RESADE

A Practical Guide to Cropping Practices for Food and Fodder Crops

Barley, Blue Panicum, Buffelgrass, Cowpea, Pearl Millet, Quinoa, Sorghum and Sugar Beet

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Recommended citation: Hammami, Z., Calle, J.P.R., Shahid, M., Nhamo, N., Singh, R.K. 2022. A Practical Guide to Cropping Practices for Food and Fodder Crops: Barley, Blue Panicum, Buffelgrass, Cowpea, Pearl Millet, Quinoa, Sorghum, and Sugar Beet. International Center for Biosaline Agriculture (ICBA), Dubai, 45p.

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Foreword One Message from IFAD

DR. MALU NDAVI
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Investment in agricultural research for development (AR4D) is recognized as a *sine qua non* for the transformation of food systems to meet the global demand for food and contribute to emerging challenges that might hinder the achievement of the Sustainable Development Goals. The success of AR4D lies in its direct relevance and effectiveness, and the high returns on investments and the catalytic impact of AR4D on rural development in general, and on rural poverty reduction in particular, have been demonstrated. Further, the role of AR4D becomes even more pertinent considering the rapidly changing context in marginal lands, which requires context-specific research to provide locally validated solutions – both biophysical and socioeconomic. Thus, continued investment in AR4D is imperative. It is not an option for the transformation of food systems under the prevailing environment of population increase and concomitant climate change.

IFAD recognizes the International Center for Biosaline Agriculture (ICBA) as an international center of excellence for AR4D in marginal environments given its mandate in investing in research to generate international public goods for local contextualization for development impact. Indeed, the broad thematic areas of ICBA's research address persistent and emerging global, regional, and local challenges, including climate change mitigation and adaptation, natural resource management, and improved nutrition. On the other hand, IFAD, as a specialized agency of the United Nations and an international financial institution, invests in country programs to introduce, expand, or improve food production systems and to strengthen related policies and institutions within the framework of national priorities and strategies, with the ultimate beneficiaries being rural communities. Thus, the operations of these two institutions are synergistic and complementary; hence, their partnership optimizes delivery of their respective mandates.

The RESADE project is the first to be financed by IFAD and the Arab Bank for Economic Development in Africa (BADEA) following the signing of the memorandum of understanding between IFAD and ICBA. To date, the progress in the implementation of RESADE has been assessed as satisfactory and the preparation of this manual attests to this. More importantly, while ICBA is recognized as a center of excellence for AR4D, the preparation of manuals such as this one positions it as a knowledge hub. ICBA is also well placed to deliver development outcomes through influencing agricultural policies and the use of technology and innovations proven effective in the resource-poor and disadvantaged environments in which IFAD and ICBA target groups pursue their smallholder agriculture-based livelihoods. Therefore, over the next nine years, continued and more contextualized knowledge generation and sharing must be central to investments by ICBA. This will improve efficiency gains, allowing more food to be produced with the same or less land, water, and other inputs, while maintaining the environmental integrity of systems, and this will be part of the center's contribution to the Sustainable Development Goals.

Foreword Tow from ICBA Director General

DR. TARIFA ALZAABI
Acting Director General, ICBA

Many factors hamper agriculture in most of sub-Saharan Africa. Two, land degradation and climate change, stand out in terms of their impact on smallholder farmers, the main producers of food on the African continent. These factors significantly diminish smallholder farmers' yield and income. As a result, hunger and poverty are serious concerns.

Coupled with climatic extremes, salinization, a major type of land degradation, heightens risks to food security and the livelihoods of rural communities that depend on agriculture. The use of inappropriate irrigation practices and saline water resources makes things worse. What is more, this situation is exacerbated by inadequate water supply and low water quality in dry areas.

These problems make it difficult and even impossible to economically produce food on salt-affected soils where water is scarce. This is why it is important to introduce smallholder farmers to crops and practices that are more suitable for the conditions in which they grow their food. With droughts becoming more frequent and severe, these crops and practices also need to be climate resilient.

This idea is behind our project "Improving Agricultural Resilience to Salinity through Development and Promotion of Pro-Poor Technologies" (or RESADE). Financed by the International Fund for Agricultural Development (IFAD) and the Arab Bank for Economic Development in Africa (BADEA), this four-year project targets seven sub-Saharan African countries: Botswana, The Gambia, Liberia, Mozambique, Namibia, Sierra Leone, and Togo.

Its goal is to increase agricultural productivity and income of rural households in salt-affected areas by introducing salt-tolerant crops and associated agronomic management practices, creating value chains for new crops, and developing the capacity of farmers and extension workers in salinity resilience and climate-smart agriculture in collaboration with national agricultural research and extension systems.

As smallholder farmers need skills and technologies to grow new salt-tolerant crops, knowledge and technology transfer are an integral part of the project. This guide has been compiled with this objective in mind. It provides critical information on management practices for several food and forage crops.

The guide is just another building block in efforts toward climate resilience and sustainable livelihoods through crop diversification. More diverse food systems are more likely to support the achievement of the Sustainable Development Goals, especially the ones on zero hunger and poverty.

This guide is designed to serve as a handy reference not only for smallholder farmers and extension specialists but also for anyone who is interested in learning best practices in sustainable production of salt-tolerant food and forage crops.

I therefore hope that this guide will find its way to as many users as possible.

I also hope that readers will find it informative and interesting.

Preface

Agricultural production has stagnated in most countries in sub-Saharan Africa because of a wide range of constraints. Land degradation and climate change stand out as key impediments to agriculture's contribution toward diminishing household food insecurity and poverty. Over time, the increasing prevalence of saline soils negatively affects the production potential of marginal areas. Similarly, inappropriate irrigation methods and seawater intrusion have made many countries vulnerable to soil salinity. At the same time, the decrease in available freshwater has become a major limiting factor facing the agricultural sector, especially in the dry regions. Continued sustainable cultivation of these areas is particularly challenging if farmers have limited know-how on the use of suitable salt-tolerant crops and their varieties, appropriate soil amendments, and associated crop management practices. These challenges are the major reasons for food and feed insecurity, malnutrition, and environmental degradation, besides the limited resource base in the marginal regions of sub-Saharan Africa. Strengthening crop production systems through crop diversification can diminish the impacts of climate change on communities.

