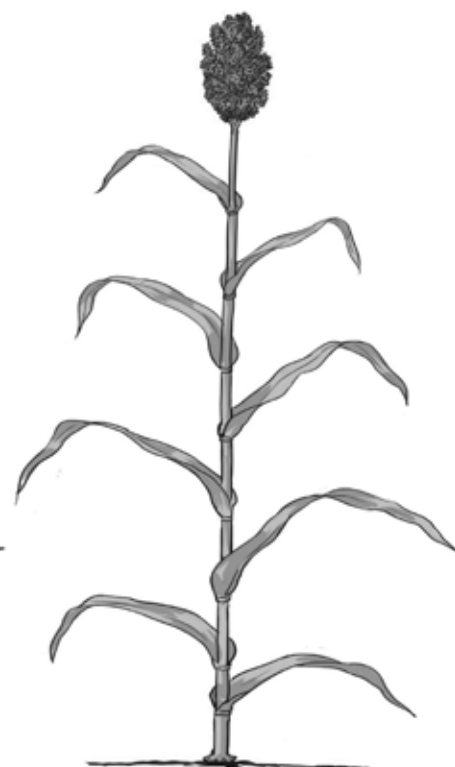
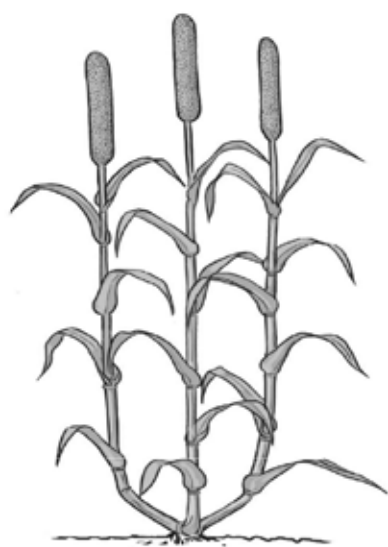


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Sorghum- and millet-legume cropping systems



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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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1. Introduction

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

Rural extension workers will find this handbook particularly useful for guiding their clients as they shift from producing sorghum and millet under traditional cropping systems for subsistence to more market-oriented enterprises through sustainable intensification.

The guide aims to provide, in a single publication, all the most important information needed to design and implement effective systems which combine sorghum and/or millet with a range of other crops, especially legumes, either as intercrops or in rotations, but with the primary focus on sorghum and millet.

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 fertilizer use efficiency and effectiveness. The overarching framework for the guide is therefore provided by ISFM.

2. Sorghum and millet cropping systems

Sorghum and millet production in Africa mainly occurs in the savannah zones in both hemispheres. Areas of high concentration of sorghum and millet production are in Western, Central, Eastern and Southern Africa. The two crops thrive well in areas where maize will not do well under rain-fed conditions: millet thrives well in even more marginal areas than sorghum.

Current average yields of sorghum and millet average about 1 tonne and 0.5 tonnes per hectare, respectively but can easily double with improved management. Maize is grown closer to the equator than sorghum and millet, and millet is grown furthest from the equator.

Sorghum and millet are either grown as sole crops or intercropped with legumes (see examples of these crops in Photo 1). It is not uncommon to see a sorghum-millet intercrop too. The sole crops are common in large-scale production while the intercrops are mainly practiced where land is limited. Millet is more drought tolerant than sorghum (see Table 1). In the drier environments, sorghum can survive best in the lowlands.



Photo 1: Examples of sorghum/millet and legume crops (A) sorghum (photo: Ken Giller (KG)) (B) millet (photo: CABI) (C) cowpeas (photo: CABI)

The decision to grow any of these crops will depend on whether one can meet the biophysical (e.g. moisture, temperature, soil nutrient levels, weed pressure) and socio-economic (e.g. labour, input costs) requirements of the cropping system. The main requirements are presented in Table 1 while some of these crops' important characteristics are listed in Table 2.

Table 1: Sorghum and millet cropping system requirements compared with those of maize.

Factor	Sorghum	Millet	Maize	Additional notes
Rainfall (mm/year)	500-1000	350-800	800-1500	Moisture is critical during flowering period. Some sorghum cultivars are well adapted to areas with 1200-1500mm of rainfall.
Tolerance to drought	medium	high	low	In the low rainfall areas, sorghum tends to be grown in the low lying lands and millets in the higher areas
Tolerance to day time temperatures (max 45°C)	medium	high	low	None can withstand high temperatures for long periods
Tolerance to low soil fertility	medium	high	low	Sorghum is usually allocated the most fertile land as it is less tolerant to low fertility than millet
Tolerance to acidity/ aluminium toxicity	medium	high	low	
Length of daylight	sensitive (flowers when days get shorter)	sensitive (flowers when days get shorter)	not sensitive	Some varieties produce less forage when grown near the equator where day lengths are shortest.
Tolerance to low soil carbon	medium	high	low	

Table 2: Characteristics of sorghum, millet and maize.

Characteristic	Sorghum	Millet	Maize	Additional notes
Nutrient use efficiency (response to applied organic and inorganic nutrients)	medium	low	high	
Susceptibility to pests & diseases	medium	high	low	
Susceptibility to Striga	high	high	very high	Both <i>Striga hermontheca</i> and <i>Striga asiatica</i>
Harvesting, threshing and winnowing	less difficult compared with millet	difficult, tedious, labour intensive stems cut hands	easiest to harvest	
Availability of market	good	fairly good (but no international market)	very good	
Unit price of grain	good	very good	fair	
Input costs	medium	low	high	
Level of management	low	low	high	
Return to investment	medium	low	high	
Suitability for intercropping with cowpea	medium (little effect of cowpea on grain)	high (little effect of cowpea on grain)	low	
Suitability of stovers to make structures e.g. fences, cages for chicken	high	high value	not used	Structures made using millet and sorghum stover can last for more than a year
Suitability of stover for livestock fodder	high (can be stored for long periods highest stover productivity of the 3 crops)	medium (can be stored for long periods)	low (used immediately after harvest - does not keep for long)	All 3 have about 4-10 g N /kg dry matter, which is low Stover can be enriched through urea treatment

Apart from the factors and characteristics listed in Tables 1 and 2, household and societal culinary preferences can also influence the choice of crop grown.

Soils in sorghum and millet growing areas are poor in fertility and this is made worse by the lack of or extremely short fallow periods. Although these crops seem to do better in poor soils than maize (Table 3), sorghum responds better to improved soil conditions than millet.

Increasing current yields of sorghum and millet depends more on good agricultural practices, e.g. timeliness of the cultural practices and the appropriateness of inputs used, but also on soil fertility.

Sorghum and millet will give a 60-70% increase in yield if the farmer uses good seed and observes timely planting at optimum spacing, timely weeding and timely fertilizer application. This is why an integrated soil fertility management (ISFM) approach, which means using good seed, fertilizers (inorganic, mineral) and good management practices, should be used to increase productivity of the crops at smallholder level.

Table 3: Reasons for growing (or not growing) sorghum/millet instead of maize.

Why grow sorghum and millet instead of maize?	Why grow maize instead of sorghum or millet?
<ul style="list-style-type: none"> • Sorghums and millets are more tolerant to adverse weather conditions than maize. • Maize cannot do as well on marginal soils as sorghum and millet. Even without fertilizer application, their deep rooting systems help them to produce harvests in situations where maize will fail. • Social-cultural significance, e.g. used in naming ceremonies. Sorghum and millet cannot be substituted with other crops for these purposes. • There is growing demand for sorghum in the food and beverage industry, e.g. in Nigeria used in place of malted barley. • Yields of sorghum more are stable than maize in adverse weather conditions. • Millet is more nutritious than maize: it has more iron and less gluten. 	<ul style="list-style-type: none"> • Under good weather and soil conditions, maize gives better yields than sorghum and millet. • Lack of international market, especially for millet. But there is a niche international market for millet as pet (bird) food and baby food. • The ratio of grain to straw is 3-times higher for maize than sorghum and millet. • Palatability of sorghum/millet straw is low compared with maize for livestock. • Sorghum and millet are highly vulnerable to bird damage.

3. Land preparation and planting

Land preparation

Land preparation is primarily aimed at having a good seed bed for the crop. In addition it is used to meet other objectives, including:

- Removal of weeds and other unwanted plants
- Avoiding soil erosion
- Slowing down run-offs to enhance water infiltration and reduce evaporation
- Supplying nutrients (especially N and P, and soil organic matter,) through application of mineral and organic fertilizer to the soil

To achieve these objectives the steps are:

- Slash unwanted vegetation but in semi-arid zone some trees and shrubs maybe kept to develop a parkland for an 'evergreen' agriculture. Evergreen agriculture involves maintenance of a green cover throughout the year – in this case incorporating selected trees and shrubs into the sorghum/millet cropping system.
- Avoid burning as much as possible. If it is essential, then gather material for burning in heaps at the edge of the field to minimize negative effects of burning whole field (see Box 1 for more information).
- Construct or repair water harvesting structures (see examples in Table 4).
- Till the land by hand, animal traction, mechanical cultivator or tractor. Tillage helps to break crust and hardpans, bury plant residues and incorporate fertilizer. The land can be flat tilled or ridged. Ridging is done to control waterlogging and is useful under Sudan and northern Guinea ecologies – crops are planted on the ridges where drainage is better.
- Organic fertilizer (manure, cover crop, mulch) and other soil amendments, such as lime, are usually applied then worked into the soil during tillage.
- Mineral fertiliser is applied mostly at planting and/or at first weeding of the crop. However, to be effective all fertilizer should be applied before the panicles emerge (Photo 2).

Box 1: Benefits and disadvantages of burning

Advantages	Disadvantages
<ul style="list-style-type: none">• Quick release of nutrients• Pest and disease control• Farmers' safety (elimination of dangerous scorpions, snakes)• Facilitate other activities, e.g. use of animal traction or hoes for land preparation	<ul style="list-style-type: none">• Land degradation – soil exposed to wind and water erosion• Loss of nutrients (ash can blow away)• Loss of biodiversity• Loss of soil carbon• Localized spots of high concentration of nutrients where fires lit• Contribution to green-house gases (global warming)



Photo 2 : Sorghum before and after panicle emergence (A) Before (photo: CABI) (B) After (photo: CABI)

To reduce soil and water loss, it is important to use the right tillage methods. Table 4 gives some guidance on what to do during land preparation and beyond.

