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Rice systems cropping guide

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Africa Soil Health Consortium: *Rice systems cropping guide*

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About the publisher

The ASHC mission is to improve the livelihoods of smallholder farmers through adoption of integrated soil fertility management (ISFM) approaches that optimize fertilizer use efficiency and effectiveness.

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Contents

1. Introduction

This cropping guide is one in a series being produced for extension workers by the African Soil Health Consortium (ASHC). The series also covers banana-coffee, maize-legumes, sorghum- and millet-legumes, and cassava systems but this guide is focused on rice – upland rainfed, lowland rainfed and lowland irrigated.

Extension workers will find this handbook particularly useful for guiding their clients as they shift from producing rice under traditional, subsistence cropping systems to more market-oriented systems through sustainable intensification.

The guide aims to provide, in a single publication, all the most important information needed to achieve higher yields of rice in a sustainable and cost-effective manner.

Although ASHC's work is focused on the needs of smallholder farmers in Africa, emerging and established commercial farmers will also find the contents relevant and useful.

The ASHC mission is to improve the livelihoods of smallholder farmers through adoption of integrated soil fertility management (ISFM) approaches that optimise fertiliser use efficiency and effectiveness. The overarching framework for the guide is therefore provided by ISFM.

The overall objective of the handbook is to provide simple, useful tips on how small to medium-scale farmers can intensify their rice production to increase yields to around 80% of the potential yield, while decreasing unit costs and increasing profitability – it is usually not cost effective to aim to achieve the maximum potential yield. The average current and attainable target yields for the three main rice systems are shown in Table 1.

Current yields are limited by multiple factors that constrain rice productivity. To achieve improved yields and income, a set of management practices termed 'best practices' should be used for land preparation through to harvesting and grain storage. Best practices include:

- Good land preparation
- Use of quality seed of improved varieties
- Establishing the correct density of plants by correct spacing at transplanting or sowing
- Timely planting
- Effective weeding
- Effective pest and disease management
- Effective water management, especially maintaining correct water levels at different stages of growth (for irrigated systems)
- Correct use of fertilizer and good management of crop residues and other organic material
- Correct and timely harvesting and post-harvest practices.

This rice systems cropping guide provides information on these best management practices and how they can be used to ensure farmers achieve the best rice yields for irrigated and rainfed lowland, and upland production systems.

Table 1. Yields in rainfed upland, rainfed lowland irrigated lowland rice.

Rice system	Current average yields (tonnes per hectare)	Attainable yields with 'best practices' (tonnes per hectare)
Rainfed upland	1	2
Rainfed lowland	2	3–4
Irrigated lowland	5	6–8

2. Rice cropping systems

There are three main types of rice production system (Photo 1):

- irrigated lowland
- rainfed lowland
- rainfed upland.

There is a fourth system, the mangrove swamp, but this represents only about 6% of the rice growing area.

Note: ‘lowland’ refers to the production technique (rice grown on land that is flooded or irrigated) not altitude – lowland production occurs at altitudes up to 2000 m above sea-level.

Table 2. Main features of the three rice systems.

	Rainfed upland	Rainfed lowland	Irrigated lowland
Estimated % of global land area planted to rice	10	30	60
Estimated % of global rice production	5	20	75
Estimated % of Africa land area planted to rice	40	46	14
Estimated % of rice production in Africa	20	47	33
Ecologies where used (see Figure 1)	Uplands, from low-lying valleys to steep slopes	Swampy, low lying areas that collect a lot of water	Flood plains, valley bottoms and terraced fields where there is sufficient water and water control infrastructure to allow irrigation
Crops per year and yields	1 crop per year Yields lower and more variable than lowland	1–2 crops per year One rice crop plus other diversified crops Yields lower than irrigated	1–2 crops per year Highest yields
Water	Soil not covered with water for most of growing season	Soil submerged for part of cropping season, depending on rainfall and groundwater	Layer of water is controlled and covers soil for most of growing season Active water management
Main factors impacting yields	High risk of drought Subsistence farming – low use of inputs	Competition from weeds and risk of drought reduces yields	Reduced risk of crop failure gives farmers confidence to use
Key management practices	No puddling or irrigation and soil not intentionally submerged Seeds broadcast or dibbled in dry soil prior to or during rains	Soils ploughed after onset of rains Bunds used to contain water, but no active management of water Transplantation of seedlings or direct seeding in dry or puddled fields	Puddling Transplantation or direct seeding Management of water levels throughout cropping season Mechanical weed control

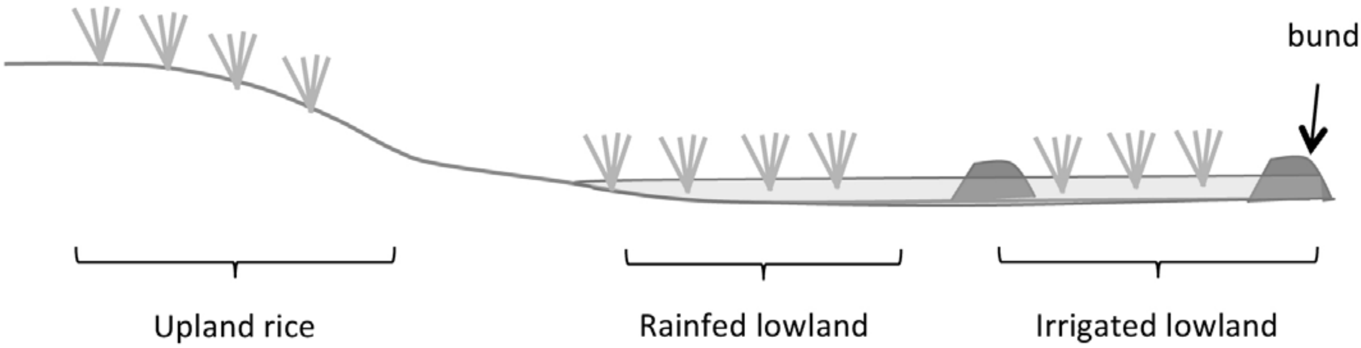

Figure 1. Ecologies where upland, lowland rainfed and irrigated lowland rice is grown.

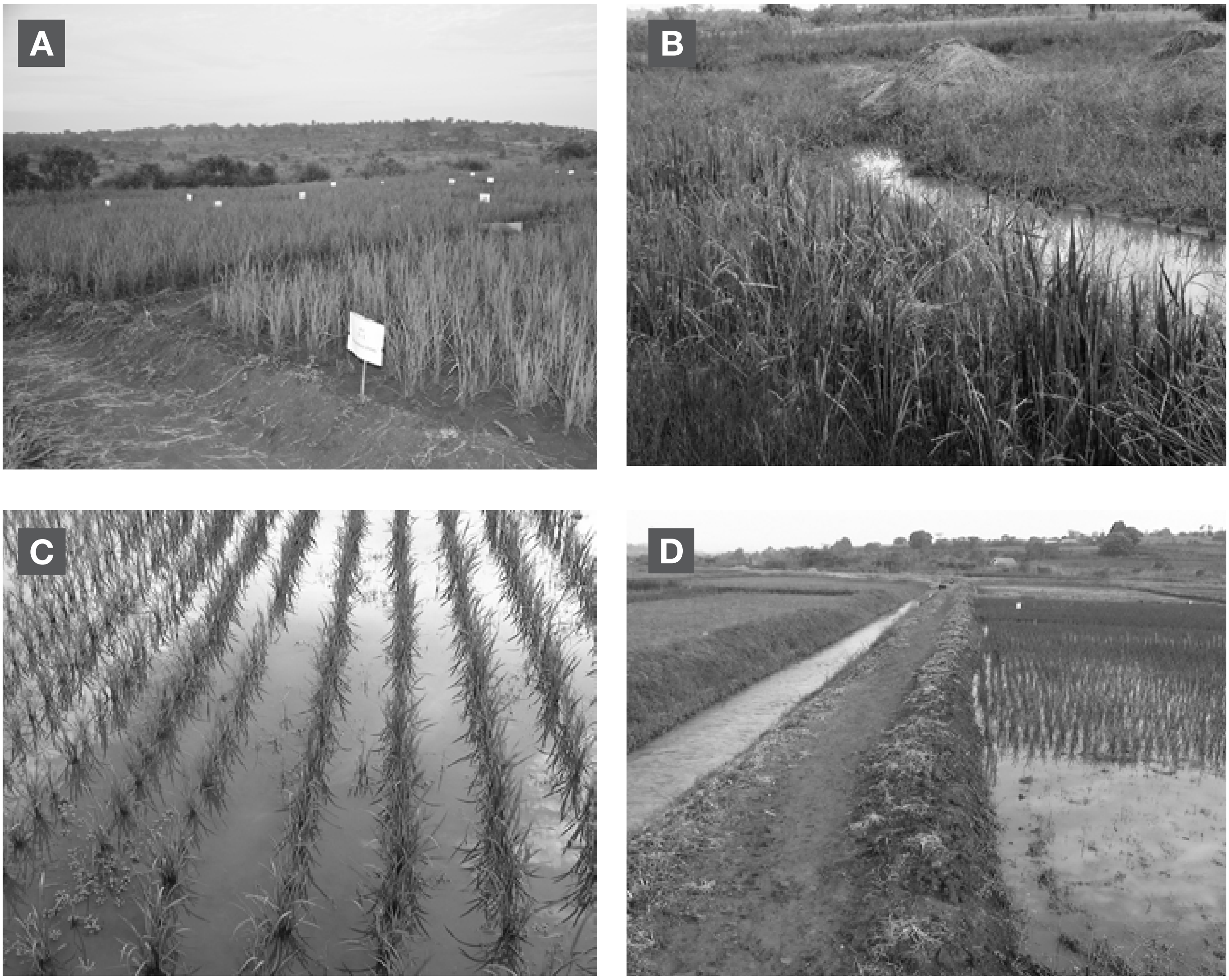

Photo 1. Rice growing in the three systems. (**A**) Upland, well-drained soil (photo: CABI) (**B**) Rainfed lowland, poorly managed water (photo: CABI) (**C**) Irrigated lowland, well managed water (photo: CABI) (**D**) Irrigated rice – irrigation canal (photo: CABI).

3. Growing conditions for rice

Soil

Soil type: Rice can be grown in a wide range of soil types. Soils with good water retention capacities are best – so clay soils with high organic matter content are ideal, but soils with high silt contents are also suitable. Sandy soils are not ideal for rice production.

Soil pH: Rice does best in soils with a near neutral pH (6–7) – that is, they are neither too acidic nor too alkaline – but lowland rice can be grown in soils with pH values in the range 4–8.

The pH value is most important in upland rice. Here, if it is too low (i.e. too acidic) there is a risk of aluminium toxicity and low phosphorus availability (phosphorus is essential to promote good root growth and tillering[1]).

In rainfed lowland rice, iron toxicity is a major problem which limits yields. Iron toxicity occurs in acidic soils and can be managed by applying lime and growing iron-tolerant rice varieties amongst other techniques.

In irrigated lowland rice systems, where soils are submerged for long periods, pH is not usually a problem. Submerged soils tend to become neutral irrespective of whether they were originally acidic or alkaline.

Climate

Rice needs a warm, moist climate with abundant sunshine to do well.

Rainfall: An average of 200 mm rainfall per month is needed for lowland rice; 100 mm a month for upland rice.

Flowers open in the morning and it is best not to have morning rain during flowering. For example, in West Africa, seed of early varieties sown in early July will flower in September–October when morning rainfall is less likely.

Temperature: If temperatures are too high (over 35 °C) flowers fail to set seed. If it is too cold (below 15 °C) growth is slow and plants fail to flower. Ideally, the optimal temperatures range should be between 20 and 30 °C; however, rice tolerates day temperature up to 40 °C. The optimum temperature is 22 to 23 °C for flowering and 20 to 21 °C for grain formation.

Sunshine: Rice does better when there is bright sunshine, especially in the 45 days before harvest when at least 6 hours of sunshine are needed each day.

Key messages

- Rice does best in soils with good water retention capacities, e.g. clay soils with high organic matter.
- The optimum pH is 6–7 but lowland rice can be grown in soils with pH values in the range 4–8.
- Amount of rainfall required is about 200 mm per month for lowland and 100 mm for upland rice.
- Rice production is seriously reduced if temperatures are below 15 °C or above 35 °C.

[1] Tillering means shoots which grow from the base of the rice stem.

4. Land preparation and planting

Land preparation

The objectives in preparing land for rice cultivation are to control weeds, make a good bed for rice plants to grow, achieve the right soil structure and to incorporate crop residues, manure and mineral fertilizer into the soil.

Too deep ploughing should be avoided. A depth of 15–20 cm is enough for rice: deeper ploughing risks moving the most fertile soil too deep for the rice to benefit. Ploughing should be followed by harrowing.

For lowland rice, because rice is grown under flooded conditions, it is best grown on land that is nearly level. Where the land has a steep slope or has an uneven surface, the field should be levelled to a slope of less than 1% (i.e. a drop of less than 1 m for every 100 m length) to enable flooding to an even depth (Photo 2). To achieve a level for a new field, the topsoil should be moved to another position, the sub-soil levelled and the topsoil then returned. For old fields, levelling is done during tilling and harrowing. Alternatively, dykes or bunds can be built to separate the field into a number of different level sections.

Land preparation practices will also vary depending on whether rice is first grown in a nursery bed and then transplanted, or direct sowing takes place.

Lowland rice: Land preparation stops at harrowing if direct seeding. If preparing field for transplanting, harrowing is followed by puddling and levelling. Puddling means tilling the flooded field with the objective of developing a hardpan to reduce water loss through percolation into the ground. Puddling is especially effective in clayey soils.

Upland rice: Land preparation stops at harrowing.

When soil pH is low (acidic), liming to achieve the optimal pH range is required and is best done during land preparation. Soil acidity can reduce nutrient availability, especially phosphorus, while causing aluminium toxicity in upland soils and iron toxicity in lowland soils. About 2 tonnes of lime per hectare is required to increase pH by one unit on clayey soils, but less is required for loamy soils. The lime should be applied by broadcasting and incorporating into the top 15–20 cm of the soil during ploughing.

Choice of varieties

Rice varieties should be selected that have grain characteristics suitable for the market; for example, grain that is white if rice is to be milled and sold to consumers, or grain with a yellow tint if rice is for parboiling. The variety should also be suitable for the local ecology and have desirable plant characteristics; for example, for famers who harvest by hand, plants of a height that allows for easy harvesting – that is, about 1.1 m tall at maturity – are suitable. The variety chosen should also have high yield potential.

Photo 2. Land preparation. (**A**) Making bunds for water management (photo: CABI) (**B**) Tractors can be used to make bunds (photo: CABI) (**C**) In the irrigated system, land can be ploughed soon after harvesting, and the next crop planted (photo: CABI) (**D**) Levelling can be done manually (photo: CABI/IPNI) (**E**) A well prepared field for irrigated rice should be level, the height of water should be uniform (photo: CABI) (**F**) Depth of water is not uniform. (photo: CABI).

Seed selection and planting

Seed can either be farmer-saved from the previous harvest or improved varieties can be purchased from seed producers or seed companies. Preferably, fresh seed should be obtained to ensure the seed is clean and of the desired variety. Use of seed that is a mixture of different varieties should be avoided as they mature at different times, which complicates harvesting.