The predicted impacts of climate change for sub-Saharan Africa such as irregular rainfall patterns are already evident in the western and southern parts of the continent. Limited annual rainfall has led to increased incidents of drought. Without the adoption of climate-smart technologies, smallholder farmers face an increased risk of losing current assets and future opportunities. The combined effect of increased soil salinity and climate effects will have a huge impact on the production potential of dryland farming in salt-affected environments. The project "Improving Agricultural Resilience to Salinity through Development of Pro-Poor Technologies" (RESADE) aims to improve food security and diminish the poverty of poor smallholder farmers, especially women, in areas affected by salinity through (i) introducing salt-tolerant crops and best agronomic management practices, (ii) developing value chains for the systems of crops introduced, and (iii) strengthening the capacity of farmers and extension workers in salinity-tolerant and climate-smart agriculture in collaboration with the national agricultural research and extension systems (NARES). Current efforts are being made to combat and alleviate increasing salinization using sustainable integrated crop production practices. The deployment of appropriate salt-tolerant crop varieties along with associated best management practices has been reported to increase production by about 23% in an environment-friendly and cost-effective way for salt-affected lands.

Crop diversification is another important step in increasing the resilience of smallholder farming systems to the impacts of climate change and salinization. A diverse cropping system has a high potential for supporting the attainment of Sustainable Development Goals 2 on hunger, 1 on poverty, and 10 on climate, which African governments are pursuing. In view of these challenges, this technical and practical cropping guide has been developed as a handy tool for trainers, extension workers, and progressive farmers for supporting their day-to-day operations from establishment to crop husbandry, and is a part of the many documents from the RESADE project. This guide contains insights on cropping practices and recommended management practices for multi-purpose food and forage crops important in a smallholder farming setting. The guide emphasizes improved production (fresh and dry biomass) for smallholder farmers in the intervention areas of the RESADE project. The guide will benefit farmers through increased productivity, support sustainable natural resource management, and contribute to poverty reduction in the region

Crop Diversification Team, RESADE Project

ICBA, Dubai, United Arab Emirates

Feb, 2022

1. BARLEY (*Hordeum vulgare* L.)

1.1 Introduction

Barley (*Hordeum vulgare* L.) is one of the staple cereal crops contributing to food security, income, and social stability. It is cultivated in more than 105 countries and is characterized by wide environmental adaptation. Barley ranks fourth in both production and area under cultivation. There is evidence that barley production occurs in extended regions from the arctic into the subarctic zone and subtropics in the Mediterranean region. It has good resistance to dry heat, low annual rainfall, and salty environments, among the biophysical growth-limiting factors. However, its productivity remains low under marginal environments, with an average grain yield of less than 1 t/ha. In this context, breeding and careful selection of germplasm with high tolerance of abiotic stress factors have led to a collection of high-yielding barley genotypes.

Worldwide, barley production primarily supports livestock feed development, human food consumption, and malt for use in beer production. Both food barley and malting barley have been studied for improved productivity because of the central role they play in the livelihoods of farm families. In countries where integrated crop-livestock production systems are developed, barley plays a significant role as a food and feed source.

The downward trend in food-barley production has been largely attributed to the negative impacts of abiotic factors such as soil degradation and climate change. In marginal areas, variable weather patterns have led to increased aridity characterized by low and erratic rainfall. Land degradation has caused soil pH challenges (both acidity and salinity). Appropriate management of soil and water salinity in some marginal areas has not been achieved easily. The predicted climate changes and variability will further increase the negative impact of these factors in the future. However, barley is among the suitable crops for marginal agricultural areas.

Fig. 1.1. Two panicle types, two and six rows, that distinguish cultivated barley species.

Barley (*Hordeum vulgare* L.), a monocotyledon, self-pollinating herbaceous plant, belongs to the Poaceae (Gramineae) family, which grows 30-120 cm in height. It has a typical fibrous root system consisting of seminal roots and post-embryonic nodal roots. The stems are straight, having nodes to which the leaves are attached. The plant consists of the main stem and two to five secondary stems called tillers when fully developed. The leaves are linear, 5 to 15 mm wide, and are produced alternately on the tillers' sides.

Cultivated barley has been categorized into three types: *Hordeum vulgare*, *H. distichum*, and *H. irregulare*. The first type has a six-row panicle, whereas the last two have two rows (Fig. 1.1). All the lateral florets are sterile in *H. distichum*, while alternate lateral florets are sterile in *H. irregulare*. In *H. vulgare*, the three spikelets on each of the notches are fertile and the produced kernels amount to a total of six rows on each ear (Fig. 1.1). *Hordeum vulgare* L. is one of 32 species of the genus Hordeum, while *H. vulgare* subsp. spontaneum has been recognized as cultivated barley's ancestor.

Barley phenology has been divided into six stages: germination, seedling development, tillering, stem elongation, booting and flowering, and (ripening and harvesting) (Fig. 1.2).

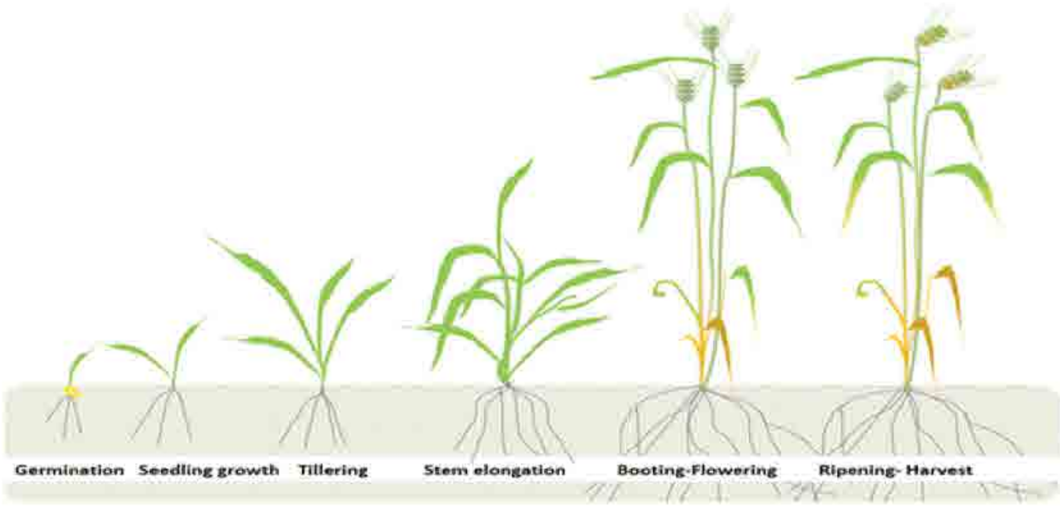

Fig. 1.2. The six stages of barley growth and development.