Table 4: How to reduce water loss in the soil.

Challenge	Actions to address challenge
Reducing runoff and wind erosion	Contour ploughing (ploughing across the slope, not along it). Harrowing ploughed fields at right-angles or diagonally to the direction ploughed. This ensures a well-levelled field. Erect stone bunds or live (vegetation) bunds. Dig zai pits (see Box 5, page 30). Maintain perennial vegetation cover (pasture or cover crops). Apply mulch (e.g. crop residues). Create terraces on steep slopes. Cut stalks instead of uprooting, leaving roots of plants in soil at harvest.
Improve infiltration	Add soil organic matter, such as animal manure to improve water holding capacity and reduce crust formation. Loosen the soil on flat land, e.g. by ploughing. Create contour bunds and zai pits (see Box 5). Shallow tillage to break up soil crust.
Reduced evaporation and transpiration	Apply mulch. Use varieties with high water-use efficiency.

Choice of variety

Sorghum and millet come in different cultivars and varieties that are adapted for various areas and uses. These influence the choice a farmer will make in what to grow. The choice of varieties will also depend on the length of the growing period and other considerations discussed below.

There are two types of millets: pearl millet, also known as bulrush millet, and finger millet. Pearl millet is grown in western, central, eastern and southern Africa, and finger millet is mainly grown in eastern Africa. Finger millet has smaller grains than pearl millet: the grains of pearl millet are about 3-4 mm long while those of finger millet are about 1.5 mm long.

Sorghums and millets provide both food for people and fodder for livestock. The stems have many uses; for example they can be used for fencing, weaving and firewood. The grain can be used as a staple food or to make beer; for sorghum, red types are preferred for beer and white types for food. The red types of sorghum have high tannin content which makes them bitter: birds do not eat them and they store better.

Sorghum and millet cultivars include early, medium and late maturing types (Table 5). The greater the number of days to reach maturity, the taller the crop stands and the better the yield under good moisture, nutrient and temperature conditions. However, under arid conditions where moisture becomes more limiting, the early maturing cultivars will be more reliable to give good yields. Therefore the choice of maturity types will depend on prevailing conditions.

Some cultivars will flower early if exposed to days with many hours of sunlight and will flower later if exposed to days with fewer hours of sunlight. For example, in West Africa, sorghum planted in April-June tends to flower in August-September when days are long. These

differences in maturity periods are exploited in intercropping. Farmers often plant both early and late maturing millets at the same time and in the same field with the aim of having a staggered harvest.

Table 5: Maturity types and their duration.

Crop	Maturity types/growth habit	Days from sowing to harvest	Height (m)
Millet	early	60-90	1.5-2.5
	late	90-135	3-4.5
Sorghum	early	90 – 100	2.5
	medium	100 - 120	4
	late	120 -160	4
Cowpea	*determinate	60-70	0.3-0.6
	**indeterminate	more than 70	creep or climb to over 1.2 m

***Determinate:** Flowering continues only until the first flower formed develops fully into a pod. All the pods mature within a short period and all can be harvested at the same time. Most determinate types are erect, that is they grow upright and do not need support.

****Indeterminate:** Growth of terminal buds and flowers continues until adverse growth conditions (for example drought or frost) set in. So, pods mature over a longer time and more than one harvest is required. Many of these types climb or creep along the ground.

Legumes used in intercropping of sorghum and millet are mostly cowpea, groundnuts and soybean, the latter only in wetter ecological zones, e.g. where rainfall is over 700 mm per year. Since most of the determinate cowpea varieties on the market mature in around 60 days, it is good to intercrop them with medium and late sorghum and millet varieties to minimize competition for nutrients and sunlight.

Traditionally, however, the indeterminate, long duration cowpeas are intercropped with these cereals. When using an indeterminate variety in an intercrop, it should not be allowed to climb the cereal plants, especially before the cereal heads emerge, to avoid shading.

Soybean has only recently started to be grown as an intercrop with sorghum or millet. Due to its longer maturity periods (almost the same as the most of the varieties of the cereals) it is advisable to grow soybean in strips (see examples of plant arrangements in section on planting of intercrops).

Other agronomic considerations that should be taken into account in the choice of cultivar/ varieties include:

- timing and distribution of rainfall
- tolerance to pest and diseases, such as Striga, mildew, spittle bugs and birds (at maturity)
- resistance to drought/dry-spells
- responsiveness to nutrients applied
- relative yield

The socio-economic factors that need to be considerations include:

- Available market for the cultivars – colour of grains, taste of food produced from them and demand by buyers. Some cultivars have high commercial value because they are used in large-scale food and beverage industry, such as baby foods and breweries.
- Farmer preferences – some varieties are preferred for household food and others for animal feed.
- Mitigation of hunger gaps - mixing different maturity types spreads risks and helps to ensure availability of food for a long period, thereby enhancing food security. This is the main reason why sorghum, millet and legumes are traditionally grown together.

Before planting

There are some activities necessary to carry out just before planting to prevent wastage of seed and ensure establishment of a good plant population of the cereals and legumes. These are:

- germination test
- seed treatment
- determination of a thousand seed weight
- in some cases, raising seedlings in a nursery for transplanting.

Germination test

Most farmers plant many seeds per hole as they are not sure of the viability of the seed. A germination test can be a useful guide to how many seeds should be sown in a hole. The test gives an idea of how many 'normal' seedlings can be expected from a given number of seeds. 'Normal' means the root and shoot parts are not deformed and look healthy, not diseased.

There are two main ways of conducting a germination test: sowing onto a prepared seedbed or sowing on moist paper.

When directly sowing a sample of seed on a prepared bed, there is a risk that poultry and other animals could disturb the moist soil in search of worms, insect and the seed sown unless the beds are protected.

Using moist newspaper, this can be done indoors, thereby avoiding the risk of disturbance from domestic animals.

To conduct a germination test:

On sunken beds	<ul style="list-style-type: none"> • Prepare a sunken bed of about 12 cm by 12 cm. • Select 100 seeds randomly from the batch with a spoon. • Plant the 100 seeds closely, about 1 cm apart on the wet bed. • Water the bed if it is dry to the touch of the hand. • After 5-7 days, count the number of normal seedlings that have emerged.
On newspaper	<ul style="list-style-type: none"> • Select 100 seeds randomly from the batch with a spoon. • Take 3 newspaper sheets, arrange in layers, moisten the sheets with clean water. • Place the seeds on the 3 layers of moist newspaper in 10 rows. Each row should have 10 seeds. • Cover the seed with a layer of moist newspaper. • Roll the pile of newspaper carefully into a tube with the seed tightly sandwiched between the sheets, tie the tube with thread at the ends and in the middle. • Stand the rolled newspapers in a container with just enough water to keep them moist. • After 5-7 days, unroll the newspapers and count the number of normal seedlings that will have sprouted.
On a plate	<ul style="list-style-type: none"> • Select 100 seeds randomly from the batch with a spoon. • Line a large plate with 3 layers of moist newspaper and place the seeds on them. • Cover the seeds with another moist layer of newspaper or paper towel. • Place plate in a place where it will not be disturbed and keep the paper moist but not soggy by sprinkling water on it when dry. • After 5-7 days, count the number of normal seedlings that will have sprouted.

After counting the emerged or well sprouted seedlings the next step is to calculate the germination percentage. For 100 seeds, the number of well emerged or sprouted seed gives you the percentage; for example if 85 are counted, then the germination percentage is 85%.

One can also use 25 or 50 seeds instead of the 100 for the test, but it is not advisable to use fewer than 25 seeds as the larger sample size improves the accuracy of the test result. In this case, the germination percentage can be calculated by dividing the number of well emerged or sprouted seeds by the initial number of seeds used and then multiply by 100: for example, if 25 seeds are used and 14 emerge/sprout then the germination percentage = $(14/25) \times 100 = 56\%$.

To ensure a high germination percentage, if using own seed saved from a previous crop, it is good to get seed from healthy plants; clean seed by removing damaged seed and other material, such as stones, after threshing and drying, and store the seed materials separately from grain to be used for food, in a dry area (for more information on storage, see section on harvesting and storage). It is also good to purchase seed from a registered dealer.

Seed treatment

As well as low germination rates, farmers often also plant many seeds per hole because they want to compensate for the loss of seed through the feeding activities of soil-borne pests like ants and millipedes. Sometimes birds such as francolins dig up the seeds. Seed loss after planting can also be due to fungal infection already in the seed or present in the soil. In addition, seed may fail to germinate due to dormancy.

Sometimes sorghum and millet seed cannot germinate straight after harvesting due to a dormancy period. After the seed has been stored for about 3 months it germinates normally. Most pearl millet varieties do not show dormancy and can germinate after harvest. Dormancy is a useful trait when the crop is in the field because it ensures that the grains do not germinate on the heads if rained on. Dormancy can be broken by seed priming (see below).

From the germination test done on moist paper, one can sometimes see fungal growth on some infected seedlings. This should prompt the farmer to carry out seed treatment, either by dusting the seeds with a fungicide or priming (see below).

Seed priming means soaking the seed in water overnight and then planting it the following day. The main benefit of seed priming is that it shortens the germination period. It can also reduce disease incidence in seeds and can break seed dormancy in some crops like sorghum and millet if this is an issue. This helps to ensure even and uniform germination. In arid areas, seed can be primed just after a heavy rain overnight and sown in the moist soil the next day to gain a head-start in germination.

Transplanting

In areas where the onset of the rains are not certain (mostly in the Sahel belt) farmers often plant up to about 20 millet seeds per hole awaiting the rains to come. The need for large amount of seed can be reduced either by priming the seed on the eve of direct sowing (see above) or planting them in a nursery and transplanting the seedlings after 40 days.

The nursery bed needs to be a well-prepared seed bed. The seedlings are watered as needed.

Transplants are mainly used when the fields to be planted are small because it is labour intensive. It can also be used to fill gaps in the field when adverse conditions affects field establishment. Traditionally, farmers do not raise seedlings in a nursery but rather transplant seedlings from well-established stands to the failed stands because many seeds are sown in one hole.

