddling	Turning the soil into a muddy or watertight paste through tillage.
Ratoon	To develop another crop from stubble after a crop has been harvested.
Rogueing	Removal of infected and undesirable individual plants (off-types) from a field. A rogue is a plant that is growing from a seed that is shed or dropped by a previous crop.
Run-off	The overflow of water over the bunds from a field.
Sedges	Aquatic plants that bear a close resemblance to

	the grasses and can be distinguished by a thin triangular stem.
Spikelet	The basic unit of the rice inflorescence consisting of two sterile glumes, the small axis below the glumes, and the small flower.
Threshing	Operation of detaching or separating the rice grains from the panicle.
Tiller	A vegetative branch of the rice plant composed of roots, culm, and leaves which may or may not develop a panicle.
Tillering	The ability of a rice plant to produce stems, tillers.
Milling recovery	Percentage of whole plus broken grains of milled rice that can be obtained from a given quantity of clean rough rice.
Transplanting	To remove seedlings from the nursery (seedbed) and plant them in the field.
Variety	A group of cultivated plants which is distinguished from another variety and which retains these distinguishing characteristics in following generations. Variety is synonymous with cultivar.

The Agrodok series

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