The center of origin, also related to the center of diversity, defined here as the geographical region where domesticated or wild plants first exhibited distinct genetic characteristics is important in the development of barley the center of diversity is the location where an organism exhibits the highest degree of variation. For barley, several suggestions have been put forward regarding its center of origin. The most widely accepted is the Fertile Crescent in the Middle East. Other hypotheses have proposed multiple centers of origin, such as Tibet, Ethiopia, and North Africa, particularly Morocco.

THE ECONOMIC IMPORTANCE OF BARLEY

FOOD: Barley is part of the human diet in many regions of the world. Approximately 6% of the barley crop is consumed as food worldwide. Indeed, barley is part of the diet in North Africa. Research has shown that barley's per capita consumption ranges from 10.6 to 88.6 kg per person per year in Tunisia and Morocco, respectively.

FEED: More than 70% of the barley crop is used as animal feed. Barley is an excellent source of fodder for livestock. Although there are numerous ways of producing feed from barley, the green harvest at the stem elongation stage (ear at 1 cm, second node detectable) for green fodder and the grain harvest at new shoot maturity are widely practiced. Farmers also use dry processing to form hay or straw and upgrading of the by-product of the grain harvest or the wet process in the form of silage.

BEER PRODUCTION: Approximately 21% of barley grain is used for brewing, malting, and distilling purposes. This is a major ingredient in some alcoholic drinks. The use of barley for this purpose requires particular criteria to meet product quality and standards. In general, two-row barley meets these criteria better and for this reason it is more prevalent in the beer-brewing industry.

BENEFIT TO FARMERS: The price of barley on the world market has been steadily increasing (FAO, 2022). Therefore, farmers can reap more economic benefits through barley production.

CROP REQUIREMENTS: Barley can grow in different types of soil in both hot arid and semi-arid regions. The crop is adapted to different soil types ranging from very sandy to heavy clays. Other soil characteristics related to drainage capacity are important considerations, especially in soils that are saline or where irrigation water is characterized by high salt content. Barley can be planted in a rotation system that includes root crops, vegetables, millet or sorghum, or other fodder crops. Being less nitrogen demanding, barley can also be planted after another cereal. On the other hand, it is advisable to retain stubble from previous crops and avoid overgrazed land. Green manure can also be used as an intercrop.

1.2 Land preparation

The purpose of land preparation is to provide the necessary soil conditions that will enhance crop establishment. Soil tillage is one of the most expensive and critical operations conducted on conventional farms each season. The primary reason for tillage is to prepare the soil so that a crop can be established. The general objectives of soil preparation are as follows:

- ✓ To ensure good seed contact with the soil for plant establishment, decrease the size of soil clods and decrease the number of fragments.
- ✓ To support seed emergence and establishment of a homogeneous crop, it is advisable to diminish the slope of the land through leveling.
- ✓ Remove, incorporate, or transform plant residues.
- ✓ Manage soil water (both wetting and drying).
- ✓ For weed control, mechanical pre-treatment (ploughing) can be carried out in plots invaded by weeds. It is advisable to stimulate weed germination by irrigation (false sowing).
- ✓ Mix and incorporate manure, base fertilizer, lime, or any other soil amendments.
- ✓ Break the pest cycle by destroying mature insects, their eggs, larvae, and breeding nests.
- ✓ Decrease wind and water erosion by making a rough surface.

Fig. 1.3. An illustration of good seedbed preparation, which supports good plant establishment and drainage of excess water.

Generally, one deep ploughing followed by one or two harrowings (crosswise) at a minimum is sufficient to obtain a good seedbed tilth (Fig. 1.3). However, for heavy soil, two ploughings may be needed depending on the clay content. In some instances, the first tillage is done using a moldboard plough, one-way disc plough, or two-way disc plough. The second tillage is often carried out to obtain better soil tilth, conserve moisture, manage weeds, and cut crop residues from previous coping seasons. This can be accomplished using various harrows, rollers, sprayers, and mulching and fallow tools (Fig. 1.4).

There are five major types of harrows: the disc, the spike-tooth, the spring-tooth, the rotary cross-harrow, and the soil surgeon. Rollers or pulverizers with V-shaped wheels make a firm and continuous seedbed while crushing clods.

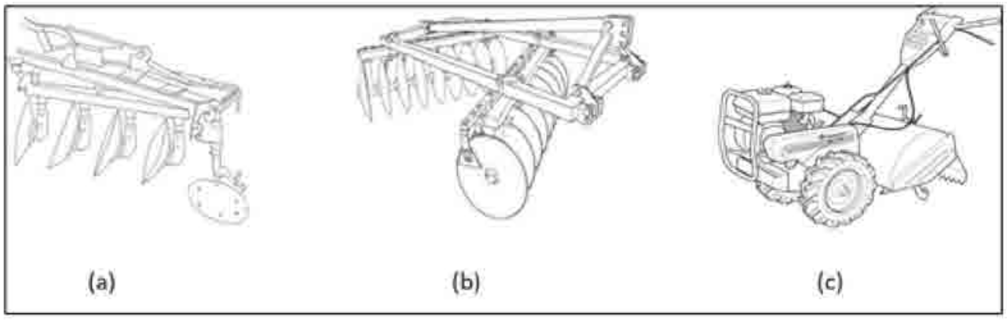

Fig. 1.4. Three tillage implements for use in land preparation: tractor-drawn (a) disc plough and (b) disc harrow and (c) a walking power tiller.

Waterlogging is one of the major challenges farmers face during the rainy season. Crops that are sensitive to flooding often become affected by the presence of too much water in the root zone because of poorly drained soils. This inhibits the soil's ability to provide an optimum plant growth environment and affects its physical, chemical, and biological properties. In addition, water stagnation has a significant adverse effect on the development of root biomass and thus on plant growth and productivity. Optimum water and air content are important for the physiological performance of plants at all growth stages.

Barley cannot survive stagnant water and a flooded root zone for a long time. Successful barley production requires developing methods of enhancing drainage and improving soil aeration. Decreasing soil inundation, controlling salinity, and rehabilitating land for cultivation are the three a functional field drainage system. Various methods have been recommended to alleviate waterlogging problems, such as surface drainage and mole drains. One of the affordable techniques that is easy to implement is the raised-bed cropping system (Fig. 1.5).

The required equipment for preparing raised beds depends on numerous factors such as farm size, local cost of available equipment, and topography of the land in question (altitude and slope are the main determinants). Mechanical and manual land preparation methods are used in developing countries.