Transplanting has several advantages, including:

- Striga control – seedlings raised in a nursery have already well developed roots that the Striga roots cannot attach to when transplanted.
- Good plant density—a good crop stand can be ensured.
- Vigour – the good seed bed prepared in the nursery coupled with the watering regime ensures vigorous seedlings as compared to direct sowing.
- Controls shoot fly and spittle bug damage (see Table 11 in section 5 – What can go wrong).

But also some disadvantages:

- It is labour intensive.
- Once plants are lifted from the nursery bed they must be planted within a short time.
- The nursery should be close to the field to avoid delays between lifting from nursery and planting.

Planting

In general sorghum and millet is planted when the rains have established to ensure a good stand and vibrant growth. The date of planting is also important as the first two-thirds of the crop's maturity period must occur when growing conditions, especially moisture, are optimal. The last third of the crops' growing cycle is mainly spent in filling the grains and ripening (maturing), which requires lesser rainfall and higher temperature as compared to the first two-thirds.

Another factor to take into consideration when determining the dates of planting is the day length. This is important to consider because some varieties of sorghum and millet are photo-period sensitive. This means that such varieties will remain in vegetative growth (not flowering) while days are short and will not flower until longer days are experienced.

Sorghum and millet is predominantly grown in mixed cropping systems with various configurations of intercrops, all aimed at optimum exploitation of moisture, sunlight, nutrients and space (above and below ground).



Figure 1: Millet and cowpea plants (showing above and below ground biomass).

Sorghum

The aim is to establish about 3 seedlings per hole. To achieve this, if germination rate is very high (over 95%), farmers should sow 3 seeds per hole; if germination is poorer, farmers should plant about 4-5 seeds per hole.

If the seed has a germination percentage of 80%, on average 4 of the 5 seeds will germinate. However, if the germination percentage is below 60%, it means out of the 5 planted, on average less than 3 will emerge. In such a case it is advisable to double the seed rate by planting 10 seeds per hole.

The seeds should be planted at a depth of 0.8-1.5 inches (2-4 cm), thinned to 2 seedlings per hole. Where less than 2 seedlings emerge, gaps can be filled using seedlings thinned from other holes.

In sole cropping, a wide range of planting distances are used for sorghum. The distance between rows (inter-row spacing) varies from 40 – 90 cm depending on the settings of the machines used to make the ridges or if they are made with a hoe. If the ridges are made with a hoe, the inter-row spacing is closer; when machines are used, rows tend to be wider.

The wider the inter-row spacing, the closer the within-row spacing, mostly ranging from 15 – 40 cm (see Photo 3 for row planting). At these varying spacing, with 2 plants per hole the seed rate will be about 7-10 kg of sorghum seed per hectare. Yields increase when the plant population also increases, so long as there is adequate moisture and nutrients conditions. Seed rates also need to be increased if germination percentage is poor.



Photo 3: Sorghum planted in rows (image: Andre Bationo (AB))

Millet

Traditionally, farmers often sow many seeds per hole – sometimes as many as 50 – especially in areas with intense wind erosion or if planting is carried out before rains start. This is to prevent the seed from sinking deeper in the sandy soils and also to compensate for loss of seed carried away by the wind.

However, a significant amount of seed can be saved if farmers use seed with a good germination percentage, prime their seeds overnight and plant when the rains have established. Under such circumstances, farmers can sow just 5 seeds per hole, thinning to 2-3 seedlings after establishment as millet will tiller, i.e. produce side shoots.

Millet is planted at a depth of 0.8-1.5 inches (2-4 cm). In heavy clay soils and in soil that has large clods, seeds should be planted in well prepared soil so that the seedlings can emerge with the least effort. On sandy soils they should be planted deeper to prevent them from drying up.

In sole crops, both inter-row and within-row spacing vary from 20-100 cm. On poorer soils it is good to use wider spacing to reduce the below-ground competition by the lateral roots of neighbouring plants.

Millet produces a lot of tillers and the wider the spacing the more tillers a stand produces. The closer they are planted the more difficult it is to work in between the plants, for example for weeding: most smallholder farmers who use hoes for weeding prefer the wider spacing - the fewer plant stands are compensated for by the more profuse tillering.

Legumes

Legumes are sometimes planted in monocrops in rotation with sorghum and millet. Short duration legumes can sometimes be grown early in the season, preceding the main crop if the rainy season is long. For example, short duration cowpea that matures in about 2 months can

be planted at the beginning of the rainy season, harvested and the stover slashed down, and sorghum or millet then planted immediately after in the same season.

For cowpeas, the seed rate is about 12-25 kg per hectare. Erect varieties can be planted at inter-row spacing of 50 cm and within-row spacing of 20 cm. Semi-erect and creeping varieties can be planted at inter-row spacing of 75 cm; within row spacing can be 30 cm for semi-erect types and 50 cm for creeping types. For all types, 3 seeds should be planted per hole if germination percentage is good, or 4 seeds per hole if germination percentage is poor. Thin to 2 seedlings two weeks after planting.

Intercrops

In intercrops, the distance between sorghum rows (inter-row spacing) can be between 60 and 90 cm to make room for the intercrop (a legume or millet or both). The within-row spacing can be 40-60 cm if no other crop will be planted between the sorghum stands in the row. If another crop will be planted between the sorghum stands in the row then the within-row spacing of sorghum can be between 60 and 80 cm – similar to the inter-row spacing.

Legumes are the main intercrop partners in the sorghum and millet cropping systems, although other crops such as okra and sesame also feature.

Often farmers either mix cereal and legume seeds together, planting them in no particular pattern, or plant them separately and at different times. In an intercrop situation it is best to plant the legumes and the cereals in different holes in an ordered pattern to maximize yield. For example, two rows of cowpea spaced at 20 cm x 20 cm are alternated with a row of sorghum/ millet (see Figure 2).

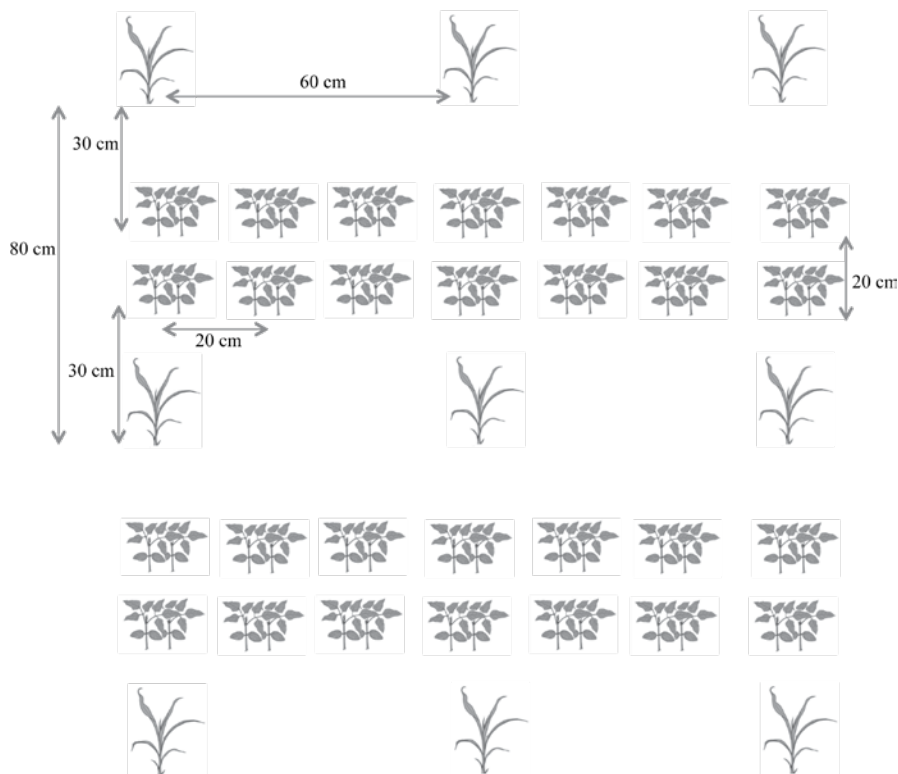


Figure 2: Sorghum-cowpea intercrop

Factors to consider when choosing spacing pattern for intercrops include:

- the maturity period of the crop (short, medium, long duration)
- the farmer's objective, e.g. if sorghum, millet or cowpea is for dual purpose (for grain and fodder), plant at higher densities if the objective is to get more fodder.
- The priority crop, e.g. the farmer might be more interested in cowpea than sorghum; in such a case the cowpea stands will be more than those of sorghum.

The creeping types of cowpea are normally preferred in intercrops as they are more adapted to shading than the erect types used in sole cropping. Another reason why farmers prefer the creeping types in intercrops is that the erect types have fewer leaves; the creeping ones have more leaves which also can serve as a green vegetable for the household, which is useful for dietary diversity. Creeping type are effective moisture and soil conservation tools as they cover the soil.

Due to the numerous benefits derived from growing legumes in association with sorghum and millet (see Table 6, below), it is good to increase the legume component in intercrops.

Table 6: Why combine sorghum/millet with legumes?

Advantages	Disadvantages
Reduces use of mineral fertilizer	More labour intensive
Legume as a cash crop, increases ability to buy inputs, e.g. fertilizer	Increased pesticide use – if cowpea is introduced
Nutrition – legumes are a good protein source	High cost of legume seed compared to the cereals
Better crop-livestock integration – enhanced fodder quality	Potential reduction in yield of cereal
Better soil conservation (soil cover by legume)	
More efficient use of land	
Biodiversity improved in the field	
Reduced risk of pests and diseases	
Root exudates from legumes increases phosphate rock solubility/uptake of N	
Improved physical, chemical and biological properties of the soil	
Better weed control	

Key messages

- Prepare a good seedbed – avoid burning plant materials as much as possible
- Reduce water loss from the soil by using practices like contour ploughing, applying mulch, maintaining a crop cover
- Include legumes in the system to improve soil fertility and productivity
- Plant crops at the beginning of the rainy season
- Before sowing, carry out germination test, then adjust seed rate to take into consideration germination percentage
- Preferably soak seeds overnight before planting to improve crop establishment
- For sorghum, establish about 3 seedlings per hole, thinned to 2 seedlings per hole. Sow seeds at 0.8-1.5 inches (2-4 cm) depth. In sole cropping, between row spacing can be 40 – 90 cm and within row spacing can be 15 – 40 cm. The wider the between row spacing, the smaller the within row spacing. Seed rate is about 7-10 kg seed per hectare. In intercrop, sorghum rows can be 60-90cm apart.
- For millet, sow 5 seeds per hole, thin to 2-3 seedlings after establishment. Sow at a depth of 0.8-1.5 inches (2-4 cm); plant deeper in sandy soil than in clay soil. In sole crops, both between and within row spacing can vary from 20-100 cm and should be wider in poor soil.