Seed from some varieties does not germinate well if harvested and planted immediately but germinates better if stored for some time before planting. This period during which seed germination is poor is referred to as the 'dormancy period'. Some varieties have a dormancy period of 2–3 weeks after harvesting. If planting freshly harvested seed, it should be dried in the sun for 1–2 days to break dormancy.

Prior to sowing a germination test should be performed. For this, 100 rice seed grains should be placed on wet paper in a waterproof container. After five days the number of germinated seeds is counted. To calculate the germination rate:

$$Germination\ \% = \frac{Number\ of\ seeds\ germinated}{Number\ of\ seeds\ sown} \times 100$$

Ideally, germination rates should be 80–100%; if 60% or below, the farmer should either obtain fresh seed or adjust the seed rate accordingly. For example, if the target seed rate is 80 kg per hectare and germination is 60%, then the amount of seed to be sown per hectare is:
80 kg × (100/60) = 133 kg.

Before planting, the seed should be winnowed to remove chaff. To remove unfilled grains, place seed in water: unfilled grains will float to the surface and can be removed.

Rice seed can be direct sown as dry seed, direct sown as pre-germinated seed, or the seed can be started off in a nursery and the young seedlings transplanted to the field later. Each method has advantages and disadvantages and is suited to different situations and systems (see Table 3).

Direct sowing: This is always done for upland rice and can also be done for lowland rice.

For upland rice, dry sowing can be done by broadcasting, or planting in rows. If planting in rows, seeds can be placed in holes or furrows. For broadcasting 80–100 kg seed per hectare is applied. If planting in holes, space at 20–30 cm (between and within rows) with 2–3 seeds per hole: this will require less seed, just 40–50 kg per hectare. If planting in furrows, space furrows at 25–30 cm and place seeds at 5 cm intervals along the furrow: this will require about 75–80 kg of seed per hectare. After broadcasting the seed is covered, for example with the use of a spine-toothed harrow. For row sowing, the distance between rows is determined by the width of the weeding implement used.

For rainfed or irrigated lowland rice, dry seeding (i.e. planting of dry seed into dry or moist soil; dry seed is seed that has not been pre-germinated) can be done in rows or broadcast. In rows, 80 kg per hectare dry seed is used; for broadcasting 100–120 kg seed per hectare is used.

Note: If water control and drought are problems, transplanting is preferable to direct sowing.

Transplanting: Transplanting seedlings is one option for lowland rice systems. Here seeds are sown in a nursery bed and seedlings transplanted into the field.

Nursery for seedlings

The nursery bed can either be in the main plot (Photo 3), or somewhere else: in some rice growing schemes there is one site for all the farmers' nurseries.

If in the main plot, select a location not too far away from the irrigation canal for easy access to water.

Because of rice yellow mottle virus, it is better to have the nursery away from the field border. This is because insects living in the border can infect plants; weeds in the border provide good habitat for insects as the border is always moist due to the closeness to the drain.

There are three main options for producing seedlings:

1. Sowing dry seed in dry nursery beds, which are then flooded. Seedlings grown in this way have deeper roots, which makes them more difficult to transplant.
2. Sowing pre-germinated seeds on to wet mud. Seedlings grown in this way have more shallow roots and are therefore easier to transplant. Seed can be broadcasted on the muddy seed bed instead of planting in rows to save on labour. If the seedbed is 1 m wide, for every 10 m length of seedbed use 1 kg seed.
3. Sowing in a dapog nursery, also referred to as a mat nursery, for which a number of different modifications have been developed. The nursery is made on a firm surface that roots cannot easily penetrate and hence uprooting seedlings from the nursery is easier than from dry or wet mud nurseries.The nursery bed can be constructed over sheets of plastic, banana leaves or a concrete surface. Before planting, a wooden frame can be used to create cells, each measuring 30 cm × 50 cm and 4 cm deep. A mix of soil, well-rotted manure and rice hulls is placed in the frame and the frame is then removed. Alternatively the soil mixture can be placed on the firm surface without using the wooden frame. Pre-germinated seeds are then sown in the nursery by broadcasting. If the seedbed is 1 m wide, for every 10 m length of seedbed use 10 kg seed.

The width of the nursery bed should allow for working without stepping on the bed (Photo 5). A width of 1 m is ideal and the bed should be raised to about 5 cm above the ground surface.

The size of the nursery depends on the type of nursery and the area to be planted. If seeding on wet mud, the nursery should be about a tenth of the area to be planted; if seeding using the dapog method, the nursery should be about a hundredth of the area to be planted.

Photo 3. Nursery can be set up in the field (photo: CABI/IPNI).

How to pre-germinate rice seed

To pre-germinate rice seed, submerge a jute sack containing seed in water for 24 hours (Photo 4). After 24 hours, remove the bag from water and place in a shady place where the air can circulate around the bag. Ensure than the temperature of the bag does not exceed 42 °C. After another 24 hours the pre-germinated seed is ready for sowing: this should be done before the roots are more than 5 mm in length.

There is no need to apply fertilizer in the nursery if the seedlings will be transplanted at nine days. If, however, seedlings are to be planted in a field where water control is not good (e.g. which is not levelled properly or that has a high depth of water) apply fertilizer (such as 50 g diammonium phosphate (DAP) per square metre) to make the plants grow faster and taller so that they can better withstand the water.

Transplanting seedlings

Seedlings should be transplanted between 9 and 21 days from sowing for seedlings grown from both pre-germinated seed and dry seed. If crabs in mangrove are a problem, allow seedlings to grow for more than 21 days so they can better resist predation. If transplanting after 21 days, fertilizer can be applied to the nursery if nutrient deficiencies are expected (for example, 50 g DAP per square metre).

Wet-bed seedlings should be planted at a depth of 1.5–3 cm and dapog seedlings at a depth of 1.5 cm. This is because the roots of dapog seedlings do not grow as deep as those for wet-bed seedlings.

It is best to plant seedlings out in the rice fields in rows, with regular row and between-plant spacing (see Table 4 for suggested plant arrangements). Row planting has a number of advantages over random planting: it makes weeding and fertilizer, herbicide and insecticide application easier and also helps ensure optimal planting density. To ensure straight lines and correct spacing, wire, twine or wooden planting guides can be used (Photo 6).

For mechanized transplanting, the dapog type nursery is required. The seedlings are raised in a soil mixture on a firm surface. When transplanting, seedlings are uprooted in a mat and placed into the rice planter.

Extra seedlings should be temporarily planted around the edge of the field and used to fill any gaps after around 10 days.

Photo 4. Pre-germinating seed. (A) Get clean paddy rice seed (photo: CABI) (**B**) Wash the seed. Remove debris and floating seed (photo: CABI) (**C**) Soak seed in water for 24 hours (photo: CABI) (**D**) After 24 hours, pour out water (photo: CABI) (**E**) Place seed in bag (photo: CABI) (**F**) Roll bag with seed inside (photo: CABI) (**G**) Place bag in bucket, or another container (photo: CABI) (**H**) Seed can stay in bucket for 24 hours (photo: CABI) (**I**) Periodically check the condition of seed (photo: CABI) (**J**) If too dry, add more water (photo: CABI) (**K**) Sprouting seeds (photo: CABI).

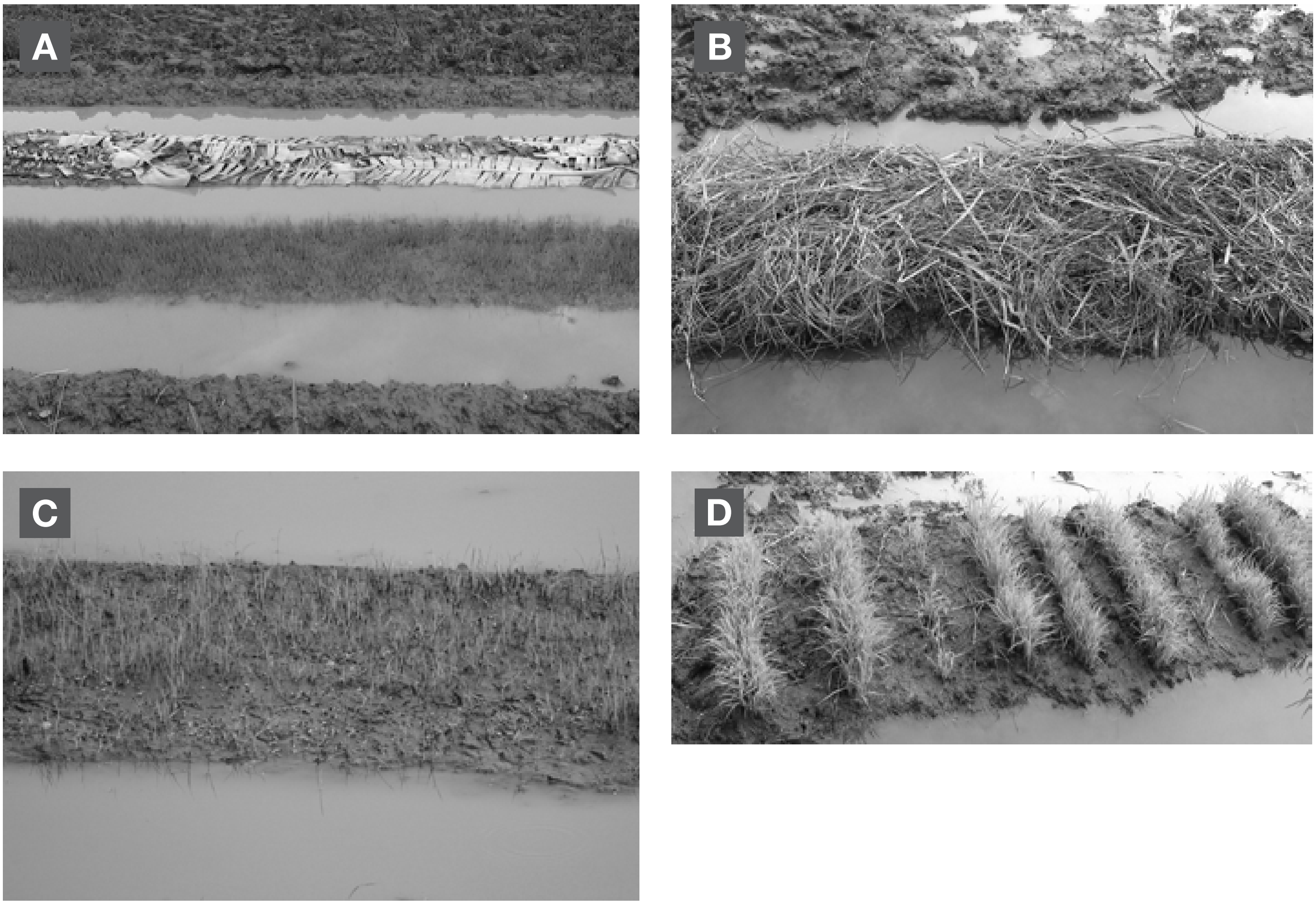

Photo 5. Seedlings in nursery bed. (**A**) Seeds covered with banana leaves to prevent drying of surface when seeds are sprouting (photo: CABI) (**B**) Avoid covering seedbed with rice straw or grass. Straw and grass may have seed which can grow, contaminate the crop and may be difficult to control (photo: CABI) (**C**) Newly uncovered seedlings (photo: CABI) (**D**) Dormancy can be a problem with seed of some rice varieties - for example, 3rd and 7th row from left in the photo (each row is a variety). If dormancy is suspected, wait for at least 2–3 weeks after harvesting seed before planting it (photo: CABI).

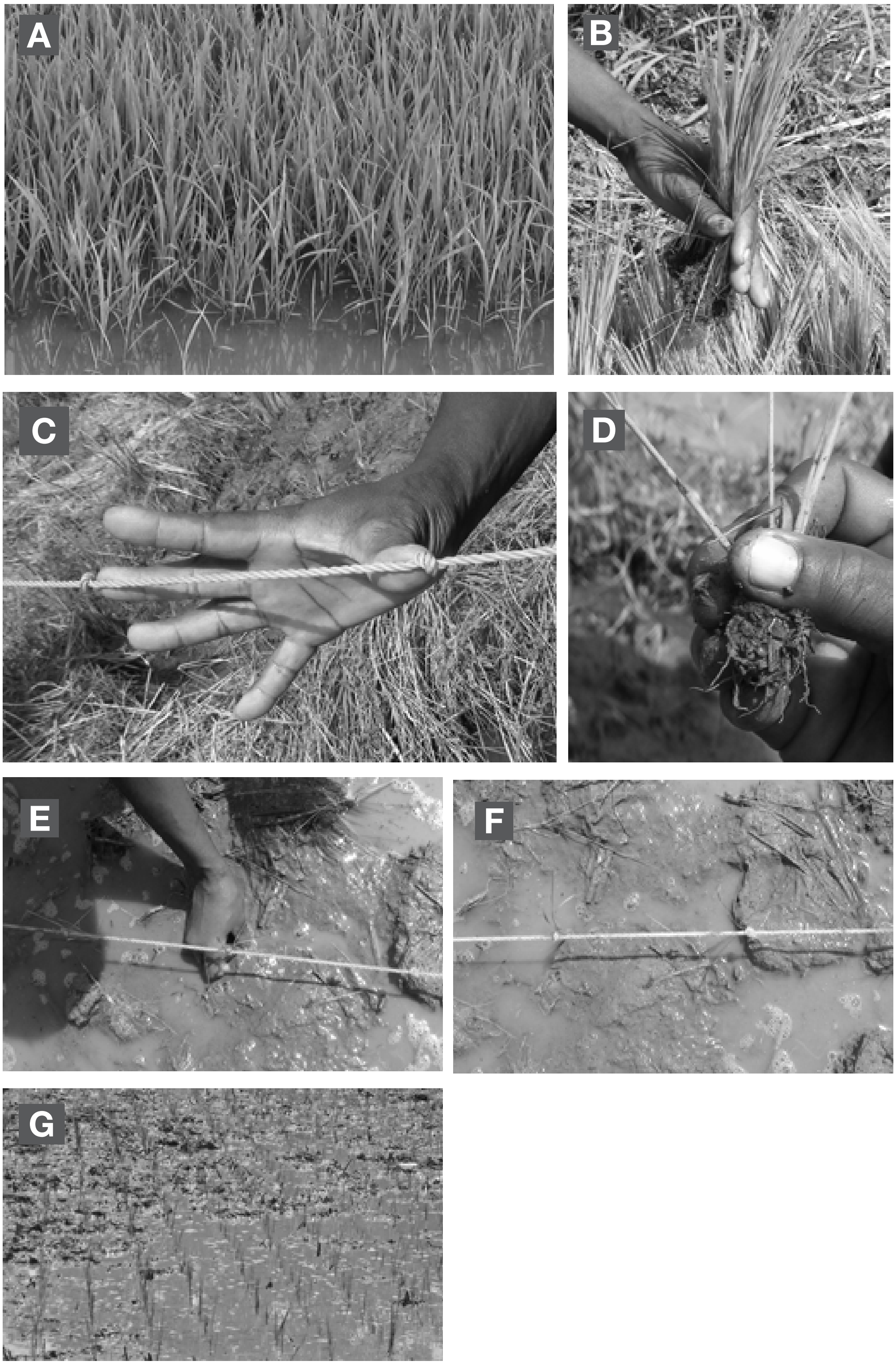

Photo 6. Transplanting seedlings from nursery. (**A**) Seedlings in nursery ready for transplanting (photo: CABI) (**B**) Seedlings uprooted for transplanting – if too tall, cut off tips to encourage seedlings stray upright on transplanting (photo: CABI) (**C**) Seedlings can be spaced at 20 cm between rows and 20 cm along rows. This planting rope is marked at 20 cm intervals (photo: CABI) (**D**) Place 2–3 seedlings at each point (photo: CABI) (**E**) Place the seedlings gently into the mud, with the node remaining above the water (photo: CABI) (**F**) Seedlings spaced at 20 cm (photo: CABI) (**G**) Seedlings in rows (photo: CABI).