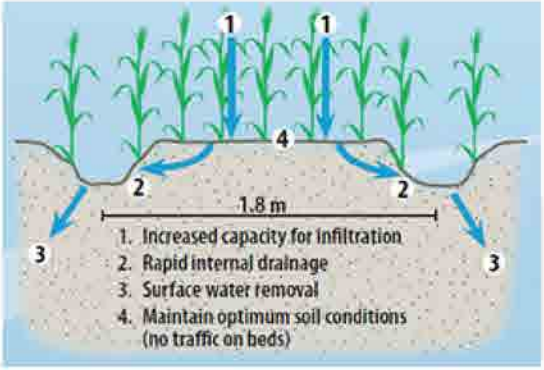

Fig. 1.5. A cross-section of a raised bed: drainage and aeration are enhanced while preventing waterlogging.
Source: https://s3.amazonaws.com/soilquality-production/fact_sheets/ /Raised_bed_cropping.

1.3 Sowing

The highest yields and quality are usually obtained from early sown barley. Early planting has the advantage of using the whole crop growing season. Late planting, on the other hand, decreases the length of the effective growing season.

SOWING DEPTH: The recommended sowing depth for barley is from 3.5 to 7.0 cm. Deeper sowing could result in lower germination percentage, longer period of seedling emergence, or stunted plants. Increased susceptibility to root rot diseases has been observed where deep sowing was practiced. There is a close relationship between good crop establishment and overall yield in barley. Uniform crop establishment significantly influences crop yield; hence, the importance of maintaining a recommended sowing depth through precise seed placement

SEED RATES: The target plant population per hectare is an important factor that determines overall yield. Seeding rates are important for farmers, and these vary across crop varieties and seed size and weight. Where machine planting is used, the seeding plates need to be adjusted for both seed size and weight. The best use of seed size and weight is when farmers use graded seed from official seed-producing companies. In order to keep to the recommended seeding rates, farmers need to obtain adequate information from the seed company or agents regarding seed quality. Regardless of the source, good seeds need to be clean and of uniform size for seeding rates to be easily achieved at the field level.

The following formula can be used to determine the seed rate:

$$\textbf{Seed rate } (kg/ha) = \frac{\textbf{Target plant population}/m^2 \times \textbf{Thousand} - \textbf{grain weight (g)}}{\textbf{Germination \%} \times \textbf{Expected establishment (\%)}}$$

High plant density is not recommended as barley has a high tillering capacity. However, this is a general rule, which could be adjusted for a region where weather conditions hinder tiller formation. The seed rate should be calculated to achieve a target plant population, adjusting for expected establishment losses.

PLANT POPULATIONS: Plant populations can be estimated when the crop is fully established using the quadrant method. Place a 0.5 m × 0.5 m quadrat randomly in the field and count the number of plants within the quadrat. By repeating this, an average plant population at establishment can be calculated. The obtained average of all counts can be multiplied by 4 to obtain the number of plants per m2 and this figure can then be converted to plants per hectare.

With a target plant population of 200-250 plants/m², a seeding rate of 120 kg/ha can be used to arrive at the target population. However, the target plant population varies depending on local conditions. A higher plant population can be considered if conditions impede tiller formation. Target plant populations of 300-400 plants/m2 can be used to achieve a number of ears ranging from 400 to 500 at harvest.

Key facts to remember:

- Barley has a limited capacity to compensate for decreases in seed rates.
- Germination is driven by adequate soil moisture, temperatures above 0 °C, and aeration.
- Emergence speed is highly dependent on soil temperature and sowing depth.

SEED VIABILITY: Seed viability is an important attribute of all seeds used in agriculture. Viable seed has higher germination percentages. Official seed sources or trusted seed sources are important for farmers to obtain viable seed. Once seed has been procured, farmers can run a seed germination test to assess viability. The germination test results can be used to calculate the required seed to achieve the target plant population

SEEDLING VIGOR: Germination and seed emergence depend on many factors. A well-prepared seedbed with adequate water, and soil tillage is important for supporting vigorously growing seedlings. Seed vigor is important in early plant growth stages as it decreases crop losses to pests and diseases and other physicochemical factors. High seedling vigor makes the plant population achievable and decreases costs associated with gap filling and seedling replacement. Achieving an early crop with high seedling vigor is the first important step in obtaining a good harvest.

Precaution: Flooded or nearly saturated soils decrease the volume of air in the soil. With few soil pores left for oxygen, crop performance will decline. Under such conditions, despite normal imbibing, oxygen becomes limiting and diminishes germination. Barley is vulnerable to diseases such as loose smut, rust, Fusarium wilt, and leaf blight under extreme moisture conditions. As a preventive measure, treat the seed with suitable fungicide before planting.

1.4 Water and fertilization management

IRRIGATION: Irrigation water requirements vary in quantity and distribution over time depending on the variety, target yield, and climatic conditions (temperature and rainfall). Being drought- and salt-tolerant, barley can grow even when rainfall is less than 250 mm and the salinity of irrigation water is up to 10 dS/m. The use of saline water with electrical conductivity (EC) of >10 dS/m does cause significant yield loss in tolerant genotypes. Even though barley can grow in soils with EC of 15 dS/m, irrigation should be supplied with an adequate leaching fraction and an appropriate drainage system.

IRRIGATION METHODS: For small areas, it is advisable to use drip irrigation; sprinkler irrigation is also a suitable method that can help to achieve high yield (Fig. 1.6). Surface irrigation (furrows) and submersion irrigation are not recommended because they could induce an overuse of water resources and energy and have low irrigation efficiency. The standardization of flow rates at the basin entrance allows better water distribution and improved yield in using irrigation. In recent times, drip irrigation has been designed to save water and increase water productivity.

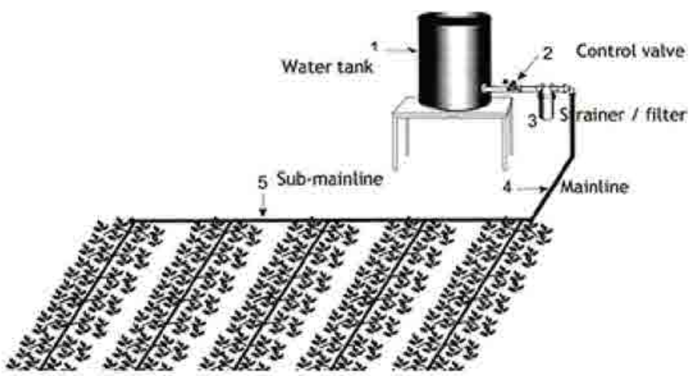

Fig. 1.6. Drip irrigation systems are used to supply the required amount of water at the target spot in a field, thus increasing field water-use efficiency.