4. Crop management

Sorghum and millet nutrient management

Both sorghum and millet do better in poor soils than maize. Even without fertilizer application, their deep rooting systems help them to produce harvests in situations where maize will fail: sorghum and millet roots can penetrate up to 2 metres to reach moisture and nutrients while maize reaches down no more than about one metre. Sorghum and millet are often grown on lighter soils (sandy to loamy sandy) than maize.

Current yields of sorghum and millet achieved by smallholders in Africa are about 1 tonne and 0.5 tonnes per hectare, respectively. There is, however, large annual variability as they are grown in areas prone to dry spells which can severely affect yields.

These low yields can, however, be doubled and annual variability reduced by use of good seed, dry spells mitigation technologies and good agronomic practices (timely planting at optimum spacing, timely weeding, timely and appropriate application of organic matter and mineral fertilizer, and use of soil amendments to correct soil acidity and other problems) – that is an integrated soil fertility management (ISFM) approach.

Sorghum responds better to improved soil conditions than millet, although millet is more resilient and better able to deal with stress, such as dry spells and low nutrient content of the soils.

Sorghum and millet respond differently to fertilizer application: if a farmer grows both crops, it will often make more sense to apply available fertilizer to sorghum rather than millet, but there are exceptions - see Box 3, If you have to choose to microdose either sorghum or millet, which crop should you choose?

Before the decision is taken to apply fertilizer, farmers need to be guided through simple cost-benefit calculations to make sure the additional expenditure is justified (see Box 2, Will fertilizer application be profitable?).

Box 2: Will fertilizer application be profitable?

In Table 9: Sorghum, in the first example of a suitable fertilizer for sorghum, 2 bags of DAP and 2 bags of urea were used per hectare of sorghum to give a grain yield of 2000 kg per hectare and a stover yield of 4000 kg per hectare.

The yield would have been just 600 kg per hectare of grains and 1100 kg per hectare of stover without fertilizer application.

But how beneficial is using fertilizer in this example?

Below is a worked example of how to calculate the financial benefit using some estimates of prices for grain, stover and fertilizer. When extension workers and farmers repeat these calculations they should, of course, use prevailing local prices.

Without fertiliser:

Value of grains: 600 kg @ \$0.30 per kg = \$180

Value of stover: 1100 kg @ \$0.05 per kg = \$55

Total value of sorghum harvest per hectare = \$235

With fertiliser:

Value of grains: 2000 kg @ \$0.30 per kg = \$600

Value of stover: 4000 kg @ \$0.05 per kg = \$200

Total value of sorghum harvest per hectare = \$800

Cost of fertilizer:

2 bags of DAP @ \$30 each = \$60

2 bags of urea @ \$30 each = \$60

Total cost of fertilizer per hectare = \$120

To calculate if it was profitable to use fertilizer: (total value of sorghum with fertilizer - total value of sorghum without fertilizer) - total cost of fertilizer = (\$800 - \$235) = \$565 - \$120 = \$445 per hectare.

So, here the farmer recovered the \$120 invested in fertilizer and made an additional \$445 per hectare by using fertilizer. In this case the investment in fertilizer was very worthwhile, but with lower prices for grain and stover, and/or higher prices for fertilizer this may not be the case. For an investment in fertilizer to be worthwhile, the profit needs to be at least twice the amount invested; so, for an investment of \$100, the anticipated additional profit needs to be at least \$200.

Sources of nutrients

As they grow and develop, sorghum and millet take their nutrients from the soil.

The three major nutrients plants obtain from the soil are nitrogen, phosphorus and potassium. For sorghum and millet grown in most soils in sub-Saharan Africa, nitrogen (N) and phosphorus (P) are the two that farmers need to focus on, especially if crop residues are well managed to sustain potassium (K) in the soil. Most K taken up from the soil is stored in the stover and so can be recycled in the system if crop residues are returned to the soil.

Soils already contain some N and P but not at the levels required by sorghum and millet to produce higher yields. To ensure economic, sustainable millet and/or sorghum production on the same piece of land, nutrients need to be added through application of mineral fertilizer and organic matter at a level that will complement what the soil already contains.

Depending on the circumstances, farmers may also need to take measures to address dry-spells (see Box 5, *Zai pits*) and acidity (see *Soil amendments other than organic matter*), both of which can cause yield reductions.

There are two main types of nutrient sources relevant for sorghum and millet crops: mineral fertilizers and organic matter.

Mineral fertilizers, also known as inorganic or chemical fertilizers, are manufactured and sold for use by farmers. They only supply nutrients and do not help maintain soil health and structure in the same way that organic matter does (see below).

There are many different kinds of mineral fertilizer but they all fall into two main types: those that supply two or more nutrients and those that supply only or mainly a single nutrient.

NPK fertilizers supply the three major plant nutrients - N, P and potassium (K, also known as potash). Different NPK fertilizers are often available which contain different proportions of N, P and K. These are labelled, for example NPK 15-15-15. The first number is the percentage of the fertilizer that is N; the second number is the percentage of the fertilizer that supplies P; the third number is the percentage of the fertilizer that supplies K¹. So, the higher the number, the more of that nutrient the fertilizer supplies: for example, NPK 17-17-17 will supply more N, P and K per kg of fertilizer applied than NPK 15-15-15: NPK 15-15-15 will supply 150 g N while NPK 17-17-17 will supply 170 g N per kg of fertilizer.

Diammonium phosphate (DAP) supplies two of the three major plant nutrients, N and P. DAP contains 18% N and 20% P (equivalent to 46% P₂O₅): one kg of DAP supplies 180 g of N and 200 g phosphorus (equivalent to 460 g of P₂O₅).

Urea is a good example of a single nutrient, or straight fertilizer – urea only supplies the nutrient nitrogen (often abbreviated to N). Urea contains 46% nitrogen (N): one kg of urea therefore supplies 460 g of N but no phosphorus (P) or potassium (K).

Other examples of single nutrient fertilizers are single superphosphate (SSP; 20% P₂O₅) and triple superphosphate (TSP; 46% P₂O₅), both of which supply the nutrient phosphorus (P).

¹ The figure for P and K actually refers to the percentage of the salts P₂O₅ and K₂O. P₂O₅ contains 43.7% P. K₂O contains 83% K.

Organic matter includes manure, agro-forestry and leguminous organic inputs, compost and crop residues.

As well as providing nutrients for plants, including N, P and K, organic matter also helps to maintain good soil health and structure: improving water retention and maintaining beneficial soil organisms such as bacteria, fungi and earthworms, amongst others.

Farmers usually produce their own organic matter from their crops and livestock, but some may also buy them from neighbours or obtain them when neighbours' cattle, sheep and goats are allowed to graze their fields after harvest and deposit dung. Some farmers can harvest organic matter in the sylvo-pastoral lands (where there is open grassland and also trees and shrubs) or produce it through fallow systems.

Mineral fertilizers

Currently, many small-scale farmers who grow sorghum and millet use no mineral fertilizer. Mineral fertilizers are relatively expensive. Many farmers do not know how to use fertilizers properly and some believe, incorrectly, that they can 'poison' the soil.

This manual includes a two-stage approach to introducing farmers to using fertilizer on their sorghum and millet crops:

1. Microdosing
2. Fertilizer application at conventional recommended rates

In both cases, to derive the most benefit, the '4Rs' of fertilizer management should be followed:

- use the right fertilizer product for the crop
- apply the right amount
- apply at the right time in relation to the crop's growing cycle
- and place the fertilizer in the right way.

Microdosing

Strategic application of fertilizer, also known as microdosing, involves applying relatively small amounts of fertilizer in the planting hole (also called hills or stands) of sorghum or millet at planting time rather than the conventional approach of broadcasting larger amounts of fertilizer all over the plot.

Microdosing is especially appropriate for poor and small-scale farmers: less fertilizer is used compared to broadcasting so the investment cost is lower. Placing the fertilizer close to the plant also means the fertilizer is better targeted at the sorghum or millet crop and so is less likely to encourage weeds

For microdosing either sorghum or millet, the small amount of fertilizer should be applied to each hill when the seeds are sown:

- First a hole should be made with a stick, hoe or machete at the appropriate spacing.
- Next the fertilizer should be placed in the hole and covered with a little soil.
- Finally the seeds are sown and covered with soil – taking care to ensure the seeds and fertilizer do not touch: the sorghum or millet seed should be planted at a depth of 2-4 cm.

A common recommendation for microdosing millet is to apply 4 kg P per hectare

(equivalent to 9.2 kg P₂O₅). Three examples of how this can be achieved are:

Example 1: Apply 6 g NPK 15-15-15 per hill of millet. This is equivalent to 60 kg NPK 15-15-15 per hectare, assuming a planting density of 10,000 hills per hectare (1 metre spacing between rows and 1 metre between plants within a row). This is about one-fifth (20%) the amount of P fertilizer recommended for sustainable millet production – see *Fertilizer for sustainable cropping*, page 31.

Example 2: Apply 2 g DAP per hill of millet. This is equivalent to 20 kg DAP per hectare, assuming a planting density of 10,000 hills per hectare. This is about one-fifth (20%) of the amount of P fertilizer recommended for sustainable millet production for which additional nitrogen fertilizer, such as urea, is also recommended – see *Fertilizer for sustainable cropping*, page 31.

Example 3: Apply 5 g single superphosphate (SSP) per hill of millet. This is equivalent to 50 kg SSP per hectare, assuming a planting density of 10,000 hills per hectare. This is about one-fifth (20%) the amount of P fertilizer recommended for sustainable millet production for which additional nitrogen fertilizer, such as urea, is also recommended – see *Fertilizer for sustainable cropping*, page 31.

Trials have shown that, in the short term, microdosing can increase millet yields by around 50% or more: for example, if a farmer obtained a yield of 400 kg per hectare with no fertilizer, a yield of around 600 kg per hectare could be expected with microdosing.