Table 3: Characteristics of dry and pre-germinated seed sowing and transplanting.

	Dry seed sowing	Pre-germinated seed sowing	Transplanting
Features	Dry seed broadcast or sown in rows into dry soil	Seeds are pre-germinated, then sown in a wet bed	Seeds are pre-germinated, grown in a seedbed, then seedlings are transplanted to a wet field
Advantages	Less labour required than transplanting	Increases rate and percentage of seedling emergence Less labour required compared with transplanting Requires less water during land preparation	Good plant growth, tillering and yield Optimum plant density obtained Less weed competition as seedlings grow ahead of weeds Good weed control Uniform maturity
Disadvantages	Seeds are placed on the soil surface and can be eaten by birds and other animals Weeds can be a problem as both weeds and rice emerge at about the same time Lodging can be a problem as plants may not be firmly anchored to ground	Weeds can be a problem Waterlogging can be a problem, especially when crop is young if land is not level	More labour required
Suitability for upland	Suitable	Not suitable	Not suitable
Suitability for rainfed lowland	Suitable if water is well managed	Suitable	Suitable
Suitability for irrigated lowland	Suitable	Suitable	Suitable

Table 4. Optimal spacing for different types of variety and seasons.

Variety	Dry season: fertile soil	Dry season: poor soil	Wet season: fertile soil	Wet season: poor soil
Tall, leafy, heavy tillering, susceptible to lodging	30 × 30 cm	25 × 25 cm	35 × 35 cm	30 × 30 cm
Short, lodging resistant	20 × 20 cm	20 × 15 or 20 × 10 cm	20 × 20 cm	20 × 15 or 20 × 10 cm

Key checks

- Plough soil to a depth of 15–20 cm, and then harrow. Avoid deep ploughing.
- For lowland rice, level field to a slope of less than 1%.
- For upland rice, always plant seeds directly in field.
- Lowland rice can be sown directly, or seed can first be grown in a seedbed and then seedlings transplanted to field.
- If direct seeding, seeds can be pre-germinated or planted before pre-germinating.
- For nursery seeding, pre-germinate seeds before planting.
- No need to apply fertilizer in nursery if transplanting within the recommended 9–21 days after sowing. If transplanting later or into deep water, apply 50 g DAP per square metre to nursery.

5. Rice management

Water management: irrigated lowland rice

Active water management is only possible in irrigated lowland rice. The objective here is to keep a water layer to control weeds: the water acts like a layer of weed-suppressing mulch for land plants.

It is important to ensure that the point at which nodes start should not be under water. The water level must increase with the height of the plant: maximum depth should not exceed 10 cm.

From transplanting to panicle initiation maintain a depth of 2–3 cm of water, after panicle initiation 5–7 cm, then drain field 7–14 days before harvesting. After tillering, raising the water level from 2–3 cm to 5–7 cm does not have any impact on plant development.

When applying fertilizer (see Page 19), drain water, apply fertilizer, then wait at least three days before letting water back in.

Weeding

Weeds can be controlled mechanically, pulling by hand or using a machine, or by use of herbicides.

Herbicides can be used to control difficult weeds, such asoryza weeds (e.g. wild rice) and grasses with rhizomes. If using herbicide, apply non-selective types before ploughing to destroy all types of weeds. The weeds are then ploughed in 21 days after applying the herbicide.

The decision on the type of herbicide to use should depend on timing and type of weeds. Some herbicides can be applied before weeds emerge; for example, butachlor, a pre-emergence herbicide, does not harm rice but controls many annual grasses, sedges and broadleaved weeds. Alternatively, a selective post-emergent herbicide can be used after crop establishment when weeds start to appear; for example, propanil, a post-emergent herbicide, controls grasses but not broadleaved weeds. The herbicide should be sprayed when weeds are at the 2–3 leaf stage. This controls weeds for about one month. Later, weeds can be controlled by pulling out by hand or using a mechanical weeder.

The field must be kept weed-free until harvest (Photo 7) as weeds affect the quality of rice grains or seed. Some farmers stop weeding when the rice has flowered, but this is not recommended.

Manure that is not well decomposed can be a source of weed seeds. Weed seeds can also be carried to neighbouring fields through irrigation water. To avoid introducing weeds into rice fields, manure should be well decomposed and weeds should be destroyed before they form seeds.

For irrigated lowland rice, farmers should maintain a shallow layer of water. Farmers often put in too much water thinking they can control weeds better that way but this is bad practice. With good levelling of the soil, a water depth of about 2–5 cm can be maintained to control weeds.

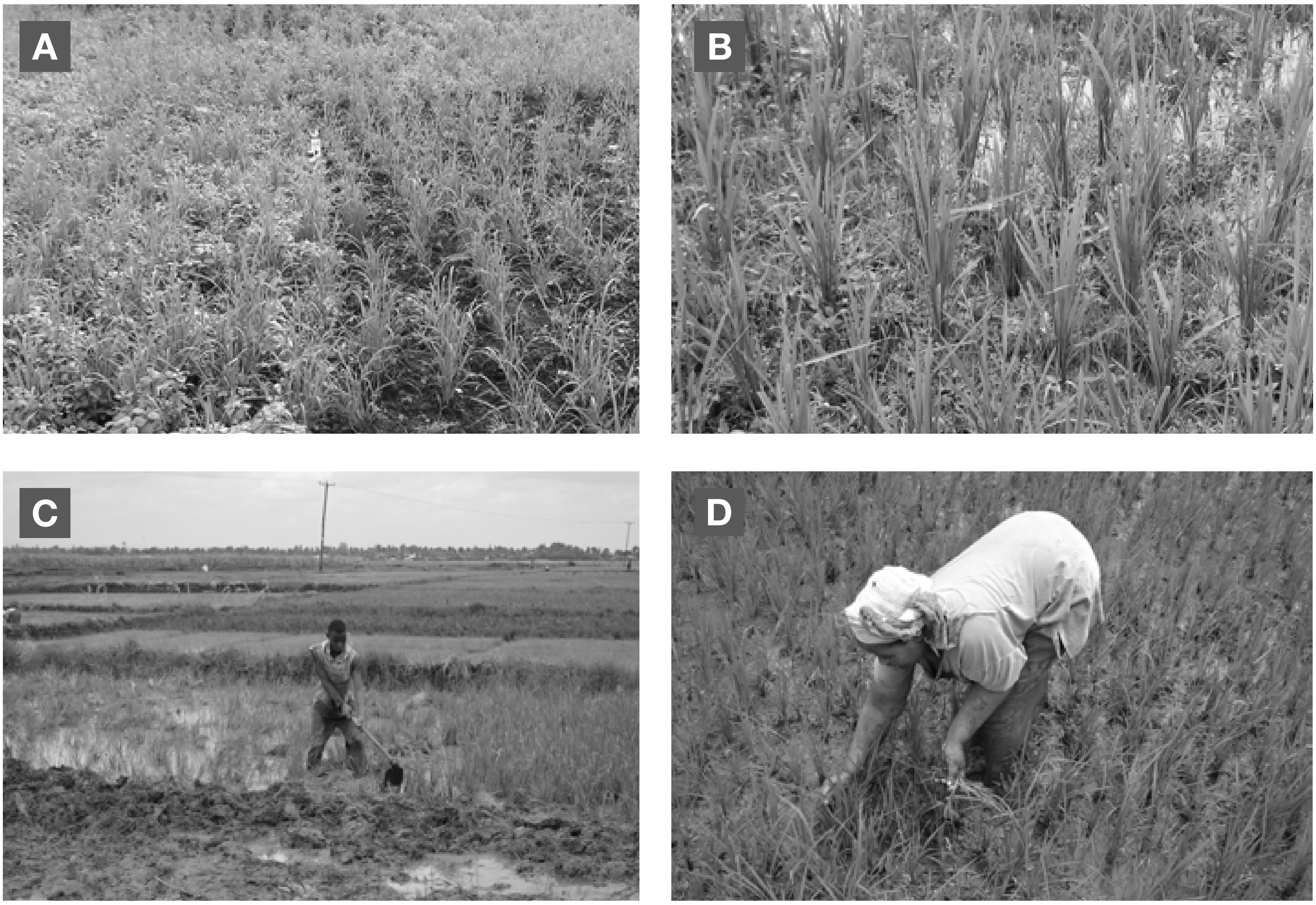

Photo 7. Weeding. (**A**) Upland rice unweeded (photo: CABI) (**B**) In irrigated rice, weeds can be controlled to some extent by managing water (photo: CABI) (**C**) Manual weeding using hoe (photo: CABI/IPNI) (**D**) Pulling out weeds (photo: CABI/IPNI).

Nutrient management

To ensure sustainable production and avoid depleting and degrading the soil, the nutrients removed when the rice crop is harvested need to be replaced.

For every tonne of rice grains plus straw harvested around 22 kg of nitrogen (N), phosphorus equivalent to 10 kg of P_2O_5 and potassium (K) equivalent to 27 kg of K_2O are taken up from the soil by the crop.

These nutrients can be replaced by application of mineral fertilizers and organic matter (such as manure and rice straw) to the soil, and also by the use of nitrogen-fixing legumes such as green manures and in crop rotations.

Not all the fertilizer applied to the soil is available to the crop. To allow for this – which is known as 'fertilizer use efficiency' - for every additional tonne of grain harvested, fertilizer containing around 60 kg N, 30 kg P_2O_5 and 30 kg K_2O needs to be applied to support long-term sustainable cropping.

Fertilizer use

The optimal type and amount of mineral fertilizer that is needed will vary in different locations and situations. Some general guidelines are provided in the tables below – see The 4Rs: right source, rate, time and place, below.

The aim of these guidelines is not to maximise production; rather it is to increase yields by about one tonne per hectare for upland and rainfed lowland rice, and by up to 3 tonnes per hectare for irrigated lowland rice (see Table 5). Although higher yields are possible, aiming to increase yields by between 1 and 3 tonnes per hectare is more cost-effective and also likely to be within the reach of smallholder farmers.

These recommendations are based on the use of five fertilizers that are commonly used on rice: diammonium phosphate (DAP); muriate of potash, also called potash (MOP); urea in the form of small granules (about 2mm in diameter) and urea in the form of 'super granules' or pellets (3-5 g each); and NPK 15-15-15.

Table 5. Average current yields and achievable yields when good seed and fertilizer are used other and good agronomic practices are followed.

Rice system	Average current yield tonnes per hectare	Achievable target yield tonnes per hectare
Upland rice	1	2
Rainfed lowland rice	2	3-4
Irrigated lowland rice	5	6-8

Fertilizer response curves

The way that crops, including rice, respond to fertilizer can be described by a fertilizer response curve (see Figure 2): this shows the impact of increasing amounts of fertilizer on yield.

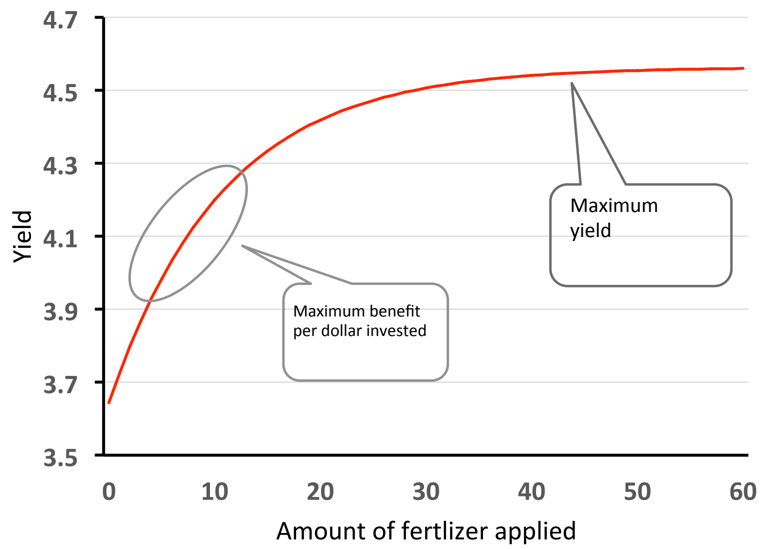

Figure 2. Fertilizer response curve.

As the figure shows, to begin with the yield increases steeply as more fertilizer is added, but as the amount of fertilizer applied increases, the extra yield achieved decreases. Eventually adding more fertilizer will have no further impact on yield.

The best return on investment in fertilizer is achieved where the response curve is steepest– here the greatest increase in yield is achieved per unit of fertilizer added (circled in yellow in the diagram). So the recommendations given below aim to fall on this, the steepest part of the curve.

Actual increases in yield will, however, vary depending on many variables. These include:

- the characteristics of the site, for example the soil may be locally deficient in one or more nutrients in addition to N, P and K (which are the focus of these recommendations)
- weather – especially rainfall and amount of sunshine
- pests and diseases present
- other management practices, such as varieties used, water management and weeding
- incorporation of organic matter to the soil, including livestock manure and rice straw
- quality of mineral fertilizer being used: some fertilizers are sub-standard – they may not contain the amount of nutrients shown on the label . Fertilizer should therefore only be purchased from trusted sources, such as local agro-dealer shops.

So, if target yields are not achieved following these recommendations, then expert assistance should be sought to work out what factor is holding back production.

Short term gains and sustainable cropping

In comparison to use of little or no fertilizer, the fertilizer recommendations given below are likely to increase yields and generate higher incomes from sales of surplus production in most situations, at least in the short term.

Although adopting the recommendations provided below is better than applying little or no fertilizer, the soil might still be ‘mined’ – more nutrients might be taken out with the crop than are being replaced each season by application of mineral and organic fertilizer.

Ideally farmers should, therefore, use these recommendations for a few seasons only. After this they should consider reinvesting some of their increased profits from their higher yields, for example by paying for laboratory soil and leaf tests. The results of these tests can be used by experts to design much better fertilizer recommendations suited to their farms which will maintain soil health and support sustainable production in the future. In some cases multi-location nutrient omission trials to determine soil nutrient supply potential and N, P and K responses may be possible, but these are outside the scope of this guide.

The 4Rs: right source, rate, time and place

If site specific fertilizer recommendations are available these should be followed. In case these are not available, this section provides some examples of basal and top-dressing options.

The guidelines below are simple, blanket recommendations based on the ‘4Rs’ - that is the right source, right rate, right time and right place of nutrient management.

Usually nitrogen is the first most limiting nutrient to rice production followed by phosphorus and potassium, and so these guidelines focus on these three major nutrients.