FERTILIZATION: Fertilizer applications should be based on soil test data. In the absence of such data, use of the following blanket recommendations can be considered:

Nitrogen: The nitrogen requirement of barley is 2.5 units per quintal of grain produced.

An application of 120 kg/ha is recommended, divided into three applications:

- ✓ At sowing or at 3-leaf stage (30%).
- ✓ At 6-leaf stage, early tillering (40%).
- ✓ At stem elongation (30%).

Phosphorus and potassium: The following rates are appropriate:

- ✓ Application of 50–70 kg/ha of diammonium phosphate (DAP) at the time of sowing improves yield.

Trace elements should be applied following soil analysis results or leaf deficiency symptoms can be used to guide when to apply the fertilizer. Some trace elements, such as manganese, are easily retained in alkaline soil. Nutrient deficiency is affected by soil pH and therefore deficiencies might occur when the nutrient is fixed in the soil.

A foliar application of manganese sulfate is usually sufficient to remedy deficiency, although a few highly deficient fields require more. Application of well-decomposed organic matter (from 10 to 15 t/ha of manure) can ensure good barley grain yield where chemical fertilization is not available. Returning crop residues (stubble) to the soil also improves yield

1.5 Pest and disease management

WEEDS: Weeding can be done manually using hand-hoeing or herbicides. The use of herbicides is recommended for timely and more efficient weed removal. Without management, weeds can cause crop losses of up to 60% of potential yield.

COMMON DISEASES: Diseases adversely affect barley yield. Biotic stress is one of the yield-reducing factors in all regions where barley is cultivated. Researchers working together with farmers over the past decade have developed both cultural and chemical solutions. Below are a few examples of commonly occurring fungal, bacterial, and viral diseases and suggestions on how to manage them.

- ***Stem and leaf rust:*** Red-brown spores on stems and orange-brown circular spores on leaves appear because of rust. When severe, especially in late-planted crops, leaves die. Systemic fungicides are recommended for controlling rust.
- ***Loose and covered smut:*** The presence of olive-brown smut spore masses is evidence of loose smut attack. In covered smut, dark brown spores may cover the entire head. Planting clean seed and applying fungicides can control the effects of both loose and covered smut in barley.
- ***Powdery and downy mildew:*** Gray or white-buff masses of spores appear on leaves and in extreme cases cover the leaf. Crop yellowing, browning, or leaf tissue death is associated with mildew. Application of fungicides is recommended.
- ***Bacterial leaf blight:*** Lesions form brown stripes on leaves. Clean seed, crop rotation, and roguing are used to manage the disease.
- ***Barley yellow dwarf virus:*** Aphid-spread viral disease causes yellowing of tips and margins of old leaves. Properly timing planting, tolerant cultivars, and good plant nutrition are cultural practices used to control this disease. Insecticides to control aphids decrease disease incidence.
- ***Molya disease:*** This is caused by cyst nematodes and is an important barley disease. Repeated ploughing off-season, rotation including green manure crops, and early planting are options for management of nematodes in barley.

For chemical control of diseases, local pesticides are usually available and assistance can be sought from the agricultural extension services in your area.

1.6 Harvest, postharvest, and forage storage

Most barley varieties can regrow after cutting or grazing. The resultant ratoon crop can then be used as a basis of multiple harvests from one field.

BARLEY PASTURE: Barley can usually be cut or grazed during a period until the first node appears if farmers aim to harvest grain (dual use). For one use, the crop should be cut or grazed well before heading for the best quality of feed. Barley also produces good-quality silage or hay.

BARLEY HAY: Barley can be cut and dried to make hay. It should be cut at the milky grain stage. Barley haymaking is suitable for rotation in irrigated systems. Harvesting at the boot (a time when the sheath of the uppermost leaf encloses the head) and soft dough stages (when the grain is soft but dry) is recommended for a superior combination of hay yield and digestibility. Stored barley hay is a valuable source of forage during the dry season.

SILAGE: With barley harvested at the soft dough stage (moisture content from 64% to 72%), it is possible to produce good-quality silage due to its good carbohydrate content and a rapid drop in pH.

STRAW: Barley straw is an appropriate way to feed cattle during the dry period, especially when supplemented to the animals with other protein sources.

DUAL USE: The dual use of barley for livestock feed consists of cutting or grazing the fodder when the crop height is 30 cm (equivalent to the 1-cm head stage at one node) and then harvesting the regrowth in grain.

1.7 Nutritional attributes

Fresh forage and silage: The protein and neutral detergent fiber (NDF) contents of barley forage vary from 9% to 12% dry matter (DM) for protein and 63% to 56% DM for NDF between flowering and dough stage.

Harvesting at heading also allows increased starch. Barley forage tends to have lower cell wall components, acid detergent fiber (ADF), and lignin than other small grain forages.

STRAW: The protein and NDF contents of untreated straw range from 2% to 6% and 80% to 86%, respectively. Values for hay are intermediary between those of the straw and the fresh forage.

Table: 1.1 Nutritional characteristics of feed units for dairy and beef production.

Nutritional attributes per kg DM	Fresh forage	Grain	Straw
UFL	0.80	1.09	0.44
UFV	0.75	1.08	0.33
PDI	76	86	24

- UFL = feed unit for milk production
- UFV = feed unit for maintenance and meat production
- PDI = protein truly digestible in the intestine for rumen

Precaution: Forage barley is prone to nitrate accumulation that can lead to nitrate toxicity. Values of NO_3-N that exceed 0.226% are considered toxic to all types and classes of livestock.

GRAIN YIELD: Mean grain yield under irrigation ranges from 1.5 to 4.5 t/ha. Barley can be harvested when the grain moisture content is 18-20% if drying is carried out immediately after harvest to avoid losses during storage. Otherwise, harvesting should be done when the moisture content is 14-15%.

Small machinery in the market can combine threshing and grading operations for crops (Fig. 1.7).

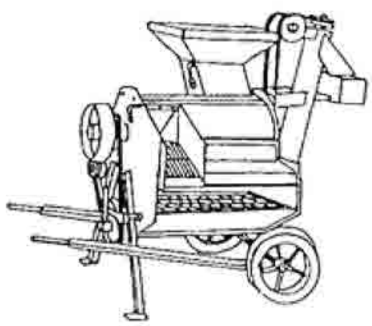

Fig. 1.7. Threshing, seed sorting, and grading equipment suitable for use on smallholder farms.

Barley seed can be stored without loss when the moisture content in the grain approaches 12%. Storage with moisture above 14.0% results in a loss of germination capacity. Ideal storage conditions are met in the presence of natural aeration or by frequent turning of the grains in the storage place. For barley planned to be used for animal feed, moisture less than or equal to 14.5% is acceptable.