A common recommendation for microdosing sorghum is to apply 4 kg P per hectare

(equivalent to 9.2 kg P₂O₅). Three examples of how this can be achieved are:

Example 1: Apply 1.5 g NPK 15-15-15 per hill of sorghum. This is equivalent to 60 kg NPK 15-15-15 per hectare, assuming a planting density of 40,000 hills per hectare (0.6 metre spacing between rows and 0.4 metre spacing within row). This is about one-sixth (15%) of the amount of NPK recommended for sustainable sorghum production – see *Fertilizer for sustainable cropping*, page 31.

Example 2: Applying 0.5 g DAP per hill of sorghum. This is equivalent to 20 kg per hectare, assuming a planting density of 40,000 per hectare. This is about one-fifth (20%) of the amount of DAP recommended for sustainable sorghum production for which additional nitrogen fertilizer, such as urea, is also recommended – see *Fertilizer for sustainable cropping*, page 31.

Example 3: Apply 1.25 g single superphosphate (SSP) per hill of sorghum. This is equivalent to 50 kg SSP per hectare, assuming a planting density of 40,000 hills per hectare. This is about one-fifth (20%) the amount of fertilizer recommended for sustainable sorghum production for which additional nitrogen fertilizer, such as urea, is also recommended – see *Fertilizer for sustainable cropping*, page 31.

Trials have shown that, in the short term, microdosing can double sorghum yields: if a farmer obtained a yield of 600 kg per hectare with no fertilizer, a yield of around 1200 kg per hectare could be expected with microdosing.

Box 3: If you have to choose to microdose either sorghum or millet, which crop should you choose?

If a farmer is growing both sorghum and millet, is microdosing with only P, as suggested above, but cannot afford to apply fertilizer to both crops it probably makes most sense to apply the available P to the millet.

This is because millet is better able to cope with a shortage of N than sorghum. This means, in this situation, millet will respond better to the added P than sorghum would.

Box 4: Farmer friendly fertilizer measurements

It is difficult for farmers to know what 2 g of DAP or 6 g NPK fertilizer 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 soda¹. The bottle-top can then be used as a scoop for measuring fertilizer.

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 or rectangular container filled with a range of fertilizers.

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

To apply 2 g of DAP per planting hole, 2 bottle-top measures are needed for every 5 holes.

To apply 6 g of NPK 15-15-15, two bottle-top measures are needed per hole.

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 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.

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

¹ The standard metal crown cork bottle-top has a 2.8 cm diameter and a tdepth of 0.5 cm, giving a volume of 3 ml (3 cm³). It has 21 ‘teeth’.

In addition to the microdosing fertilizer recommendations outlined above for millet and sorghum, it is recommended that farmers also improve the organic matter status of their soil by applying manure or compost (see *Organic matter*, page 34). This will increase the use efficiency of the nutrients in the mineral fertilizer.

In countries where phosphate rock is available, it is recommended to apply phosphate rock in order to prevent soil mining. See *Soil amendments other than organic matter*, page 35.

It is also recommended that farmers increase the legume component in the cropping system. Legume crops used as rotations or intercropping benefit the soil due to biological nitrogen fixation from the atmosphere. See *Legumes rotations and intercrops*, page 20-21.

Microdosing is a relatively low-cost way of boosting yields in the short term – a good first step from using no fertilizer towards sustainable intensification. By increasing production, perhaps producing a surplus for sale, this cash income (or money saved from buying food) can be used to buy more fertilizer next season. In this way farmers graduate from using little or no fertilizer, to low-cost microdosing and finally to sustainable intensification in which the soil nutrient balance is maintained by the application of higher level of fertilizers.

Microdosing can be more effective if it is combined with simple complementary technologies (see Box 5, *Zai pits*).

Box 5: Zai pits

Zai pits (Photo 4) are simple hand-dug holes which help to conserve water and contain higher levels of organic matter and nutrients than the surrounding soil. They are particularly useful for degraded soils and in regions where rainfall is poor and erratic. Zai pits improve infiltration of rain water and also capture runoff – in doing so they reduce soil erosion and importantly mitigate dry spells or drought.

The planting pits are about 20-40 cm in diameter and 10-15 cm deep, with 12,000 to 25,000 pits per hectare. See Photo 4.

The pits are dug during the dry season and available organic matter, such as leaves, stems and manure, is added. After the first rainfall, the pits are covered with a thin layer of soil and the seeds placed in the middle of the pit and covered. Mineral fertilizer can also be applied in the pits at planting – following the guidelines, above, for microdosing.

The major disadvantage of this approach is the labour required: it takes between 300 and 450 hours to dig zai pits on a hectare of land.



Photo 4 : Zai pits (photo: Abdoulaye Mando)

Fertilizer for sustainable cropping

After practicing microdosing for a few seasons, and seeing for themselves the benefits, farmers should be encouraged to graduate to using the full recommended amount of fertilizer to support sustainable cropping in the long term. Although this will require the use of more fertilizer than in microdosing, and so will be more expensive, this approach will help to ensure higher yields are achieved in this and future years.

For sustainable cropping, mineral fertilizer is usually applied as both basal fertilizer and top dressing.

Basal fertilizer

Basal fertilizers are applied before or at planting. These fertilizers contain the nutrients that crops need for early growth or those that are not easily lost from the soil in the root zone.

For sorghum and millet, the main types of fertilizer which should be applied before planting are phosphorus (P) fertilizers as well as organic matter. Most soils (over 80%) in the sorghum and millet belt are deficient in P.

Top dressing

Top dressing refers to mineral fertilizer, especially nitrogen, that is applied at some time after planting.

Nitrogen (N) should be applied as a top-dressing to sorghum and millet before the panicles (flowers) emerge (see Photo 2, page 12): a common mistake is to apply N when the grain is filling out, which is too late.

The most commonly available N fertilizers available to farmers are urea, diammonium phosphate (DAP) and sulphate of ammonia (SA).

Application of fertilizer

The three main ways that fertilizers can be applied to the soil are:

- i) broadcast
- ii) in bands
- iii) placed in the hole where the seed will be or is planted (spot application).

Each method has its advantages and disadvantages, summarised in Table 7, below.

Table 7: Advantages and disadvantages of three methods of applying fertilizers

Advantages	Disadvantages
Broadcast Improves the fertility of the whole field, not just fertilizing the crop Less labour needed than banding or spot application	Needs to be ploughed in or incorporated to be effective Nutrients, e.g. P, more in contact in soil and therefore fixed more More weeds will grow and compete with the crop
Banding Targets the crop - fertilizer is more available to plants and less available to weeds P and K fixed is less as contact with soil is reduced Saves time and labour by applying when preparing ridges	Needs to be worked into the soil to be effective Requires more labour than broadcasting Can scorch the plant if applied too close to young seedlings
Spot application, e.g. microdosing (see above) More precise targeting P and K fixed is less as contact with soil is reduced	Needs to be incorporated to be effective Can harm the seed if it comes into contact with the fertilizer

Some examples of fertilizer types, rate of application and timing for sustainable cropping

The overall aim is to apply fertilizer at rates which are most profitable for the farmer, not to maximise yields, and also to maintain soil fertility in the long term.

Generally, sorghum responds better to fertilizer than millet – so if growing sorghum and millet and applying both N and P, more fertilizer should be applied on sorghum than on millet.

As a rule of thumb:

- Not more than 40 kg of N and 20 kg of P per hectare should be applied to millet.
- For sorghum, the maximum N should be 60 kg and maximum P should be 20 kg per hectare.

The amount of mineral fertilizer required to supply 40 or 60 kg of N will vary depending on the fertilizer used: different types of fertilizer contain different amounts of N. Similarly, the amount of fertilizer required to supply 20 kg P will vary depending on the fertilizer being used.

In the tables below, some examples are given which show how the required nutrients can be supplied using different types and combinations of fertilizer. The tables focus on the two main nutrients, N and P, and aims to supply the maximum amounts of N and P recommended in the above rule of thumb.

Table 8: Millet. Various fertilizer options to supply 40 kg N and 20 kg P per hectare; 10,000 stands per hectare. If yield is up to 1 tonne per hectare, this should maintain soil nutrients to support sustainable farming.

Fertilizer options	kg per hectare	g (bottle-tops ²) per stand
DAP (basal) and urea (top dressing)	100kg (2 bags) DAP at land preparation AND LATER, BEFORE PANICLES EMERGE 50kg (1 bag) urea as top dressing	10 g (2 bottle-tops per hole) DAP at land preparation AND LATER, BEFORE PANICLES EMERGE 5 g (5 bottle-tops per 4 holes) urea as top dressing
SSP (basal) and urea (top dressing)	220 kg (4.5 bags) SSP at land preparation AND LATER, BEFORE PANICLES EMERGE 90kg (1 bag) urea as top dressing	22 g (6 bottle-tops per hole) SSP at land preparation AND LATER, BEFORE PANICLES EMERGE 9 g (2 bottle-tops per hole) urea as top dressing
NPK15-15-15	305 kg (6 bags) at land preparation	30 g (10 bottle-tops per hole) at planting
Manure ³ and TSP and urea	2 tonnes manure AND 40 kg (1 bag) TSP at land preparation AND LATER, BEFORE PANICLES EMERGE 50kg (1 bag) urea as top dressing	70g manure AND 4 g (half a bottle-topper hole) TSP at land preparation AND LATER, BEFORE PANICLES EMERGE 5 g (5 bottle-tops per 4 holes) urea as top dressing

² Metal beer or soda crown bottle-tops – level not heaped full.

³ It is assumed here that only half the nutrients in the manure will be available in the first season.

Table 9: Sorghum. Various fertilizer options to supply 60 kg N and 20 kg P per hectare; 40,000 stands per hectare. If yield is up to 2 tonne per hectare and all the stover is returned to the soil this will maintain soil nutrients to support sustainable farming.