These guidelines are intended for use in situations where the soil preparation and planting advice given in this cropping guide has been followed; in seasons where rainfall is close to normal and/or irrigation water is available in adequate amounts; and the soil either has no problem with soil alkalinity or salinity, or appropriate steps have been taken to address these issues (see Section 6, *What can go wrong*).

The fertilizer recommendations below are provided as both kg per hectare and g per square metre[2]. Farmers are, however, likely to find it difficult to measure or accurately estimate small amounts of fertilizer. To help overcome this problem see box, Farmer friendly fertilizer measurements, which shows how cheap, locally available items can be used as calibrated scoops to measure fertilizer.

Basal fertilizer is applied when the plot is being prepared for planting or at the time of sowing or planting. It provides nutrients needed by the crop early in its growing cycle and also nutrients which are slowly released over the growing season. For lowland rainfed rice, where water levels cannot be managed, all fertilizer has to be applied as basal fertilizer.

Top-dressing is application of fertilizer after the crop has started growing. It provides nutrients, especially nitrogen, which are needed later in the crop’s growing cycle, for example when the panicle (grain) is forming and also nutrients which, if applied earlier, would be lost into the air or water.

Upland rice: The following tables give some examples of the right amounts of basal and top-dressing fertilizers for upland rice.

[2] There are 10,000 square metres in a hectare: grams per square metre is therefore the amount in kg per hectare divided by 10,000

Applying these fertilizers can help farmers to increase their yields from about one tonne per hectare to about 2 tonnes.

The combination of either Example 1 basal fertilizer plus Example 1 topdressing, or Example 2 basal fertilizer plus Example 2 topdressing will both supply a total of about 60 kg N, 30 kg P_2O_5 and 30 kg K_2O per hectare.

	Basal fertilizers for upland rice	
	kg per hectare (number of 50 kg bags)	grams per square metre
Example 1	200 kg (4 bags) NPK 15-15-15	20 g NPK 15-15-15
Example 2	65 kg (1.3 bags) DAP AND 50 kg MOP (1 bag)	6.5 g DAP AND 5 g MOP

Basal fertilizer should be applied when the soil is being prepared for the upland rice crop. The fertilizer is broadcast and then harrowed into the soil.

The top-dressing should be applied in two equal splits: the first around 21 days after seeding and the second at panicle (seed head) initiation, around 45-50 days after seeding. Top-dressing should be applied after a good rain when the soil is moist: do not apply to dry soil. If a mechanical weeder is being used, the top-dressing can be applied at the same time as weeding.

	Top-dressing for upland rice	
	kg per hectare (number of 50 kg bags)	grams per square metre
Example 1	65 kg (about 1.3 bags) urea split into 2 equal applications	6.5 g urea split into 2 equal applications
Example 2	100 kg (about 2 bags) urea	10 g urea split into 2 equal applications

Lowland rainfed: Because the water level cannot be managed in this system, all fertilizer needs to be applied when the soil is being prepared for the rice crop (basal) – no top-dressing is applied.

The following table give two examples of the right amounts of basal fertilizers for improved, high-yielding varieties grown in lowland rainfed rice systems: either Example 1 or Example 2 should be applied.

Applying these fertilizers can help farmers to increase their yields of lowland rainfed rice from about 2 tonne per hectare to 3 to 4 tonnes. In both examples, the basal fertilizer will supply about 60 kg N, 30 kg P_2O_5 and 30 kg K_2O per hectare. The basal fertilizer should be broadcast and then harrowed into the soil.

	Basal fertilizer for lowland rainfed rice	
	kg per hectare (number of 50 kg bags)	grams per square metre
Example 1	200 kg (4 bags) NPK 15-15-15 AND 65 kg (about 1.3 bags) urea	20 g NPK 15-15-15 AND 6.5 g urea
Example 2	65 kg (1.3 bags) DAP AND 100 kg (about 2 bags) urea AND 50 kg MOP (1 bag)	6.5 DAP AND 10 g urea AND 5 g MOP

If traditional, tall varieties are grown, which are prone to lodging, just the urea (100 kg per hectare) can be used.

Lowland irrigated: The following tables give some examples of the right amounts of basal and top-dressing fertilizers for high-yielding varieties grown in lowland irrigated rice systems.

Applying these fertilizers can help farmers to increase their yields of lowland irrigated rice from about 5 tonne per hectare to up to 8 tonnes. The combination of either of the basal fertilizer options plus Example 1 of the top dressing options will together supply about 150 kg N, 45 kg P_2O_5 and 45 kg K_2O per hectare.

Either of the basal fertilizer options can also be combined with top dressing Example 2: although this supplies less N, this option (urea super granules) is more efficient and so either top dressing option will support similar levels of production.

The basal fertilizer should be applied by broadcasting before puddling.

	Basal fertilizer for upland irrigated rice	
	kg per hectare (number of 50 kg bags)	grams per square metre
Example 1	100 kg (2 bags) DAP AND 30 kg (0.6 bags) MOP	10 g DAP AND 30 g MOP
Example 2	300 kg NPK 15-15-15	30 g NPK 15-15-15

For normal granulated urea (Example 1, below), the top dressing should be applied in two equal splits: the first 10-15 days after transplanting and the second at panicle initiation. To apply urea, the field should be drained so it is muddy, the urea applied by broadcasting and, after 2–3 days, the field re-flooded. Urea should not be broadcast on flooded fields as this will lead to high losses of N.

The pellets (also called super granules) used in the deep urea placement (DUP) method (Example 2, *Top-dressing for upland irrigated rice*) are much larger than normal urea fertilizer granules – typically 3 to 5 grams. They release N slowly and losses are reduced compared to ordinary granules; they are also more efficient, resulting in larger increases in yield per unit of urea applied – so less urea can be used when pellets are used in place of granules. For the DUP method, the urea is applied once only at the tillering stage. One 3 gram super granule should be placed between every four plants in every other row at a depth of 7-10 cm[3].

Crops grown in irrigated lowland systems in the dry season, when sunshine is abundant, need more N than crops grown in the lower yielding wet season. Rice that is deficient in N is paler than healthy crops (see *Nutrient deficiencies*, page 32).

	Top-dressing for upland irrigated rice	
	kg per hectare (number of 50 kg bags)	grams per square metre
Example 1	230 kg urea split into 3 equal applications	23 g urea split into 3 equal applications
Example 2	187.5 kg super granules for DUP in one application at tillering only	19 g super granules for DUP* in one application at tillering only

*Assuming row and plant spacings of 20 cm x 20 cm, that is 250,000 plants per hectare. One 3 gram urea pellet between every 4 plants in every other row (equivalent to one pellet per 4 plants) totals 62,500 x 5 g = 187,500 g (187.5 kg) per hectare.

Note: If traditional varieties are grown, only up to a maximum of 100 kg urea per hectare is recommended: application of higher levels of nitrogen to traditional (tall) varieties is not advisable because these varieties tend to lodge (fall over).

Farmer friendly fertilizer measurements

It is difficult for farmers to know what small amounts of fertilizer, such as 10 g of urea, looks like and they will not have access to weighing scales.

The solution to this problem is to identify a locally available container, such as metal crown cork bottle-top for beer or soda[3]. The bottle-top can then be used as a scoop for measuring fertilizer.

For larger amounts, discarded water bottles make useful containers.

Different fertilizers have different densities, so while a bottle-top full (level, not heaped) of NPK 15-15-15 will weigh 3 g, a bottle-top full of DAP will weigh just under 5 g.

For those with access to the internet, a tool (the OFRA fertilizer calibration tool) is available at CABI-ASHC website (www.africasoilhealth.cabi.org). This tool enables the user to calibrate any circular container that can be filled with a range of different fertilizers.

See table, below, for other fertilizers: values in this table have been calculated using the CABI tool.

Fertilizer type	Weight of fertilizer (g) per metal beer or soda bottle-top full
CAN	3
DAP	5
MOP	6
NPK 15-15-15	3
SSP	3.5
TSP	7
Urea	4

So, for example, to apply 10 g of urea per square metre of soil, two and a half bottle-tops full of normal (granular) urea fertilizer are needed: 2.5 x 4g = 10 g

To apply 20 g of NPK 15-15-15, just under 7 bottle-top measures are needed per square metre: 7 x 3g = 21 g. For larger amounts, a cut-off plastic water bottle will be a more convenient measure, but this will need to be calibrated using the *OFRA fertilizer calibration tool*.

Once farmers have some experience of using the measure they will know what the appropriate amount of a given fertilizer looks like. They can then stop using the measure and apply a three-finger pinch of fertilizer which corresponds to the right amount. From time to time it would be advisable to check that their pinch is delivering the right amount of fertilizer.

Use of CAN and other nitrate fertilizers

Nitrate-containing fertilizers, such as ammonium nitrate or calcium ammonium nitrate (CAN) are not suitable for rice when applied at or before planting. Unlike ammonium-containing fertilizers (such as DAP and ammonium sulphate, and also urea, which is hydrolysed to ammonium), the nitrogen in nitrate-containing fertilizers can be lost quickly by denitrification once the field is flooded. They can, however, be used for topdressing when uptake of nutrients is proceeding rapidly as the topsoil is covered with a mat of roots and N losses are therefore minimized.

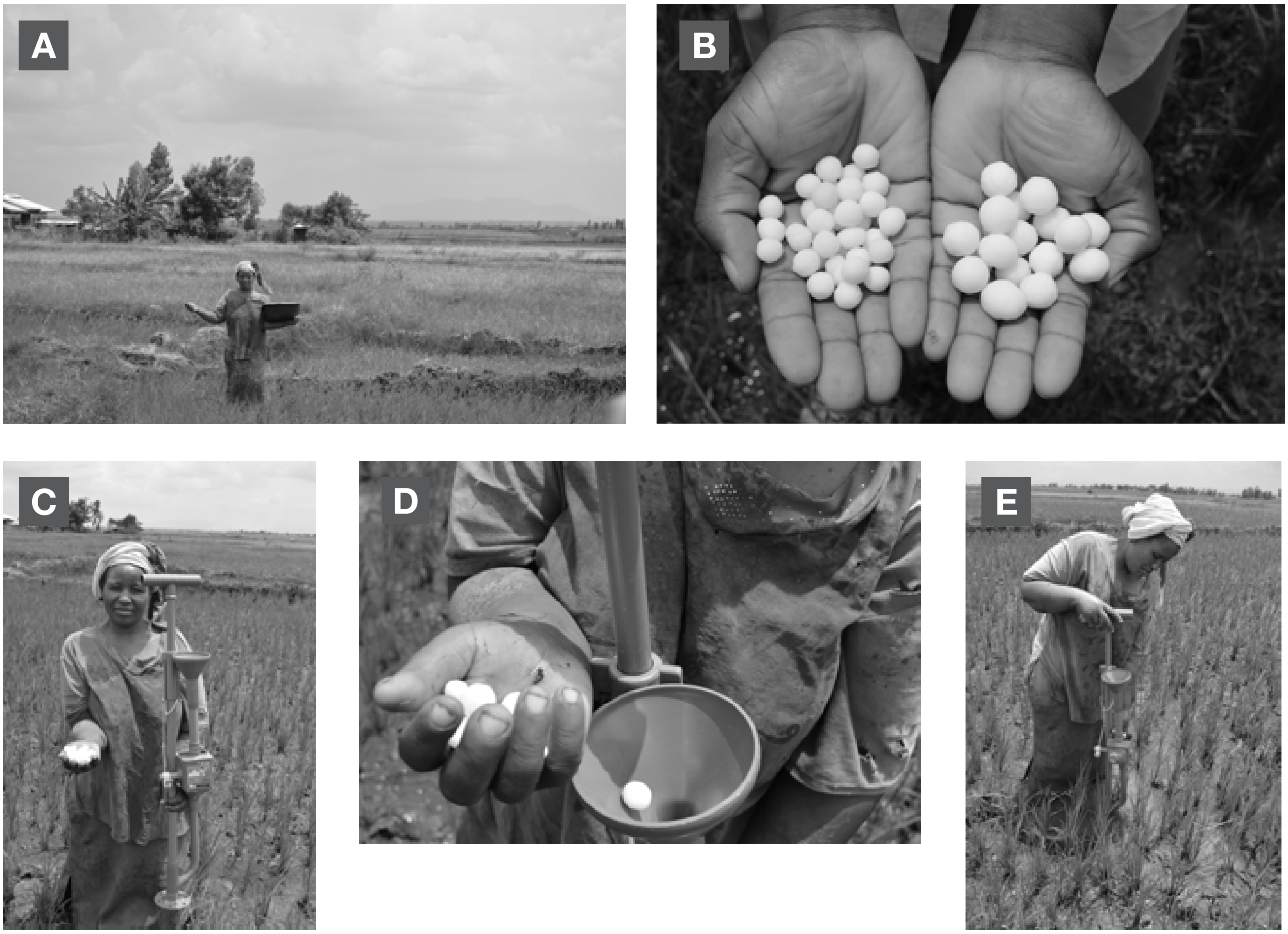

Photo 8. Applying fertilizer. (**A**) Topdress with nitrogen fertilizer at tillering and panicle initiation. The fertilizer is usually broadcast making nutrient losses high (photo: CABI/IPNI) (**B**) Applying nitrogen fertilizer in form of pellets reduces nutrient losses and synchronises crop demand with nutrient release. The size of pellet can be varied to take into consideration the amount of fertilizer required (photo: CABI/IPNI) (**C**) The pellets can be pushed into the ground by hand or an applicator (photo: CABI/IPNI) (**D**) Fertilizer is placed in the funnel (photo: CABI/IPNI) (**E**) The funnel containing fertilizer is then placed into the ground (photo: CABI/IPNI).

Use of manure

When available, animal manure can be an important resource for improving rice yields. Addition of manure helps to maintain soil organic matter at good levels. Manure is also an important source of nutrients, which are mostly released following its decomposition.

However, manure contains a lower density of nutrients compared with mineral fertilizers and the amount of nutrients contained in manure available on smallholder farms is usually insufficient to sustain required levels of rice productivity. If manure is purchased it can be more expensive than equivalent amounts of mineral fertilizer and is also much more bulky, which makes transport expensive.

Using manure in combination with fertilizer gives better yields than using either input alone. Ideally, 5–10 tonnes of animal manure per hectare (0.5 to 1 kg per square metre) should be applied each year on the surface and incorporated during ploughing. Some studies have suggested that with addition of manure at this level, the requirement for mineral fertilizers can be reduced by half. So, farmers who apply manure in this way could reduce the amount of mineral fertilizer suggested in the tables by half.

The nutrient content of manure, however, varies considerably. So, if farmers reduce mineral fertilizer they need to be on the look-out for signs of nutrient deficiencies, especially of N, in their rice crop; see Section 6, What can go wrong, for descriptions and photographs of rice crops with various nutrient deficiencies and details of what to do when these signs are seen.

Use of green manure

Green manures are mostly nitrogen-rich legume crops grown to provide nitrogen for the next rice crop and to add organic matter to the soil. Green manures are planted before or after rice, when the land is vacant, allowed to grow for some time, then slashed and either left on the soil surface or ploughed into the soil.

Although green manure can be used in all rice growing systems, they are especially useful for improving poor upland soils, which are often acid or easily eroded. They are also useful in situations where timely availability of mineral fertilizers is unreliable. Green manures should be considered when soil organic matter and N levels are low and fertilizer prices are high, particularly in regions with long growing seasons.