2. SORGHUM (*Sorghum Bicolor* L. MOENCH)

2.1 Introduction

Sorghum [Sorghum bicolor (L.) Moench] is cultivated on more than 40 million hectares worldwide and yields more than 57 million metric tons per year. Sorghum is an important cereal crop grown for its grain and forage; hence, its importance in the provision of both human and livestock nutrition. It is a versatile crop grown under a range of environmental conditions. Sorghum is widely grown in arid environments because of its ability to tolerate drought. It is relatively more salt-tolerant than other cereal crops, with several varieties now available for cultivation in pH-affected soils (Fig. 2.1). The identification of a sizable genetic pool for salinity tolerance offers good scope for integrating salt tolerance characteristics into appropriate breeding programs to improve sorghum productivity in saline soils. In developing countries, sorghum is an essential component of cropping systems in which the emphasis is on growing food crops to improve food security. It is also valued as livestock feed through the use of dry stover after grain harvest, growing forage varieties, and as an energy source when grown as a biofuel crop. Sorghum is highly water-use-efficient and tolerant of drought, heat, and soil salinity. However, sorghum's productivity has not increased in relation to the growing demand for the crop. The average yield of sorghum in sub-Saharan Africa is about 0.7 t/ha, which is about 20% of the potential yield of 3.5 t/ha and half the global average of 1.3 t/ha.

Fig. 2.1. Farmers cultivate a range of sorghum varieties with different grain colors. For food and feed.

Sorghum is one of the most important annual food crops globally, especially in marginal environments. Sorghum usually grows to a height of 1 m to 2 m, but often tall forage varieties grow up to 5 m. It has a fasciculate root system, cylindrical stems with knots, and develops alternate green leaves. The stems and leaves are covered with white wax and the pith (or middle part) of the stems of some varieties is juicy and sweet. The leaves are approximately 5 cm in width and 76 cm in length.

The Sorghum genus belongs to the family Poaceae. The genus has high morphological variation; hence, the development of many classification divisions. Three main species have been identified: *Bicolor*, *Arundinaceum*, and *Drummondii*, which are the cultivated species, wild species, and weedy forms, respectively.

CULTIVATED SORGHUM SPECIES: Cultivated sorghum (*Sorghum bicolor* (L.) Moench) has been categorized into five basic races: *Bicolor* (B), *Guinea* (G), *Caudatum* (C), *Kafir (K)*, and *Durra* (D). Cultivated sorghum is preferentially self-pollinating and has wide phenotypic variation. The inflorescence of sorghum is a panicle that ranges from loose to dense depending on the variety. Each head bears 800 to 3,000 kernels, which are in part enclosed in glumes. The kernels vary markedly in color, shape, and size. The color of sorghum glumes varies from black to red or brown (Fig. 2.1).

CENTER OF ORIGIN: The center of origin of sorghum has been identified as northeastern Africa, where the highest variability of both cultivated and wild species is found. Domestication has been traced to areas in modern-day Ethiopia as far back as 500 to 7,000 years ago. Evidence suggests that other species have their center of origin in Congo around Katanga region. The crop is also native to other parts of sub-Saharan Africa, such as southern Africa. Other authors have listed Southeast Asia and the Pacific region as centers of origin of some species.

WILD SORGHUM IN AFRICA: The wild *Sorghum Bicolor* has wide diversity in the Arundinaceum species. Four races, which have been found in Africa, are the *Aethiopicum, Arundinaceum, Verticilliflorum,* and *Virgatum.* The Aethiopicum race with small and contracted inflorescence has high variation between Mauritania and Sudan. The Arundinaceum race has been found in humid West Africa and parts of southern Africa, and it has a characteristic large inflorescence. The Verticilliflorum race, which has a typically large and open inflorescence, is found in the African savannas. The Virgatum race has been associated with the Nile valley in north-eastern Africa. The wild species cross easily with the cultivated species and, where the two occur together, fertile progeny have been found.

THE ECONOMIC IMPORTANCE OF SORGHUM

FOOD: Sorghum is important in diets of people living in dry areas. It provides 361 kcal of energy, 75 g of carbohydrate, 16 g of protein, 5 g of fat, and 26 g of fiber per 100 g of grains. It is also a good source of vitamins and micronutrients. Research has shown that sorghum consumption per capita per day is about 5-19 kg per year in areas where the crop is widely used. Dishes such as sorghum rice and sorghum meal compete with other maize dishes.

FEED: Both the grain and vegetative parts of the sorghum plant are important livestock feed sources. Good-quality sorghum grain competes with other grains for feed mixture for large livestock and poultry. Often, condensed tannins diminish the value of sorghum meal, but improved varieties do not have this challenge.

BEVERAGES: Malting sorghum is important in the production of beer and other non-alcoholic beverages. Malt is important in the production of sorghum beer and, during this process, the condensed tannins are neutralized before the malting begins. Commercial malt, beer powder, and local beer meal are some of the products and premixtures of importance in farming communities.

SORGHUM DEVELOPMENT STAGES

There is a consensus that sorghum has ten development stages from plant establishment to maturity (Fig. 2.2). Emergence, 3-leaf, 5-leaf, floral initiation, and emerging flag leaf constitute the first five stages of sorghum growth. Booting, anthesis, soft dough, hard dough, and physiological maturity are the last five stages. Sorghum has three growth phases: (a) the vegetative phase lasts about 30 days, which consists of the first four stages; (b) the reproductive phase lasts from day 30 to day 60 and is made up of the next three stages; and (c) the grain-filling and physiological maturity phase lasts from day 60 to day 90 and includes the remaining three stages.