Fertilizer options	kg per hectare	g per stand
DAP (basal) and urea (top-dressing)	100kg (2 bags) DAP at land preparation	2.5g (one bottle-tops per 2 holes) DAP at planting
	AND LATER, BEFORE PANICLES EMERGE	AND LATER, BEFORE PANICLES EMERGE
	100kg (2 bags) urea as top dressing	2.5g (2 bottle-tops per 3 holes) urea as top-dressing
SSP (basal) and urea (top-dressing)	220 kg (4.5 bags) SSP at land preparation	5.5 g (3 bottle-tops per 2 holes) SSP at planting
	AND LATER, BEFORE PANICLES EMERGE	AND LATER, BEFORE PANICLES EMERGE
	130 kg (2.6 bags) urea as top-dressing	3.2 g (threes bottle-top per 4 hole) urea as top-dressing
NPK 15-15-15	400 kg (8 bags) at land preparation	10 g (3 bottle-tops per hole) at planting

Table 10: Legume sole crop. Various nutrient sources to supply 20 kg P per hectare when legumes are grown as a sole crop in a millet or sorghum and legume rotation. Legume spacing 50 cm between rows and 20 cm between stands (100,000 stands per hectare).

Nutrients	kg per hectare	g per stand
DAP basal No top-dressing required	100kg (2 bags) DAP at land preparation	1g DAP (one bottle-top per 5 holes) at land preparation
SSP No top-dressing required	220 kg (4.5 bags) SSP at land preparation	2.2 g SSP (2 bottle-tops per 3 holes)
TSP basal No top-dressing required	100kg (2 bags) TSP at land preparation	1g TSP (one bottle-top per 7 holes) at land preparation

In intercrops, the legume is not given any additional mineral fertilizer as the focus is mainly on the cereals – so the above rules of thumb and fertilizer recommendations for millet and sorghum still apply.

Organic matter

Organic inputs come in different forms such as compost, farmyard manure (FYM), green manure from cover crops and crop residues. Some farmers construct temporary overnight pens for their cattle, sheep and goats in their fields during the dry season. The pens are moved from time to

time to new areas on the field thereby leaving the urine, droppings and left-over food spread across the field ready to be ploughed in during land preparation. Some pastoralists keep their cattle in farmers' fields in the evenings in exchange for grains and other foodstuff.

In addition, dry crop residues, such as sorghum or millet stover, can be returned to the field after harvesting. If all the sorghum stover is returned to the field, then at least half of the N and P, and around 80% of the potassium taken up by the plants is returned to the soil.

If available, organic inputs should be applied at a rate of 2 to 5 tonnes every two years. Since these inputs are rarely available in large enough quantities, application can be localised. For example, applying animal manure in zai pits, or in selected area of the farm to address specific constraints diagnosed by the farmer, or to enhance efficiency of inputs in target areas.

Soil amendments other than organic matter

Soil amendments are either non-nutritive materials or materials that build up nutrients in the long term, over years, rather than supplying nutrients primarily for one cropping season.

Most soil amendments used to correct soil acidity are also applied before planting. They include lime, rock phosphate and gypsum, and also various sources of organic matter.

Apart from correcting acidity, lime (CaCO_3) also corrects calcium (Ca) deficiency. Although highly acidic soils are not common in the sorghum and millet growing belt, where they occur soil acidity results in stunted roots of crops (see Photo 5).



Photo 5: Maize and many other crops are affected by high acidity in soils. Normal and stunted roots of maize shown in this photo – stunted roots of millet and sorghum would look similar (photo: CABI)

Gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) act as a source of both calcium (Ca) and sulphur (S). It improves alkaline soils and treats aluminium toxicity. It is also used to improve soil structure by improving particle aggregation and inhibiting or overcoming dispersion (cracking) in clayey, saline and sodic (sodium laden) soils.

Sodic soils are alkaline soils with a high pH (above 9) due to the presence of excessive sodium

carbonate (Na_2CO_3). They are mostly found in arid and semi-arid areas and are poor in drainage because their structure impedes water infiltration thus increasing run-offs and erosion, thereby reducing water availability for plant growth.

Rock phosphate is good for building long-term soil capital as it slowly releases P. Rock phosphate should be applied to soils every 3 years at a rate of 60 kg P_2O_5 per hectare. The rock phosphate can also be applied to compost which is then applied to the soil.

Rock phosphates from different sources contain different amounts of P: to supply the required amount of P, the amount of rock phosphate applied needs to be based on its P content. For example, if using Tilemsi rock phosphate from West Africa, which contains 30% P_2O_5 , requires about 200 kg Tilemsi rock phosphate.

On very light soils (sandy soil) that are suitable for millet, lime should be applied every 5 years at a rate of about 2 tonnes per hectare. Higher rates, up to about 10 tonnes per hectare, should be applied on heavier soils where sorghum dominates. If in doubt of the rate to apply, seek advice from an agricultural specialist.

Gypsum should be applied every 3 years on alkaline soils as a soil conditioner at a rate of 2-4 tonnes per hectare.

Gypsum is particularly good in promoting nitrogen fixation in legumes (groundnuts, cowpea and soybeans) (see nodulating plants, Photo 6) at low rates of 100-300 kg per hectare to supply the needed sulphur. However, that sulphur could be got more cheaply from single superphosphate (SSP). In sandy soils, groundnut pods may not fill due to calcium deficiency: gypsum should be applied at a rate of 200-400 kg per hectare just before the groundnut crop flowers to prevent this problem (Photo 7).



Photo 6: Uprooted soybean plant with nodules attached



Photo 7: Groundnut at reproductive phase

Benefits of agroforestry

One way of enhancing plant nutrition is to incorporate agroforestry (trees and shrubs) in the cropping system. Inter-planting trees and shrubs among the annual crops also brings benefits due to better soil and water conservation.

Agroforestry practices suitable for sorghum and millet cropping system include:

- Planting of legume crops, such as pigeon peas (*Cajanus cajan*) and *Dolichos* in strips (alley cropping) around or within the field in sorghum growing area. Their positions can be rotated from season to season. Guard against shading the main crops. These are most appropriate in wetter areas, 800-900 mm per year.
- Growing perennial tree legumes such as:
 - *Faidherbia albida*
 - *Acacia species*
 - *Parkia biglobosa*
 - *Moringa* (although it is not a leguminous tree)

Apart from improved soil and water conservation, agroforestry also provides other benefits, such as:

- Improves fallow, e.g. N-fixing trees and shrubs provide nitrogen-rich mulch.
- Provides fodder for livestock, whose droppings and urine are then returned to the field.
- Serves as wind breaks to control soil erosion and lodging (falling over) of crops.
- Their deep roots stabilize the soil, preventing erosion on slopes.
- Serves as live fences to protect crops from grazing animals.
- Provide fuelwood, fruits, leafy green vegetables and grains for household consumption or sale.

Weed control

Weed control is essential in sorghum and millet crops if high yields are to be achieved. After emergence, early growth of sorghum and millet is slow; weeds should be controlled, especially when the crops are young, to reduce competition.

Weeding should depend on presence of weeds. The first weeding can be at 2 weeks after planting and the second weeding at 5-6 weeks after planting.

Weeding is more easily done if crops are planted in rows.

On shallow soils, there is the need to earth-up soil around plants (e.g. to form mounds) to promote root growth – so that plants are better able to take up nutrients and water, and have good support. The crops are usually planted on flat ground, and earthing-up to form mounds can be done at the last weeding to bury weeds and conserve moisture. During earthing-up, weeds can be covered with soil to encourage rotting.

For legumes, or cereal-legume intercrops, the frequency of weeding depends on the type of legume planted. For example, creeping types of cowpea can cover the ground and suppress growth of weeds. One major weed problem in the sorghum and millet cropping system is the prevalence of the parasitic weed *Striga*. Both *Striga hermonthica* and *Striga gesneroides* are present, the former attacking cereals and the latter legumes.

Control measures for *Striga* include:

- Planting varieties tolerant of *Striga*. If unsure of varieties to use, consult local seed suppliers.
- Uprooting *Striga* plants before they flower.
- Planting legumes and cotton in rotation with sorghum and millet, or intercropping with legumes. The legumes and cotton stimulate the *Striga* seeds to germinate but they cannot attach to the roots of these non-host (trap) crops. Two years of continuous planting of non-host crops such as these can drastically deplete the *Striga* seed bank in heavily infested fields.
- Transplanting: transplanted sorghum seedlings do not release the chemical that germinating sorghum seeds release and which stimulates *Striga* seed to germinate.
- Soaking seed in carefully chosen herbicides which are not harmful to the seed before planting, but expert advice should be sought before doing this to ensure a suitable herbicide is used.
- Using herbicides to control *Striga* (a broad-leaf parasitic weed) especially in sole crops of sorghum and millet. However, if legumes or other broad-leaved crops are also present as intercrops, herbicides that control *Striga* may also damage these crops. Again, expert advice should be sought to ensure a suitable herbicide is used.
- Improve soil fertility: The impact of *Striga* on crops is less on fertile soils. This is mainly due to the shading of the *Striga* plant by the more vigorously growing sorghum or millet crop, which will have more profuse tillering (multiple stems per plant) and a higher population density of the crop. The *Striga* eventually dies because it cannot compete with the vigorously growing and taller cereal.

Harvest and storage

Machine harvest of sorghum and millet is not common in the African cropping systems. Almost all harvesting is done using cutlasses.

To harvest and store sorghum and millet:

- Harvesting should be done when the heads are dry.
- Cut plants just above the soil, leaving the roots and about 5-7 cm of the stalk intact. The roots and part of plant left in the soil will hold the soil and help prevent erosion.
- When cutting the plants at harvest, do not allow the heads (panicles) to touch the ground. This is to prevent them from getting contaminated with tiny *Striga* seeds that may be present. This is especially important if some of the harvested grains will be used as next season's seed.
- Harvested heads should be dried on clean hard-paved surfaces or on tarpaulins to prevent contamination from sand, stones and weed seeds. The area should be kept clean, for example by preventing animals from urinating and defecating on the produce. Under hot sun, drying can take

about 4 days. Through experience, farmers can tell if grain is dry enough for storage by biting - dry grain cracks on biting.

- Depending on the practices of the household, the grains could either be threshed and winnowed before storage, or it can be stored on the panicles (heads) un-threshed in bags.
- The dominant practice is to store the grains on the heads, especially when they are mainly for household consumption. This approach appears to have some advantages, including :
 - reducing pest attack on grains
 - rationing use of harvested grain – because it takes time to thresh before cooking this discourages household use.

If some of the grain will be used as seed:

- Large heads of the desired variety should be selected which are free from disease.
- The sorghum or millet heads should be carefully dried before storage.
- Selected heads can be hung from the rafters above fireplaces in the kitchen or a room where smoke from fires dries it, which will help to keep it free from pests.