Incorporation of a green manure crop before planting rice can add the equivalent of around 2 bags (100 kg) of urea per hectare, so the top-dressing can be adjusted accordingly saving the farmer significant amounts of money. For upland rice the green manure could save all the urea topdressing; for lowland rainfed rice it could save all the urea in both basal fertilizer examples; and for lowland irrigated rice it could reduce the amount of topdressing urea by about 40%.

If farmers plan to use green manure as part of their nutrient management package they need to chose the right green manure:

- It needs to suit their growing conditions –the climate, soil and water available.
- It must be easy and cheap to grow.

- Good quality seed that germinates well needs to be readily available.
- It needs to grow without need for irrigation, fertilizer or pesticides.
- Its growing season must fit the time available between rice crops: it must not delay rice planting
- The benefit in terms of nitrogen fertilizer saved must be significantly greater than the cost of seed and labour needed. So, if the green manure provides 100 kg N per hectare, the cost of seed and labour should be no more than the cost of about 2 bag of urea per hectare.

Some examples of green manure crops suitable for use in rice cropping systems in Africa include:

Sesbania (*Sesbania rostrata*): A small semi-aquatic leguminous tree that naturally occurs in Africa. It has nitrogen fixing nodules on both stem and roots. Sesbania is fast growth and able to convert large amounts of atmospheric nitrogen into a usable form for plants – the equivalent of 1 to 2 bags of urea per hectare in between 40 and 60 days. A constraint to growing this green manure can be availability of seed.

Sesbania seed is best broadcast at the rate of 30 kg per hectare (3 g per square metre) before the onset of rains. The better the land is prepared, the better the crop establishes; also the seed rate can be reduced on well prepared seed beds to 16 kg per hectare. Germination rates are improved if the seed is immersed in very hot water (100°C) for just 3 seconds. In irrigated systems, water should be applied if the soil cracks and leaves are shed. The crop is incorporated into the soil before it becomes too woody, which is between 45 and 60 days after sowing. To do this the crop can be slashed by hand prior to ploughing; alternatively it can be knocked down using a plank drawn by draft animals, and then ploughed in. If available, machines such as hydrotillers or tractors and rototillers can be used.

Other legume crops: Various legume crops, such as soybeans, pigeon peas and mung beans, can be grown as fast growing green manure crops that can accumulate significant amounts of nitrogen within 45–60 days of sowing.

Residue management

If farmers are able to return the rice straw to the field and use mineral fertilizers then the soil's nutrient balance will be much improved. However, demand for alternative uses for straw, including as fuel for cooking, as a thatching material and as feed for livestock, may make this difficult or even impossible.

Rice straw and stubble contains about 40% of the nitrogen (N), 33% of the phosphorus (P),85% of the potassium (K), 44% of the sulphur (S) and 85% of the silicon (Si) taken up by rice plants. Incorporation of straw into the soil therefore returns much of the nutrients taken up by the crop. The straw should be spread uniformly in the field to avoid creating 'nutrient hotspots'.

Where mineral fertilizers are used and all the straw is incorporated, reserves of soil N, P and K are maintained or even increased and micronutrients (e.g. zinc) are also returned to the soil.

Burning straw results in the loss of almost all the N content, but losses of P, K and S are smaller. Burning also results in 'hotspots' of nutrient accumulation in parts of the field where the fires occurred while other parts of the fields get depleted. Burning is, however, less labour intensive than incorporating straw into the soil.

Early, dry, shallow tillage (5–10 cm depth) to incorporate crop residues and enhance soil aeration during fallow periods has been shown to increase N availability up to the vegetative growth phase of the succeeding rice crop. Shallow tillage of dry soil requires a four-wheel drive tractor and should be carried out up to 2–3 weeks after harvest in cropping systems where the dry-moist fallow period between two crops is at least 30 days.

Note: Incorporation of straw and stubble when wet soil is ploughed results in a temporary immobilization of N. Crop establishment should be carried out 2–3 weeks after straw incorporation; alternatively, urea (as a source of N) should be applied along with straw. However, the benefits to yield from incorporation of crop residues are greater in the long term.

Photo 9. Residue management. (**A**) A pile of straw ready for burning (photo: CABI) (**B**) Ferrying rice stover to feed livestock (photo: CABI).

Crop rotations

In upland rice: Rice can be rotated with crops including maize, sorghum, millet, cotton and legumes, such as cowpeas and beans.

Farmers tend to prefer to apply nutrients to rice and maize rather than sorghum and millet as the returns to investment are higher. Rice is the most profitable crop to apply fertilizer because it responds well to fertilizer and also because of the high price it attracts in the market. Although minimal amounts of nutrients are applied to legumes, legumes that fix nitrogen can contribute to improved soil fertility and hence indirectly lead to improved rice yields in subsequent rotations.

In lowland rainfed rice: Rice can be rotated with vegetables like potatoes (sweet and Irish), okra, tomatoes and aubergine, and also with legumes such as beans (Photo 10).

Photo 10. Rotating rice with other crops. (**A**) Growing sweet potato (right) after rice (left) helps in management of weeds, pests and diseases (photo: CABI) (**B**) Rice grown after a legume crop gives better yields than after another rice crop (photo: CABI).

In lowland irrigated rice: A rice crop can be followed by another rice crop, or vegetables such as onions (shallots), tomatoes and okra. Vegetables tend to be more profitable than rice. Farmers tend to apply mineral fertilizers and a lot of organic fertilizers to vegetables and less on rice, but rice grown after a vegetable crop can benefit from the residual fertilizer.

Nutrient deficiencies

See chapter 6, *What can go wrong*, for table listing the symptoms, situations where they are likely to occur and remedial measures for the most common nutrient deficiencies that affect rice.

Salinity management

Saline soils contain high amounts of sodium chloride; varying amounts of sodium sulphate, calcium chloride and magnesium chloride can also be present.

Salinity is not easy to identify in the field but can be diagnosed or confirmed in the laboratory by measuring soil electrical conductivity (EC), pH and sodium exchange capacity, all of which are higher in saline compared to normal soils.

Salinity leads to deficiencies of K amongst other deficiencies. This is not a problem for upland rice, but it can be a problem for lowland rainfed rice (e.g. in mangroves). Here the solution is to improve drainage or to use tolerant varieties. It is mostly a problem with irrigated lowland rice.

Salinity can be due to evaporation of irrigation water, salty water and a high water table. If it is due to a high water table, a system of drainage should be installed. If salinity is due to irrigation water evaporating and the dissolved salts becoming concentrated, fresh water should be added.

To control sodium in alkaline and sodic soils use gypsum or organic manure. Organic matter helps dissolve calcium from the soil and gypsum supplies calcium. The calcium displaces sodium, making it more easily leached from the soil.

Tolerant varieties can also be grown if salinity is a problem.

Salinity is a problem in coastal countries and alkalinity and sodicity (high sodium) in landlocked countries (e.g. in Mali).

Use of manure

When available, animal manure is an important resource for improving rice yields. Addition of manure helps to maintain soil organic matter at good levels.

Manure is also an important source of nutrients, which are mostly released following decomposition. However, manure contains a lower density of nutrients compared with mineral fertilizers and the amount of nutrients contained in manure on smallholder farms is usually insufficient to sustain required levels of rice productivity. But using manure in combination with fertilizer gives better yields than using either input alone.

Ideally, 5–10 tonnes of animal manure per hectare should be applied each year on the surface and incorporated during ploughing.

Bird scaring

Birds feeding on rice grains tend to be more of a problem if a mixture of varieties of rice is grown (Photo 10). The different varieties mature at different times but they all need to be harvested at the same time. This means early maturing varieties are most likely to be attacked by birds as they remain in the field longer as the later maturing varieties catch up. Birds also tend to attack taller varieties before moving on to shorter ones.

Birds can be scared using a combination of methods, such as scarecrows, hanging tins, cassette tapes or reflective ribbons and people making noise. The rice should be monitored regularly after flowering for bird damage.

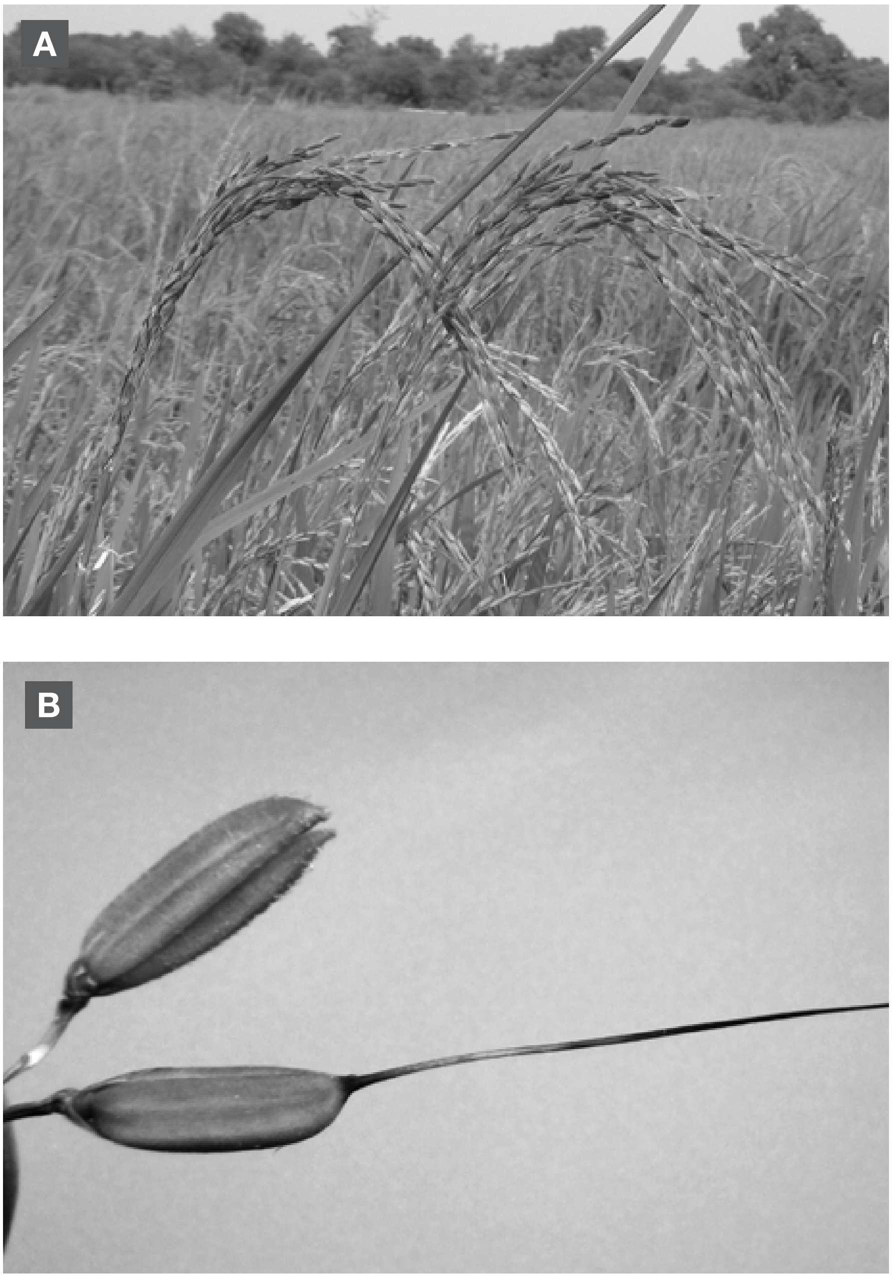

Photo 11. Plants in field – mixed varieties. (**A**) Mixed varieties can mature at different times, and can also differ in height making harvesting difficult (photo: CABI) (**B**) Presence and absence of awns is a characteristic that can sometimes be used to tell varieties apart (e.g. wild African rice has awns) (photo: CABI).

Photo 12. Time to harvest. (**A**) Rice panicles, ready (brown colour) and not ready (green colour) for harvesting (photo: CABI) (**B**) Rice panicles ready for harvesting make a distinct ‘cha cha cha’ sound when shaken (photo: CABI) (**C**) Delayed harvesting can result in loss of grains. Some varieties are more prone to this problem than others (photo: CABI/IPNI).

Harvesting

Farmers need to know the right time to harvest: rice is ready for harvest when 80% of the panicle is hard and brown. Other signs are that grain taken from the top of head is firm to the bite but not brittle (moisture content of such rice grains is about 20–25%), some grain remains in hand when the panicle is squeezed, and the head makes a rattling sound when shaken (Photo 11). Rice is ready for harvesting at about four weeks after flowering.

To harvest, the stem is cut below the rice head (Photo 12). The length of stem retained on the head depends on the method of harvesting used; for example, if harvesting by hand using a small knife, about 7.5 cm of stem is retained, but if harvesting using a mechanical harvester, stems are cut close to the ground.

If harvesting irrigated lowland rice with a combine harvester the field should be drained 15 days before the date of harvesting so that the straw is dry enough to allow for threshing.

After harvesting, the rice heads should be dried for about 3–7 days in the sun if threshing is by hand (Photo 13). If threshing is mechanised this should be done on the day of harvesting. The grains need to be drier (have a moisture content of 16–18%) if threshing is by hand.

Drying

The threshed grain should be dried to 12–14% moisture content. This can be done by putting the paddy (that is, grain enclosed by the husk) out in the sun or by using a dryer. In the Sahel the moisture content can reach as low as 8%: if it becomes too dry, the quality of rice is low due to a large proportion of broken rice at milling.

The grain should be spread in thin layers, 2–5 cm deep, and turned every 1–2 hours.

If sun-drying seed (for planting next season) more care is needed: the seed should be turned more often and not exposed to temperatures above 42 °C. If such high temperatures occur then the seed should be dried in the shade, not full sun.

If using a dryer, care needs to be taken so as not to use too much heat as this can burn the grain.

The harvested crop or paddy should be kept away from the rain. Rain or other sources of water can cause the grain to germinate or the quality can become poor as the grain gets discoloured.

Post-harvest value addition

Parboiling rice is a process used to increase the nutritional value of rice grains that have not been dehulled. During parboiling B group vitamins move from the pericarp (bran) to the grain. Parboiling therefore results in higher levels of some minerals and vitamins than normal rice. Parboiling also changes the taste, texture (firmer and less sticky), appearance (whiter) and smell (odourless), and reduces the cooking time of rice. Parboiled rice grains are also more resistant to storage pest attack than normal grains. Parboiling also reduces breakage at milling when the bran is removed.

However, parboiled rice can be more expensive due to the additional cost of parboiling, especially labour and energy. Husk removal is also more difficult and costs more.

Photo 13. Harvesting and threshing. (**A**) Manual harvesting (photo: CABI) (**B**) Mechanical harvester and thresher (photo: CABI) (**C**) Harvested rice plants drying before threshing (photo: CABI) (**D**) Rice can be threshed mechanically and bagged in field (photo: Kabirou Ndiaye, AfricaRice).

Parboiled rice is preferred by some but not all consumers. Parboiling tends to be a common practice in places where rice is a traditional crop, for example Nigeria, the Niger delta, The Gambia and Benin. It tends not to be done in areas where rice is a non-traditional crop, such as parts of Senegal and Mali.