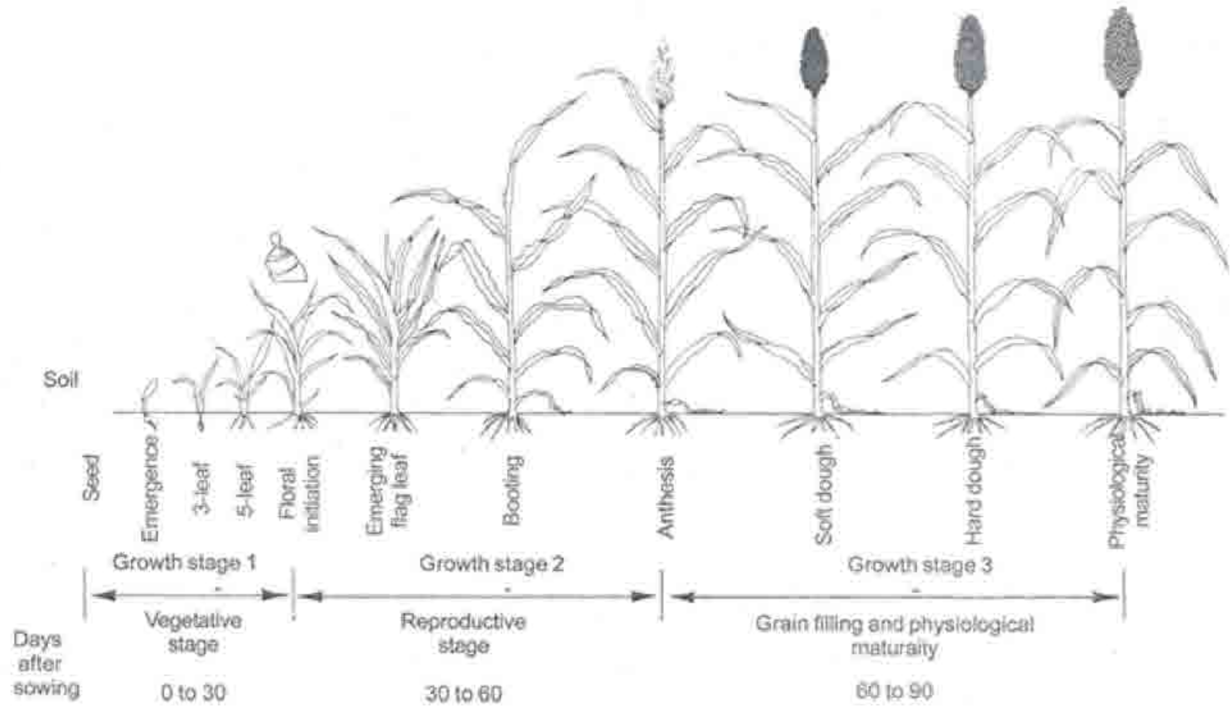

Fig. 2.2. Sorghum growth and development phases. Sources: Gerik et al. (2003); Vanderlip and Reeves (1972).

2.2 Land preparation

Land preparation can start as soon as the land is cleared of crops in preparation for the next season. The field should be thoroughly prepared and leveled to obtain a better crop stand and growth. One deep ploughing followed by two harrowings (crosswise) is often sufficient to obtain a good seedbed in most soil types. Sorghum cannot tolerate more prolonged water stagnation; hence, good drainage is essential.

2.3 Plant requirements

Sowing time: Sowing is recommended at the onset of the rainy season. A good stand development should ensure that the soil temperature at 5-cm depth is above 21 °C. Regarding irrigation, sowing during the dry season becomes an option in many areas. Sowing can also be done manually or mechanically as per the following recommendations:

- ✓ Sowing density: 10–15 kg of seeds/ha, depending on thousand-kernel weight.
- ✓ Distance: 45-75 cm between rows and 15-20 cm between plants.

- ✓ Sowing depth: 3-4 cm, depending on soil texture.

IRRIGATION: Irrigation water requirement is about 750 mm depending on the variety and target yield, and this could be adjusted according to weather conditions (atmospheric demand, evapotranspiration).

FERTILIZER MANAGEMENT: Soil amendment: 15–30 t/ha of well-decomposed manure at the time of field preparation, depending on the presence of organic matter and the nature of the soil. Fertilizer applications should be based on soil test data. In the absence of such data, the following recommendations can be used:

- ✓ 150 kg/ha nitrogen, 60 kg/ha phosphorus, and 50 kg/ha potassium. Apply fertilizer alongside rows, 5 cm below and 5 cm to the seed side at the time of sowing.
- ✓ Apply N at the rate of 40-60 kg/ha after each cut.
- ✓ In S-deficient soils (below 10 ppm available S), the application of 40-60 kg/ha S is advantageous, not only improving biomass but also quality, particularly in summer crops.

2.4 Field management

Good field management practices are encouraged for sorghum farmers. The crop grows well when pests and diseases are under control (Fig. 2.3). Biotic pressure on sorghum leads to decreased crop yield. Frequently scouting for pests and diseases is encouraged in sorghum fields. Good crop husbandry at early and late crop development stages will increase the chances of identifying and rectifying any yield-decreasing occurrences. Keeping specimens of unfamiliar pests and weeds also helps in solving new problems.

Fig. 2.3. Sorghum field in Ethiopia, Photo by ICBA (2019).

WEED MANAGEMENT: Weeds are unwanted plants that compete with the crop for all growth-supporting resources. The best weed control approach should be based on controlling weeds before they become fully grown. Weed control applied early in the form of manual, chemical, or cultural control is far cheaper than attempting to eradicate fully grown weeds. The critical period of weed control, 6-8 weeks after crop establishment, and the threshold weed densities need to be observed in order to avoid a yield penalty from weeds. Striga sp. or witchweed is a dangerous parasitic weed in sorghum and should be controlled effectively.

Cultural methods of weed control include the use of crop rotation. Establishing a diversified rotation system and alternating plant families have the advantage of suppressing weeds. The use of species such as alfalfa, millet, and barley is encouraged. The use of appropriate and approved herbicides decreases the costs of weed management. Moreover, using a weedicide is recommended for plots that are prone to high weed incidence.

BIRD ATTACK: Starting from the soft dough stage of growth, sorghum is heavily attacked by birds if no control is put in place. Birds have been found to cause huge losses, as high as 80% grain yield loss. In addition, birds (mostly house sparrows) can cause crop damage. Bird scaring is an important exercise required to safeguard the sorghum crop as it matures. Although it is common practice to keep one or two bird scarers in a sorghum field, more non-human bird-scaring methods have been developed and are often more efficient. A guard needs to be mounted against birds when the panicles have kernels in the milky stage. Some varieties have protective glumes, which helps in diminishing bird damage.

DISEASE AND PEST MANAGEMENT: Sorghum is not prone to many diseases during its development. However, a few need to be discussed here, such as downy mildew and tassel smut.

Anthracnose: Anthracnose is a fungal disease caused by *Colletotrichum sublineolum*. It is one of the important diseases and it attacks the leaf, stem, panicle, and grain, with a result of yield loss. Lesions grow and join together and can lead to leaf death. Resistant varieties significantly prevent the occurrence of this disease. In case of an attack, a fungicide can be used to effectively control the disease.

Sooty stripe: Sooty stripe is a fungal disease. Lesions with yellow to brown color occur under the leaves and as the lesions become bigger the crop is affected. Improved varieties are resistant to fungal attack. Where sorghum has been repeatedly grown or zero/minimum tillage has been applied, the disease can be severe. Standard fungicides can be sprayed to control this disease.