For cowpea:

- Indeterminate cowpea is harvested over a long period.
- If possible stover should be left in the field as mulch to be incorporated during ploughing. Alternatively the stover can be removed and used as fodder, in which case the manure should, if possible, be returned to the field.
- Wet grains do not store well. Grains should be dried well and stored in sealed, double bags (storage sacks with inner bag made of polythene) or the PICS bags which have been developed for this purpose. These air-tight bags prevent weevil damage (see Box 5, below).
- Wood ash can also be used to control insect damage. The ash is sieved to remove large particles, then mixed with cowpea in equal proportions.

Box 6: Purdue Improved Cowpea Storage (PICS) bags

The PICS is a triple-layer plastic bag that can be used to store grain under air-tight conditions. One polyethylene bag is fitted inside another, and then the two bags are placed inside a sack composed of woven polypropylene. Grain is placed inside the innermost bag, the bag is then tied tightly, then the middle bag is tied, and finally the outermost bag is tied.

The inner bags reduce the movement of air across the wall of the bag. If the grain is infested by insects before storage, the insects soon die from lack of oxygen. Insects cannot move into bags to attack grain that is stored. A major advantage is that there is no need to coat grain with insecticides before storage using this system.

To prevent the transmission of pest and diseases from the previously harvested crop, storage structures, e.g. granaries, should be cleaned and disinfected before the new harvest is stored. If storing the grain in sacks that have been used before, they should also be disinfected (see below) before re-use.

A cost effective way of disinfecting small amounts of grains and old sacks before putting in grain, is solarisation. To do this:

- Spread the dried grains or sacks on large black polythene sheets in the hot sun. Grains should be thinly spread (2-3 cm depth) - ideally in a single layer.
- Cover with a transparent polythene sheets held firmly in place by stones or other heavy objects to prevent the wind from blowing them off.

Note: If moisture builds up on the underside of the transparent sheets; the grain is not dry enough for storage and should be dried further before storage.

- The grain (or sacks) should be left out in the sun for at least 5 hours. Grain can then be placed in insect free containers. Grain should be allowed to cool before storing.

The black polythene sheets absorb the heat from the sun while the transparent sheet acts like a greenhouse, trapping the heat. In this way temperatures well above 50°C can be reached between the two sheets. The heat kills eggs, larvae, pupae and adults of insect pests, and also kills most of the pathogens in the grain mass or sacks.

Caution: Grains to be saved as seed should not be dried/disinfected using solarisation. There is a very high risk of losing viability due to the high temperatures.

Management of residues

- Sorghum/millet – after harvesting, stalks should be spread thinly on ground and dried to kill stem borers.
- Crop residues can be taken and fed to animals: ideally the manure should be returned to the field.
- Cereal stalks can also be used for livestock bedding.
- Sometimes the cereal stalks are used as building materials – for example to make fences or cages for chicken (Photo 8).
- Crop residues can also be left in the field as a mulch and source of organic matter.



Photo 8: Sorghum stalks storage and uses

Key messages

- Before deciding whether to apply fertilizer to millet or sorghum, or deciding whether to practice microdosing or to apply the full recommended amount of fertilizer to support sustainable cropping in the long term, farmers should be helped to calculate whether this is likely to be economically beneficial. This entails deducting the cost of inputs (fertilizer) from the value of the anticipated increase in yield. To be worthwhile, the value of the increased yield needs to be at least twice the cost of the inputs.
- Apply the right fertilizer product, at the right rate, at the right time, in the right place, in the context of ISFM.
- For microdosing millet (planting density 10,000 hills per hectare), apply 6 g NPK 15-15-15, or 2 g DAP or 5 g SSP per hill at planting time.
- For microdosing sorghum (planting density 40,000 hills per hectare), apply 1.5 g NPK 15-15-15, 0.5 g DAP or 1.25 g SSP per hill at planting time.
- If a farmer is growing both sorghum and millet, is microdosing only with P, but cannot afford to apply fertilizer to both crops, it probably makes most sense to apply the available P to the millet.
- For full recommended amount of fertilizer to support sustainable cropping in the long term:
 - Apply P fertilizers and organic inputs at planting and topdress with N before panicle initiation.
 - Apply manure at 5 tonnes per hectare per 2 years. Use soil amendments like lime and rock phosphate if soil acidity is a problem and gypsum if alkaline.
 - Apply fertilizer in a band or spot close to plants, instead of broadcasting, to improve efficiency of fertilizer use.
 - Apply a maximum of 60 kg N and 20 kg P per hectare to sorghum and a maximum of 40 kg of N and 20 kg of P per hectare to millet.
 - If a farmer grows both crops, it will often make more sense to apply available P and N fertilizer to sorghum rather than millet (unlike for microdosing).
- If possible, return stover to the field to reduce nutrient loss - at least half of the N and P, and most of the K taken up by the plants is retained in stover.
- Include agroforestry (trees and shrubs) in the cropping system to improve soil and water conservation.
- Control weeds especially when the crops are young. The first weeding can be at 2 weeks after planting and the second weeding at 5-6 weeks after planting.
- Harvest when heads are dry. Cut plants 5-7 cm from ground, do not let heads touch the soil, dry heads in sun on clean surfaces, thresh and store grain, or store heads before threshing.
- If saving seed from crop, select large disease free heads, dry and store.
- For legumes, harvest when pods are dry, dry pods further in sun, thresh and store grain.
- Dry cereal and legume grain properly before storage to control insect pest attack. Legumes can be stored in airtight containers.

5. What can go wrong?

Pests and diseases

If not controlled, pests and diseases can cause large reductions in yields.

Pests

The main pests that can damage the crop before and after harvesting are shown in Tables 11 and 12. Insect pests can be controlled using integrated pest management practices. If using chemicals to control pests, handle the chemicals safely (see guidelines on safe use of agricultural chemicals, at the end of the guide). Some of the important insect pests are shown in Photos 9 and 10.

Table 11: Examples of the most important diseases of sorghum and millet.

Insect	Damage	Prevention and control measures
Stem borer	Larvae tunnel through the stem whilst feeding thus causing stem breakage, lodging (stem falls over), malformation of the grain and direct damage to the ears.	Ploughing in of stover to reduce carrying over of insects from one crop to the next. Roguing of volunteer plants between cropping seasons. Planting during periods when the pest is less active. Planting early maturing varieties. Use pesticide if at least 10% of the plants are infested.
Sorghum shoot fly	The larvae feed on the growing point of the shoot of the seedling. The growing point can die, resulting in tillering in many cultivars – these tillers can also be attacked.	Planting at the beginning of the rains instead of later. Establishing high plant populations. Establishing crop by transplanting seedlings from nursery instead of sowing seed directly in field. Providing good nutrition in the nursery or at planting so plants are strong and healthy, and better able to withstand attack.
Spittlebug	White foam on leaves – the young spittlebugs use this for protection. Yellow patches on leaves. If infestation is severe, leaves or young plants can die.	In most cases, infested plants recover from damage and natural enemies are active in controlling these pests so that no intervention is needed. Planting at the beginning of the rains instead of later. Growing seeds in a nursery. Seedlings in nursery can be better protected from the dry spells. Also, transplanted seedlings are less susceptible to insect damage.
Weevil	Feed on grain.	Dry grain on surface that is free from the pest. Dry grain properly before storage. Test: properly dried grains crack when bitten. Store grain in air-tight containers.
Flour beetle	Eats flour and deposits eggs on floor. Eggs are not easily seen but the adults may be seen in the flour or nearby.	Ensure mill is free from pest before milling grain to avoid contamination. Thresh on surface that is free from the pest.
Grain moth	No visible symptoms because larva feeds inside grains.	Dry grain on surface that is free from the pest. Dry grain properly before storage. Store grain in air-tight containers.
Birds	Eat grain in the field	Harvest when crop is ready – do not let mature crop remain in field. Scare birds away using reflective tapes, noisy tins and other methods. Mix both erect headed varieties with the drooping headed ones. When the birds flock and land on the drooping ones, as they lose their balance they fly off also frighten those perched on the erect ones.

Table 12: Examples of insect pests that damage legumes

Insect	Damage	Control
Thrips	Leaves abnormally shaped; flowers fall. Serious at flowering stage, but not at podding.	Intercrop with non-legume crops, e.g. sorghum. Plant at onset of rains instead of later. Spray with insecticides, e.g. cypermethrin, dimethoate, when infestation is severe.
Aphids	Found on underside of leaves, stems; leaves curl, plants stunted and may die, excrete honeydew which encourages growth of black sooty mold on plants, spread viral diseases. Aphids are more serious during dry spells.	Plant at on-set of rains Apply insecticides (e.g. pirimicarb) if infestation/ damage is serious and crop is young and still forming new leaves.
Maruca pod borer	Flowers wilt and drop, pods and seeds damaged. Form webs that join together flowers, pod, and leaves.	Plant crops at on-set of rains. Intercrop with non-legume crops. Spray with insecticides, e.g. cypermethrin, dimethoate, when infestation is severe.
Beetles	Adults damage leaves, larva cause damage to roots causing patches of yellow plants that are stunted, can dry up and have empty pods.	Till soil after harvest to expose beetles that are in the soil to the sun. Rotate legumes with non-legume crops.
Spiny brown bug	Depressions on pods and seed coats. Seeds rot or shrivel.	Intercrop beans with non-legume crops like maize Apply insecticide, e.g. cypermethrin, if infestation is serious.
Bruchids	Holes in grains seeds.	Store grain in airtight, clean, pest-free containers, e.g. use PICs bags (see description in textbox under 'Harvesting and storage'). Coat seeds with edible oil, ash or insecticides such as pirimiphos-methyl + permethrin, fenthothion + fenvalerate.

Diseases

On sorghum, fungal diseases that affect foliage include grey leaf spot, rust, blight and anthracnose. Head smut pythium causes root rot.

On millet the main fungal disease is mildew (Table 13).

On legumes, diseases include charcoal rot, aphid-borne mosaic, rust, powdery mildew in cowpea and rosette disease, leaf spots in groundnut (Table 14).

See photos 11 and 12 for some of the important diseases.

Table 13: Examples of the most important diseases of sorghum and millet.