There are many methods of parboiling rice, but the basic steps are soaking, steaming and drying (Photo 14). Before parboiling, the rice grains are first washed and floating debris is removed. The rice is then soaked for 10–24 hours, drained, then placed in boiling water until it gelatinizes – that is, the starch becomes like a jelly. At this stage the husks partly split open. The rice is then drained and dried, after which it can be stored and milled later.

Milling

Milling involves:

1. Removal of chaff and foreign materials, such as stones
2. Removal of husks and polishing of grain
3. Sorting into grades (i.e. broken and whole grains)
4. Weighing and bagging.

Storage

Rice grain stores are vulnerable to attack from pests including insects (such as rust-red flour beetle, *Tribolium castaneum*), rodents and birds, and also fungi.

To prevent damage occurring, grain and paddy should be stored in a clean store with good ventilation. Jute bags are best as they allow good aeration; alternatively, hermetic (air-tight) bags can also be used.

Parboiled rice is less susceptible to damage during storage than raw rice.

Grain stores must have a damp-proof floor and waterproof walls and roof. It is preferable to be able to seal the store so fumigation is possible should the need arise. Sealing the storage also helps exclude rodents and birds. Examples of rice storage containers include bags and airtight metal containers. Where grain is to be stored in bags, the bags should be stacked on pallets at least 50 cm away from the walls.

Hermetic storage systems have proved to be an effective means of storing grain. By having a sealed atmosphere any insects present inside utilize the oxygen, expire carbon dioxide and eventually die through suffocation and dehydration. This will occur within 5–10 days depending on the level of insect infestation. Other benefits of a hermetic system are that the moisture content of the grain and storage environment remains constant, and the sealed system reduces the chance of damage by rodents and birds.

To avoid mycotoxin problems, which are associated with certain types of fungi, grain should be dried to a safe moisture content (12–14%) before storage. Reducing physical damage to the grain during harvesting and storage, and ensuring clean, dry insect-proof storage conditions will also help prevent mycotoxin contamination.

Photo 14. After threshing. (**A**) Rice is bagged and transported from the field (photo: CABI)
(**B**) After drying, paddy can be placed in bags, and bags can be stored in a cool dry place on wooden pallets (photo: CABI).

Seed production

If growing rice for seed, plants that are not of the desirable type must be rogued out before harvesting. After harvesting and drying (moisture content 12-14%), threshing needs to be done carefully using a slower speed than used to thresh rice for consumption to avoid damaging the seed.

Seed should be stored as paddy in either jute or hermetically sealed bags. If using jute bags, seed should be protected from insect attack by applying insecticide, such as neem, which is a plant-based product; chemicals are not needed if using hermetically sealed bags.

Residue management

Rice straw and stubble contains about 40% of the nitrogen (N), 33% of the phosphorus (P), 85% of the potassium (K), 44% of the sulphur (S) and 85% of the silicon (Si) taken up by rice plants. Incorporation of straw into the soil therefore returns most of the nutrients taken up by the crop. The straw should be spread uniformly in the field to avoid creating 'nutrient hotspots'.

Where mineral fertilizers are used and straw is incorporated, reserves of soil N, P and K are maintained or even increased and micronutrients (e.g. zinc) are also returned to the soil.

Burning results in the loss of almost all the N content, but losses of P, K and S are smaller. Burning also results in 'hotspots' of nutrient accumulation in parts of the field where the fires occurred while other parts of the fields get depleted.

Early, dry, shallow tillage (5–10 cm depth) to incorporate crop residues and enhance soil aeration during fallow periods increases N availability up to the vegetative growth phase of the succeeding rice crop. Shallow tillage of dry soil requires a four-wheel drive tractor and should be carried out up to 2–3 weeks after harvest in cropping systems where the dry-moist fallow period between two crops is at least 30 days.

Note: Incorporation of straw and stubble when wet soil is ploughed results in a temporary immobilization of N. Crop establishment should be carried out 2–3 weeks after straw incorporation; alternatively, urea (as a source of N) should be applied along with straw.

However, the benefits to yield from incorporation of crop residues are greater in the long term than in the short term. Straw spreading and incorporation are labour-intensive and more fuel can be required compared with burning. Sometimes straw is sold to livestock owners and cattle also graze on stubble left in the field (Photo 15). With time, such fields may become deficient in K.

Crop rotations

In **upland rice:** Rice can be rotated with maize, sorghum, millet, cotton and legumes, such as cowpeas.

Farmers tend to prefer to apply nutrients to rice and maize rather than sorghum and millet. Rice is the most profitable crop to apply fertilizer. Although minimal amounts of nutrients are applied to legumes, legumes that fix nitrogen can contribute to improved soil fertility and hence indirectly lead to improved rice yields in subsequent rotations.

Photo 15. Parboiling to improve the value of paddy. (**A**) The rice is washed to remove chaff and other foreign materials, and also unfilled grain (photo: CABI) (**B**) Boiling rice (photo: CABI) (**C**) The paddy is dried, then milled (photo: CABI).

In **lowland rainfed rice:** Rice can be rotated with vegetables like potatoes (sweet and Irish), okra, tomatoes and aubergine, and also with legumes such as beans (Photo 16).

In **lowland irrigated rice:** A rice crop can be followed by another rice crop, or vegetables such as onions (shallots), tomatoes and okra.

Note: Vegetables tend to be more profitable than rice. Farmers apply mineral fertilizers and a lot of organic fertilizers to vegetables and less on rice, but rice grown after a vegetable crop can benefit from the residual fertilizer.

Key messages

- In irrigated lowland rice, maintain a depth of 2–3 cm of water layer from transplanting to panicle initiation, 5–7 cm after panicle initiation, then drain field 7–15 days before harvesting.
- Keep field weed-free until harvest.
- For upland rice apply both basal fertilizer (P and K) at ploughing and topdress with N (urea) at tillering.
- For lowland rainfed rice all fertilizer (N, P and K) needs to be applied at ploughing.
- For irrigated lowland rice basal fertilizer (P and K) is applied before puddling and topdressing with N (urea) in 2 splits at tillering and panicle initiation, or only at tillering if using urea super granules.
- In irrigated lowland rice, drain field before applying urea, and re-flood field 2–3 days after applying urea.
- To control salinity due to a high water table, improve drainage or to use tolerant varieties. If salinity is due to irrigation water evaporating and the dissolved salts becoming concentrated, add fresh water.
- If available, apply 5–10 tonnes of animal manure per hectare each year.
- Reduce grain losses to birds by scaring the birds away, harvesting when grain is ready, and by avoiding planting mixtures of varieties.
- Harvest when 80% of the panicle is hard and brown, grain taken from the top of head is firm to the bite but not brittle, some grain remains in hand when the panicle is squeezed, and the head makes a rattling sound when shaken. This is at about four weeks after flowering.
- If harvesting irrigated lowland rice with a combine harvester, drain the field 15 days before the date of harvesting.
- If threshing by hand, dry the rice heads for about 3–7 days in the sun after harvesting before threshing.
- Dry threshed grain to 12–14% moisture content by putting the paddy out in the sun. If temperatures are above 42 °C, dry rice in the shade, not full sun.
- Store grain and paddy in clean, dry, store with good ventilation.
- If growing rice for seed, rogue out undesirable (abnormal) plants, thresh carefully using a slow speed and store seed as paddy.
- Ideally, incorporate straw into the soil and rotate rice with other crops.

6. What can go wrong

Rice production involves many processes, many of which have been described in this guide. Even if the farmer has done everything right, unexpected problems could still occur. Some of these problems and examples of how to respond to them are presented in the following tables.

Table 6. Nutrient deficiencies

Nutrient	Symptoms	Where likely to occur	What to do
Nitrogen (N) (Photo 17)	Stunted plants Leaves become small and pale green Symptoms appear first on older leaves Pale yellow colour develops at the tip of old leaves and proceeds to cover the leaves towards the leaf base Eventually yellow leaves turn brown, dry and die Reduced tillering	Soils with low organic matter Light textured sandy soils, which have been leached by heavy rainfall or excessive irrigation Soils exhausted by intensive cropping Waterlogged conditions	Apply nitrogen fertilizer, such as DAP or urea Deficiency can be corrected with only a limited yield reduction if remedial action is taken early during the season Include legume crops (e.g. grain legumes) in rotation with rice
Phosphorus (P)	Stunted plants, with narrow and erect leaves Leaves with blue/purple colour Symptoms appear first and become more severe on older leaves; young leaves usually remain healthy Older leaves turn brown and die Number of tillers, panicles and grains per panicle are reduced	Coarse-textured soils having low organic matter and small P reserves Saline, sodic and calcareous soils Soils exhausted by intensive cropping Acid soils and highly weathered soils Eroded soils where topsoil has been removed and degraded lowland soils	Correcting P deficiency when symptoms have already appeared is not very effective; however, application of soluble P fertilizers, such as ammonium phosphate, can reduce the effects of P deficiency Remedial action should be taken for the next crop Apply correct amounts of P as basal with P fertilizers such as DAP, NPK, TSP or SSP Apply rock phosphate Apply manure Correct soil problems, such as acidity and salinity
Potassium (K) (Photo 18)	Plants can be deficient without showing symptoms Symptoms appear only in severe deficiency conditions and mostly during later growth stages Yellow brown colour on the edges of the leaves Brown colour begins from tip of leaf and advances down the edges towards the base Symptoms appear first on old leaves	Sandy soils Soils low in organic matter Soils that receive excessive use of N or N+P fertilizers with insufficient application of K fertilizers Highly weathered acid soil Poorly drained soils	Apply K fertilizers, including NPK, MOP or SOP Rice residues contain large amounts of K; recycling residues add K to the soil Add organic manures well before planting

Nutrient	Symptoms	Where likely to occur	What to do
Sulphur (S) (Photo 19)	Stunted plants In young plants, whole plant becomes yellow and symptoms can be confused with N deficiency Symptoms appear first and become more severe on younger leaves; different from N deficiency which affects older leaves first The young leaves become dull or bright yellow but old leaves usually remain green	Soils having low organic matter Sandy soils which have been leached by heavy rainfall or excessive irrigation Soils exhausted by intensive cropping	Apply correct quantity of S mixing in to the surface soil well before sowing using elemental S, SSP or gypsum In deficient standing crops apply ammonium sulphate, magnesium or potassium sulphate
Iron (Fe) (Photo 20)	Symptoms appear first on younger leaves Deficiency symptoms appear as discoloured stripes on young leaves Whole emerging leaves become discoloured in severe conditions of iron deficiency	Mainly a problem in upland soils which have low concentration of soluble Fe Fe availability increases after flooding Low organic matter status of soils Alkaline or calcareous soils	Grow Fe-efficient cultivars In high pH upland soils, use ammonium sulphate fertilizer instead of urea to supply N Ammonium sulphate is an acidifying fertilizer which increases Fe availability Apply ferrous sulphate fertilizer broadcast at the rate of 30 kg Fe per hectare
Zinc (Zn) (Photo 21)	Symptoms occur 2–4 weeks after transplanting Many dusty brown or bronze spots appear on the leaf Spots become bigger and eventually cover whole leaf In later stages entire leaf turns bronze and dries Zn deficiency also causes stunted plant growth	Leached sandy soils Alkaline soils Levelled soils where sub-soil is exposed for cultivation: available Zn in topsoil is often double that in sub-soil Soil with heavy and excessive application of P fertilizers, which reduce availability of Zn due to zinc phosphates formation Excessively limed soils	Problematic alkaline soils should be reclaimed Use 2 kg zinc sulphate per hectare in the nursery Apply 25–30 kg zinc sulphate per hectare in Zn deficient soils Do not mix Zn fertilizers with P fertilizers If deficiency appears in standing crop apply Zn as a foliar spray at 5 kg per hectare

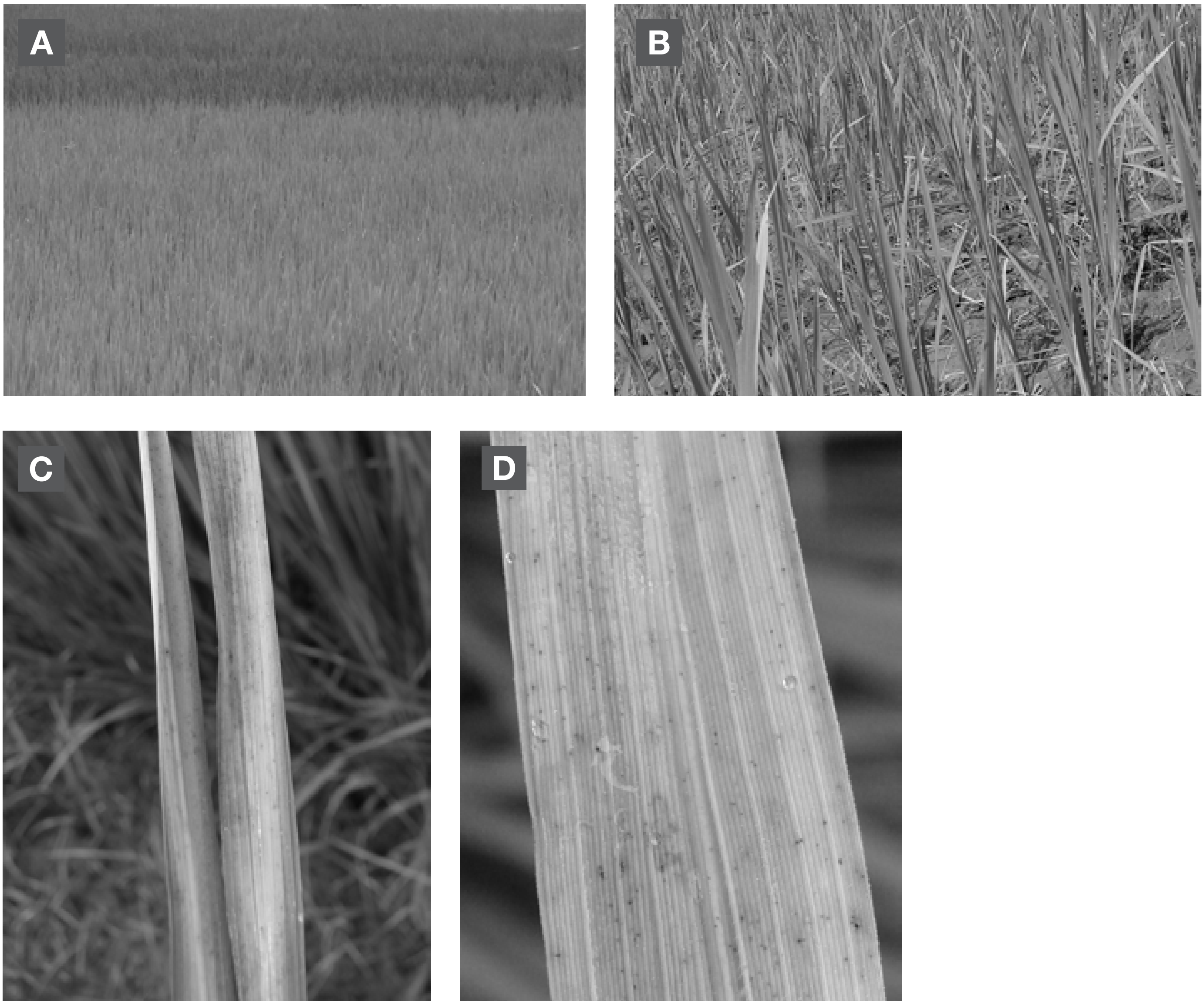

Photo 16. Nitrogen deficiency. (**A**) Nitrogen deficient plants are pale (foreground) while those with adequate nitrogen are green (background) (photo: Shamie Zingore, IPNI) (**B**) Older leaves or whole plants are yellow, tillering is reduced (photo: Shamie Zingore, IPNI) (**C**) Yellowing starts from the tip of the leaf, progresses towards the base, with the middle of the leaf yellowing before the edges. The yellowing progresses in a ‘V’ shape (photo: Shamie Zingore, IPNI) (**D**) Leaves eventually die (photo: Shamie Zingore, IPNI).

Photo 17. Potassium deficiency. (**A**) The lower leaves start yellowing (photo: Shamie Zingore, IPNI) (**B**) The yellowing starts from the leaf margins (photo: Shamie Zingore, IPNI).

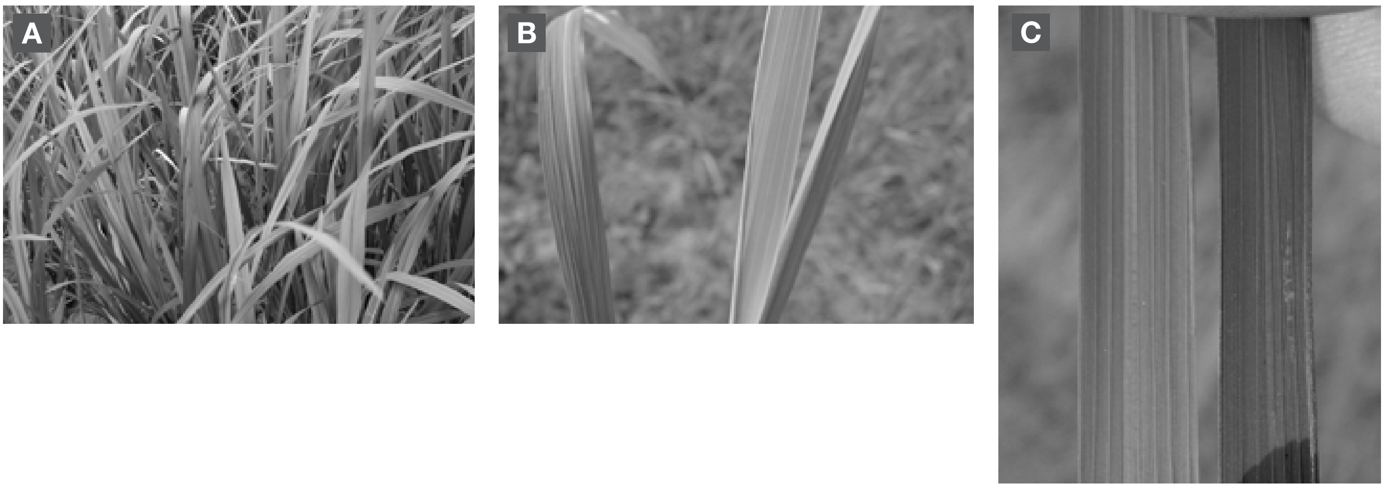

Photo 18. Sulphur deficiency. (**A**) Plants are pale yellow, younger leaves affected more. This is unlike N deficiency which affects lower leaves and the yellow colour is deeper (photo: Shamie Zingore, IPNI) (**B**) The youngest leaf (middle) showing deficiency symptoms (photo: Shamie Zingore, IPNI) (**C**) The yellowing on leaf can be uniform, but tips can die (photo: Shamie Zingore, IPNI).

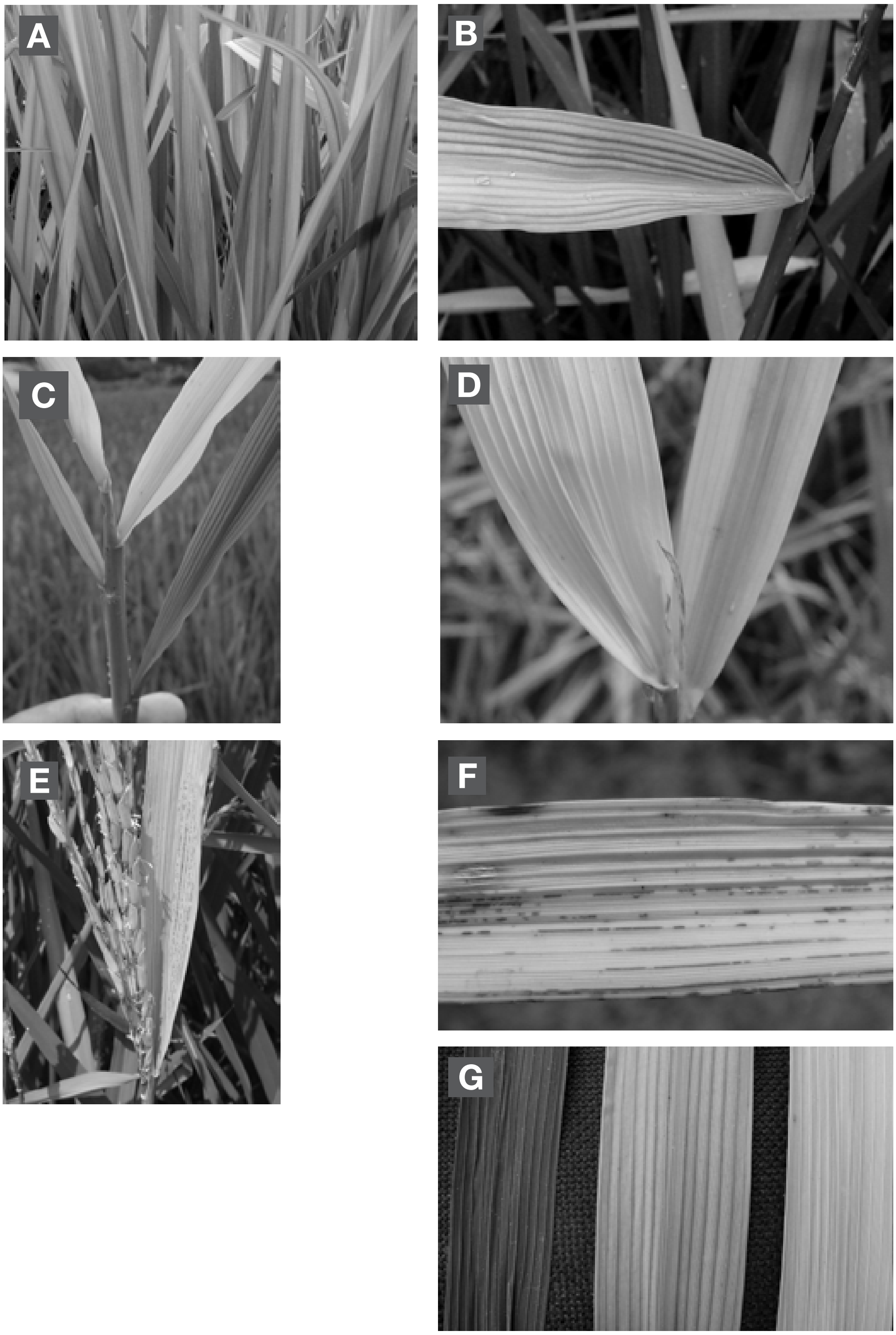

Photo 19. Iron deficiency. (**A**) Plants become pale and yellow (photo: Shamie Zingore, IPNI) (**B**) On some leaves, leaf veins remain green, yellowing (or paleness) between veins – leaf has green and yellow (pale) stripes (photo: Shamie Zingore, IPNI) (**C**) Tips of emerging leaves dry up (photo: Shamie Zingore, IPNI) (**D**) Tips of emerging leaves dry up (photo: Shamie Zingore, IPNI) (**E**) Developing panicles and flag leaf are pale (photo: Shamie Zingore, IPNI) (**F**) Pale leaves develop brown streaks (photo: Shamie Zingore, IPNI) (**G**) Healthy green leaf (left), streaks showing moderate deficiency (middle), pale colour – sign of severe deficiency (right) (photo: Shamie Zingore, IPNI).

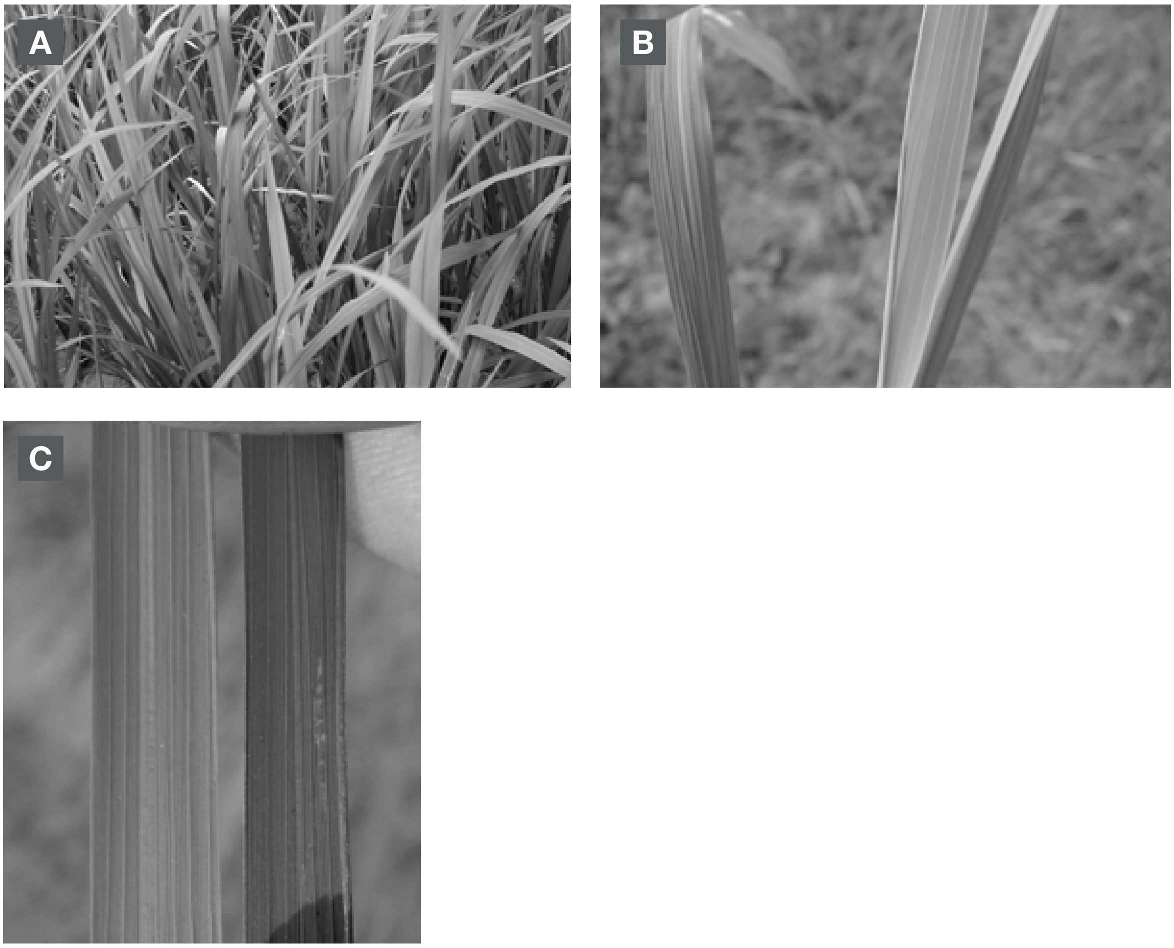

Photo 20. Zinc deficiency. (**A**) Brown patches on lower leaves (photo: Shamie Zingore, IPNI) (**B**) Light brown colour on leaf (photo: Shamie Zingore, IPNI) (**C**) Brown stripes on leaf, white stripes close to the mid-rib (photo: Shamie Zingore, IPNI).

Table 7. Examples of insect pests that damage rice

Insect	Damage	Control
Stem borers (Photo 22)	Larvae enter the stem and eat it from within Growing parts of young shoots may die (dead hearts) Flowering affected (dead heads, white panicles) Plants may fall over	Flooding and harrowing or ploughing in of straw to reduce carrying over of insects from one crop to the next Roguing of volunteer plants[4] between cropping seasons Planting early maturing varieties
African gall midge	Cylindrical swellings, known as galls, about 3 mm in diameter, can be short or up to 1–1.5 m long, caused by maggots which hatch from eggs laid by female midges Often silvery white and are generally known as 'silver shoots' or 'onion leaf galls'	Early and synchronised planting Roguing of volunteer plants between cropping seasons Ploughing in of straw to reduce carry over insect populations
Termites	Attack both young and old plants Damage roots and fill the inside of the stem with soil	Use pesticide Flooding of termite holes Digging up termite mounds and destroying nest and queen
Rice weevil & larger grain borer (storage pests)	Attack paddy and grain after milling The larvae eat the inside of the grain, emerging as adults through holes	Remove infested residues from last season Treat grain before storing with pesticide Store grain in airtight containers
Rice grasshopper (Photo 23)	The nymphs and adults eat leaves	Cultivate parts of the field that are not cultivated as this will reduce area for adults to lay eggs
Rice stink bug (Photo 24)	Attacks stems, leaves and filling grain	Remove alternate hosts such as grasses on bunds For rainfed rice, plant early at the beginning of the rains