Crop	Disease	Symptoms	Control
Sorghum	Grey leaf spot	Small spots enlarge to patches of about 5-15 mm long and 2-5 mm wide on leaves. Lesions are dark-red with a light brown centre. The patches may have a grey coating.	Plant tolerant/resistant varieties if available.
	Rust	Small swollen spots with red-brown brown powder on leaves and sheaths. More common on upper than lower leaf surface.	Plant tolerant/resistant varieties if available. Planting at on-set of rains. Destroy infected plants. Use seed from a crop that was not infected by rust.
	Zonate leaf spot	Red-brown spots sometimes surrounded by a pale-green halo on leaves. Spots increase in size and elongate parallel to the veins. Small spots have a light-brown centre surrounded by a reddish border and large spots are semi-circular may have light and dark brown bands. Infected seeds can be red-brown.	Rotate sorghum with non-cereal crops such as legumes.
	Leaf blight	Long patches with dark brown margins and light brown centres. Under humid conditions the lesions may have a grey coating	Planting resistant varieties. Intercropping with a legume.
	Anthracnose	Small round spots, become patches with light brown centre. Black spots may be present at the centre of the patch.	Plant resistant varieties. If harvested crop was infected, remove residues from the field immediately after harvesting. The residues can be fed to livestock away from the field.
	Head smut	Large, dark-brown galls (abnormal growths) emerge in place of grains. Galls covered with a white membrane which breaks open to expose a black powder. Plants become infected at seedling stage but infection not seen before the sorghum head emerges. May affect part of or the whole head.	Growing resistant varieties if available.
Millet	Downy mildew	White growth appears on underside of leaf, leaves become yellow or white, entire leaf may be discoloured or leaf may have discoloured streaks or stripes.	Plant seed from a crop that was not infected by the disease.

Table 14: Examples of the most important diseases of legumes.

Crop	Disease	Symptoms	Control
Cowpea	Charcoal rot (ashy stem blight)	In seedlings, black sunken spots on the stem close to the soil, death. In older seedlings yellowing of leaves, leaves fall, death of plants, In old plants, black dust on stem, pods and seeds.	Plant seed from a crop that was not infected Remove infected plants and burn Rotate cowpea with non-legume crops Plant resistant varieties
	Mosaic	Light green or yellow and dark green patterns on leaves, leaves crease and roll, small pods.	Plant seed from a disease free crop Plant resistant varieties Plant at on-set of rains instead of later Remove infected plants
	Rust	Small yellow raised spots on top and underside of leaves, petioles and pods; leaf spots become large, powdery reddish-brown, yellow and leaves die.	Intercrop with non-legume crops
	Powdery mildew	Scattered white patches, turn grey. Attacks all plant parts above the ground. Leaves can die and fall-off.	Plant resistant varieties if available.
Groundnut	Rosette disease	Plants stunted, leaves produced are progressively smaller, pale yellow and often curled.	Plant early in season. Remove infected and volunteer plants. Control aphids as they spread the virus which causes the disease.
	Early leaf spot and late leaf spot	In early leaf spot , dark brown spots with yellow halos on top leaf surface, spots are brown on underside of leaf. In late leaf spot, black spots on underside of leaves.	Intercrop /rotate with non-legume. Plant resistant cultivars. Remove volunteer groundnut plants. Spray with fungicides e.g. mancozeb, chlorothalonil, carbendazin.

Caution: If using chemicals to control pests and diseases, follow the manufacturers' guidelines on safe use of chemicals.



Photo 9: Pests of sorghum and millet (A) Stalk borer attack on maize (photo: CABI) (B) Spittle bug (photo: CABI)



Photo 10: Pests of legumes (A) Bug on cowpea (photo: CABI) (B) Spiny brown bug (photo: CABI) (C) Stink bug (photo: CABI) (D) Grasshopper on cowpea (photo: CABI) (E) Cowpea pods with holes (photo: CABI) (F) Damaged cowpea seeds (photo: CABI) (G) Good seeds (photo: CABI).



Photo 11: Diseases of sorghum: Head smut (photo: CABI)



Photo 12: Diseases of legumes (A) Cowpea pod with mycelium (photo: CABI) **(B) Brown spot on groundnut** (photo: CABI)

6. Economics of sorghum/millet-legume cropping systems

How to calculate whether use of fertilizer is financially worthwhile.

Example 1

In Example 3 in the section on fertilizer rates, 2 bags of DAP and 2 bags of urea were used per hectare of sorghum to give a grain yield of 2000 kg per hectare and a stover yield of 4000 kg per hectare. The yield would have been just 600 kg per hectare of grains and 1100 kg per hectare of stover without fertilizer application. But how beneficial is using fertilizer in this example?

Below is a worked example of how to calculate the financial benefit using some estimates of prices for grain, stover and fertilizer. When extension workers and farmers repeat these calculations they should of course use prevailing local prices.

Without fertiliser:

Value of grains: 600 kg @ \$0.30 per kg = \$180

Value of stover: 1100 kg @ \$0.01 per kg = \$11

Total value of sorghum harvest per hectare = \$191

With fertiliser:

Value of grains: 2000 kg @ \$0.30 per kg = \$600

Value of stover: 4000 kg @ \$0.01 per kg = \$40

Total value of sorghum harvest per hectare = \$640

Cost of fertilizer:

2 bags of DAP @ \$30 each = \$60

2 bags of urea @ \$30 each = \$60

Total cost of fertilizer per hectare = \$120

To calculate if it was profitable to use fertilizer:

(total value of sorghum with fertilizer - total value of sorghum without fertilizer) - total cost of fertilizer = (\$640 - \$191) - \$120 = \$449 - \$120 = \$329 per hectare.

So, here the farmer recovered the \$120 invested in fertilizer and made an additional \$329 per hectare by using fertilizer.

It may also be worthwhile to know how much money is made for each dollar invested - this can be done by calculating the value-cost ratio (VCR). For an investment to be worthwhile a VCR of 2 or more is required; a VCR of 1 would be the breakeven point and any value less than 1 would represent a loss.

$$\text{VCR} = \frac{\text{total value of sorghum with fertiliser} - \text{total value of sorghum without fertilizer}}{\text{Total cost of fertiliser}}$$

$$= (\$640 - \$191) / \$120 = \$329 / \$120 = 2.74$$

This means that for each \$1 invested in fertilizer the farmer got a return of \$2.74. The VCR is greater than 2. So, in this case the investment in 2 bags of DAP and 2 bags of urea for the sorghum crop was worthwhile.

Example 2

How beneficial would it be to apply 5 bags of NPK (17:17:17) on a hectare of millet, as in example 1 in the fertilizer rates section? Assuming grain yields increase from 350 kg per hectare without fertilizer to 850 kg per hectare when the fertilizer was applied, stover yields increase from 1000 to 2000 kg per hectare and prices are \$0.30 per kg for grain, \$0.01 per kg for stover and \$30 per 50 kg bag of fertilizer.

Without fertiliser:

Value of grains: 350 kg @ \$0.30 per kg = \$105

Value of stover: 1000 kg @ \$0.01 per kg = \$10

Total value of millet harvest per hectare = \$115

With fertiliser:

Value of grains: 850 kg @ \$0.30 per kg = \$255

Value stover: 2000 kg @ \$0.01 per kg = \$20

Total value of millet harvest per hectare = \$275

Cost of fertilizer:

5 bags of NPK (17:17:17) @ \$30 each = \$150

To calculate if it was profitable to use fertilizer:

(total value of millet with fertilizer - total value of millet without fertilizer) - total cost of fertilizer = $(\$275 - \$115) - \$150 = \10

So, the farmer recovered the \$150 invested in fertilizer, but made only an additional \$10 per hectare from using fertilizer. In this case, investing in fertilizer would not have been very attractive to farmers.

$$\text{VCR} = \frac{\text{total value of sorghum with fertiliser} - \text{total value of sorghum without fertiliser}}{\text{Total cost of fertiliser}}$$

$$= (\$275 - \$115) / \$150 = \$160 / \$150 = 1.07$$

This means that each \$1 invested in the fertilizer used on the millet crop yielded an additional \$0.07. In this case, the farmer would most likely prefer to invest the money in other inputs or enterprises.

The benefits of fertiliser application in the system can be improved by using combinations of best practices discussed in this guide. For example, using seed with good yield potential and that can withstand disease pressure, use of farmyard manure and compost in combination with fertilizer, seed priming, and micro-dosing (see Box 4 for more information on micro-dosing) to improve the efficiency of fertilizer use and controlling weeds to reduce competition for nutrients.

7. Guidelines for safe use of agricultural chemicals

1.	Place of purchase
•	Purchase chemicals from licensed/registered dealers
•	Pesticide should be accompanied by an information leaflet on guidelines on proper use and handling of chemical
•	Do not use banned or prohibited chemicals. If unsure, consult your local agricultural agent, or buyers of your produce
2.	Choice of chemical
•	Use the correct chemical for crop and pest. Follow information leaflet on pest and crop
•	Use recommended chemicals that are accepted in the market. Confirm with your local extension agent or buyer of coffee
3.	Correct timing
•	Follow guidelines. Check how many days you must allow between spraying and harvesting
4.	Correct quantity
•	Apply the recommended quantities
5.	Correct mixing
•	Follow guidelines on compatibilities
6.	Correct application
•	Follow guidelines on correct application method
7.	Correct handling
•	Wear protective clothing covering body, head and face to prevent contact with skin, eyes, or inhaling. Do not face into the wind when spraying.
•	Keep materials for handling spillages ready for use if needed
•	Wash off chemical that comes into contact with body with water and soap
•	Wash your hands with soap and water before eating, smoking or going to the toilet
•	Bathe and change clothes after spraying
•	Wash containers used to mix and spray chemicals
•	Visit doctor if sick after spraying. Provide doctor with name of chemical and the information leaflet for chemical to read.
8.	Disposal of chemicals and containers
•	Dispose excess diluted chemical as per manufactures' guidelines
•	Do not leave empty containers lying around
•	Follow manufacturers' instructions on disposal
9.	Storage and storage period
•	Store pesticides away from human and animal food, away from children, in locked place, with warning signs
•	Keep chemicals in their original containers
•	Storage for period recommended by manufacture. Do not use after expiry date
10.	Records
•	Keep records of chemicals used, when used, where used

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.

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