[4] Rice that grows without being deliberately planted

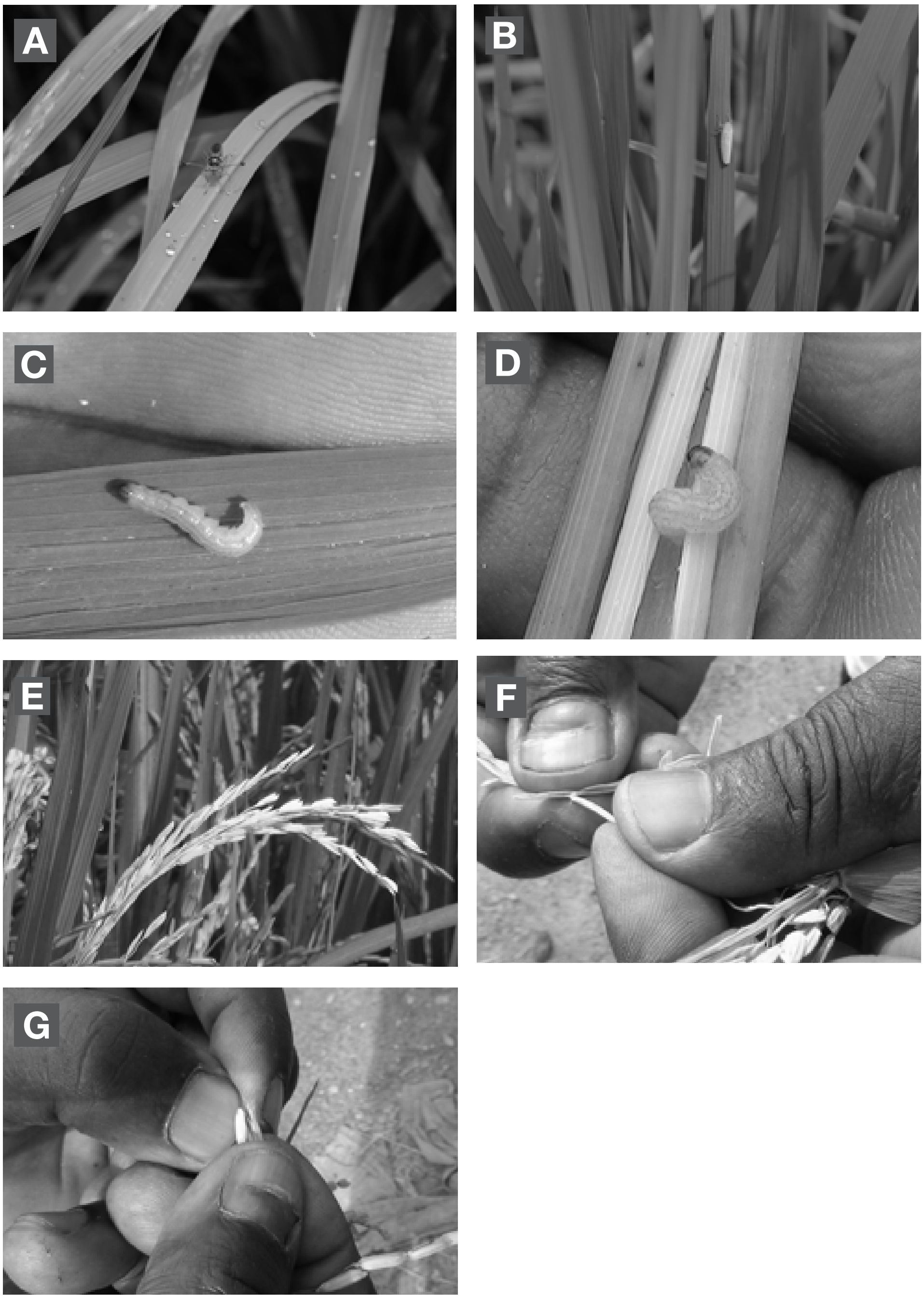

Photo 21. Stem borers. (**A**) There are many types of stem borers that affect rice – for example, diopsis (photo: CABI/IPNI) (**B**) Another stem borer – a moth (photo: CABI/IPNI) (**C**) Larva of stem borer (photo: CABI) (**D**) Stem borer damages inside of stem (photo: CABI) (**E**) Stem borer damage, 'white head' – empty panicle (without grain) (photo: CABI) (**F**) Stem borer damage, empty panicle (photo: CABI) (**G**) Normal – panicle with grain (photo: CABI).

Photo 22. Rice grasshopper causes damage to leaves (photo: CABI/IPNI).

Photo 23. Rice stink bug reduces yield by feeding on the developing grains (photo: CABI/IPNI).

Table 8. Examples of rice diseases

	Symptoms	Control
Rice blast (Photo 25)	On leaves, long lesions with pointed ends and grey or white centres; dark-green to reddish-brown margins, sometimes with a yellow halo If severe, lesions merge and leaves die; leaf sheaths dry up and whole plants may be killed Severely infected fields have a scorched appearance On leaf collars, rotting may result in premature leaf fall On lower nodes, rotting causes 'white heads' On panicles, white heads or partially filled heads; late infection after grain filling results in 'broken necks'	Resistant cultivars Avoid excessive N fertilizer and drought Field sanitation Synchronized planting
False smut (Photo 26)	Symptoms observed on grains after flowering: small green balls up to 1 cm in diameter appear on grain, the balls burst, become orange, then green	Use tolerant or resistant varieties Avoid excessive N fertilizer
Brown leaf spot	Evenly distributed oval-shaped lesions, up to 1 cm in length The spots are brown, with greyish centres when fully developed Young lesions appear as small, dark-brown spots Lesions on the panicles may lead to black spots on grain	Resistant varieties Use disease free seeds Apply good balance of inputs (e.g. supply micronutrients if deficient), also combine organic and inorganic fertilizers
Narrow brown leaf spot (Photo 27)	Narrow brown elongated spots, 2–12 mm long and 1–2 mm wide appear on the leaves, leaf sheaths, panicle	Planting early maturing varieties Early planting
Rice yellow mottle virus (Photo 28)	Leaves yellow-orange, sometimes followed by rolling Plants stunted, reduced tillering, non-synchronous flowering, spikelets do not fill with grain Disease can be transmitted by insects Young plants are most susceptible	Destroy crop residues (e.g. by burning) and uproot volunteer plants to control insect pests and plant material that could be carrying the disease Delay planting time Use tolerant varieties Use pesticides to control insect vectors

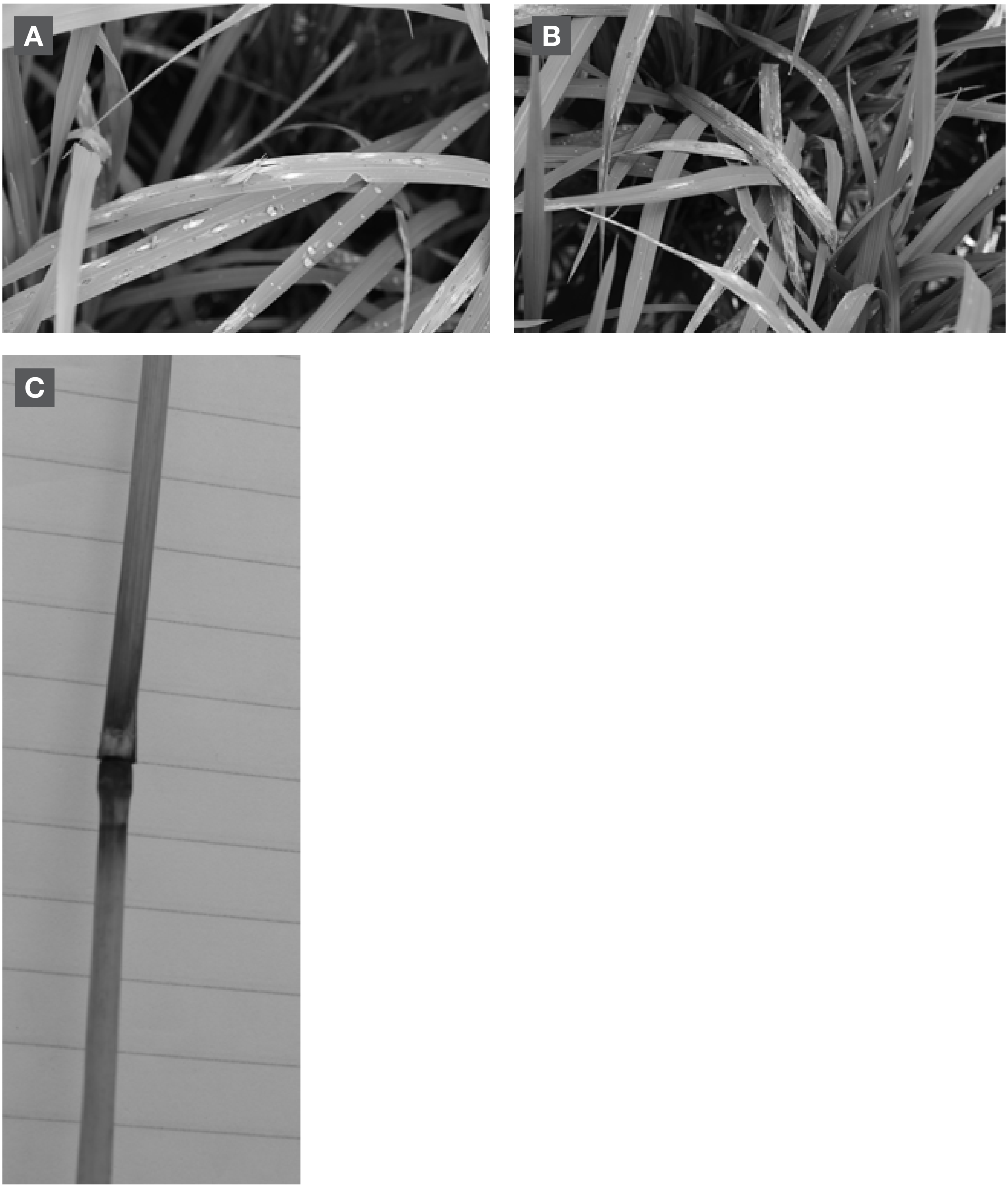

Photo 24. Rice blast. (**A**) The lesions have a grey centre, and brown border (photo: CABI/IPNI) (**B**) In severe cases, lesions on leaf merge and leaf dies (photo: CABI/IPNI) (**C**) Nodes affected by disease – if the node below the head is affected before grain filling, the grain may not fill, if affected after grain filling, the head may droop downwards (photo: CABI/IPNI).

Photo 25. False smut (photo: CABI).

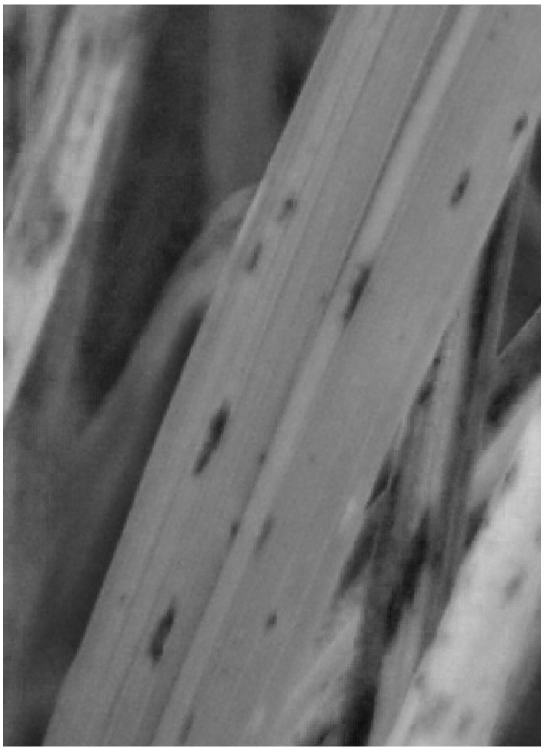

Photo 26. Narrow brown leaf spot (photo: CABI).

Photo 27. Rice yellow mottle virus (RYMV). (**A**) Plants infected by RYMV can be yellow, and are more likely to be attacked by other diseases – in this case brown spot (photo: CABI) (**B**) Leaf of plant infected by RYMV (photo: CABI).

7. Rice production economics

Rice is a major food and cash crop in Africa: farmers grow rice for sale but some of the rice can be used to meet household food requirements.

Many of the changes required for improved production require use of scarce resources such as fertilizer, manure, seeds and labour. For example, if growing improved rice varieties that give better yields than local varieties, more fertilizer may be needed to reach the high yields. But use of fertilizer should also be accompanied by good management practices (e.g. timely planting, good water management and keeping the fields weed-free).

It is important to have an idea of whether a new farming practice will be profitable (before introduction) and whether the technology is actually profitable (after introduction). The likely benefits of a new practice are calculated based on data collected elsewhere, while actual benefits are based on data collected after the introduction of the new farming practice on-farm.

The minimum increase in yield required to recover expenses incurred from implementing the new technology can give an idea of whether the new practice could be worthwhile.

For example, if a farmer has been topdressing an improved rice variety with two bags of urea and getting 3.8 tonnes of grain per hectare, but would now like to apply two more bags of urea, the increase in yield required to recover the additional cost of fertilizer (assuming the price of urea is US$ 50 per 50 kg bag and price of rice is US$ 500 per tonne) can be calculated as:

$$\text{M}inimum\ increase\ in\ yield\ required\ (t/ha) = \frac{Cost\ of\ urea\ fertilizer}{Price\ of\ rice} = \frac{(2 \times 50)}{500} = 0.2$$

So, in this case if the farmer achieved an additional 200 kg of rice per hectare, this would cover the cost of the additional urea.

The extra costs incurred with use of a new technology can also be compared with the additional benefits got by use of the technology (benefit-cost analysis).

For example, if in the above case the previous yields were 3.8 tonnes per hectare but with additional two bags of urea yields have increased to 4.5 tonnes per hectare, the value of additional yield with fertilizer compared with the cost of fertilizer, the benefit-cost ratio (BCR), is calculated as:

$$BCR = \frac{(Yield\ with\ fertilizer - Yield\ without\ fertilizer)\ \ x\ Price\ of\ rice}{Amount\ of\ \ fertilizer\ applied\ x\ Price\ of\ \ fertilizer} = \frac{(4.5 - 3.8) \times 500}{(2 \times 50)} = 3.5$$

As a rule of thumb, a BCR greater than 2 is needed for an investment to be economically attractive to farmers – that is, the extra rice produced is worth at least twice as much as the inputs used to produce them. In this case the BCR is 3.5, so this is a very attractive investment – for every US$ 1 invested in fertilizer the farmer got a return of US$ 3.5.

If additional information, for example on costs of labour, weeding and pest control is available, more detailed calculations can be carried out. Remember, the best use of a resource should be explored in order to get the best return from the input.

A point to note is that prices of inputs and produce, and also yields of crops can vary. For example, good income can be obtained by storing produce after harvest, selling when the market is not over supplied and prices are higher. Also, less fertilizer should be applied when rains are late and drought is expected, and more fertilizer can be used when rains are on time and are expected to be adequate.

For more information see:

http://www.knowledgebank.irri

A good source of additional information on rice production.

Defoer, T., Wopereis, M.C.S., Jones, M.P., Lancon, F. and Erenstein, O. (2003) **Challenges, innovation and change: towards rice-based food security in sub-Saharan Africa** – pp 219–234. In Proceedings of the 20th session of the International Rice Commission, Bangkok, Thailand, 23–26 July 2002, Rome, Italy, FAO.

Figure 1 on rice ecologies adapted from this reference.

Fairhurst, T.H., Witt, C., Buresh, R.J. and Dobermann, A. (2007) **Rice: A Practical Guide to Nutrient Management.** International Rice Research Institute, International Plant Nutrition Institute and International Potash Institute.

http://bit.ly/1jLAZzg

Important reading material on nutrient management for rice. Estimates of nutrient content in rice stover presented in this guide were based on data presented in reference. The reference also has a good collection of photographs on nutrient deficiencies in rice.

Africa Soil Health Consortium – improving soil fertility, improving food production, improving livelihoods

ASHC works with initiatives in sub-Saharan Africa to encourage the uptake of integrated soil fertility management (ISFM) practices. It does this primarily by supporting the development of down to earth information and materials designed to improve understanding of ISFM approaches.

ASHC works through multidisciplinary teams including soil scientists and experts on cropping systems; communication specialists, technical writers and editors; economists; monitoring and evaluation and gender specialists. This approach is helping the ASHC to facilitate the production of innovative, practical information resources.

ASHC defines ISFM as: A set of soil fertility management practices that necessarily include the use of fertilizer, organic inputs and improved germplasm combined with the knowledge on how to adapt these practices to local conditions, aiming at optimizing agronomic use efficiency of the applied nutrients and improving crop productivity. All inputs need to be managed following sound agronomic and economic principles.

The Integrated Soil Fertility Management Cropping Systems Guide series is an output of the Africa Soil Health Consortium (ASHC), which is coordinated by CABI.

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AfricaRice

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