Loose kernel smut: Seed treatment before sowing is advised against loose kernel smut (*Sphacelotheca sorghi, S. cruenta, S. reiliana*). Seed disinfection with a fungicide before sowing, removal of infected plants and burning them before the spores spread, the use of resistant varieties, and the use of a good crop rotation are possible options for disease control.

Possible damage can occur from European corn borer, from slugs (plots near a meadow, wet conditions), and from seedling flies. In the latter case, plant at the beginning of the rainy season to avoid seedling flies during seedling emergence.

Carry out two treatments on boring caterpillars and aphids using a systemic insecticide such as Thiodan 35 EC or Sumithion 50 EC (or Dimethoate EC) 3 weeks after emergence at a rate of 1.5 L/ha. For Striga control (*Striga asiatica, S. forbesii, S. hermonthica*), perform a good crop rotation and pull up Striga plants before flowering.

Nematodes: Sorghum hosts a range of plant-parasitic nematodes. Lesion nematodes such as *Pratylenchus*, spiral *Helocotylenchus*, stubby-root nematode *Paratrichodorus*, and stunt nematode *Tylenchorhynchus* all affect sorghum growth. Both cultural methods and application of nematicides will diminish losses.

2.5 Harvesting, postharvest, and forage storage

At maturity, the panicles can be cut and left to dry for a few days, and then threshed. All off-type panicles are discarded. Dry the seeds until complete desiccation occurs and coat them with Actellic 2% at a rate of 1 g/kg of seeds. Bag the seeds and label them with the following information: species, variety, growing cycle, yield, cultivation area, seed lot number, and weight.

GREEN FODDER: This is the primary use because sorghum plants have a high capacity to regrow and can survive several cuttings. You can make the first cut 7–8 weeks after sowing (under proper irrigation conditions) once the plant reaches 60–80 cm in height. Overall, you can make four to six cuts at a rate of one cut every 3 weeks (1 cut/month at the start and end of the cycle and 1 cut/15 days during the vegetative cycle). After each cut, irrigate and add 100 kg/ha of ammonium nitrate (33.5% N).

Note 1

Sorghum is rich in hydrocyanic acid (HCN), which is toxic to animals. Accordingly, before using sorghum as feed, it should be exposed to the sun for 3–6 hours to destroy the toxins.

Note 2

Farmers cut according to animal needs; hence, use staggered sowing or varieties with varying maturity.

SILAGE: Sorghum plants can be ensiled. Most often, in case of surplus production, part can be kept in a silo and part used as green fodder. This technique is generally less practiced.

CUTTING AND TEDDING HAY: This technique is possible, but it is not a usual practice because, at the end of the cycle, the sorghum becomes lignified and not very digestible.

BIOMASS YIELD: In the form of green fodder, sorghum can produce up to 12 t/ha, that is, approximately 20 t/ha of dry matter. The nutritional value varies according to the vegetative stage of the plant and the mode of use (Table 2.1).

Table 2.1. Palatability, chemical analysis, and digestibility of sorghum feed.

	UFL/kg DM	MAD g/kg DM	Digestibility (%)
Green fodder	0.7	120–150	70–72
Silage	0.5–0.6	50	60–62

Harvesting should be done when the seed hardens and moisture content falls below 15%. Sorghum is very prone to sprouting on the ear in wet weather, so harvest the crop at the first opportunity. Sorghum can be harvested by hand if the fields are small. The heads are cut and left to dry before threshing on a clean drying floor. Heads dried on a drying floor should not be spread more than 20 cm deep and should be turned frequently. The ear heads are often threshed manually using wooden sticks or mallets to separate the seeds. Tractor wheels or metal-disc threshers can also be employed. Winnowing against wind separates the glumes and ear-head chaff. Large areas are harvested using combined harvesters. This method is particularly suitable for the more uniform and short-statured cultivars.

3. PEARL MILLET (*Pennisetum glaucum* L.)

3.1 Introduction

Pearl millet grows on 28 million hectares and about 32 million metric tons are harvested annually worldwide. Pearl millet is a major warm-season cereal in the semi-arid regions of Africa and South Asia. In the developing countries of these regions, the crops are essential components of low-resource agriculture and are primarily grown for food. Pearl millet is a highly nutritious cereal with a protein content surpassing 10%. Its amino acid profile is better than that of maize and sorghum. Its mineral content is also high. Pearl millet is also valued as feed and forage crop. Pearl millet is highly tolerant of drought and heat and is moderately tolerant of soil salinity.

Pearl millet is a good forage because of its high leaf-to-stem ratio and high yield potential. It can reach a height of more than 4 m at full maturity. Pearl millet will regrow after cutting or grazing and can be used in a multiple-harvest scenario. Pearl millet is a drought-tolerant crop and grows well in light or sandy soils. Although moderately tolerant of saline soils, it does not survive in standing water. With a changing climate, the introduction of drought- and salt-tolerant crops in affected areas has become a priority to ensure food security and boost agricultural productivity.

Pearl millet (*Pennisetum glaucum* L.) is a tropical cereal crop and it is one of the most important cereal crops in the world. It is ranked as the sixth major crop globally after rice, wheat, maize, barley, and sorghum in terms of planted area. Pearl millet is an annual highly tillering C4 plant that can reach 1-4 m in height, with a 1–3-cm stem diameter (Fig. 3.1). The leaves are lance-like, with a length of 20 to 100 cm and a width of 5 to 50 mm. The plant has a cylindrical spike, often called a panicle, 15–140 cm in length. The seed size is 2 to 5 mm, with a large variability according to the variety. Several commercial cultivars are available on the market in many countries.

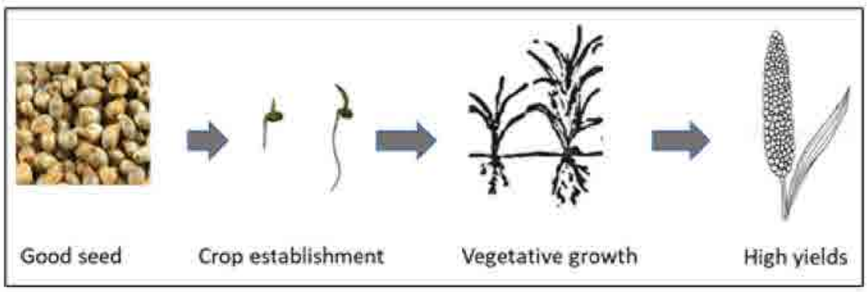

Fig. 3.1. Pearl millet growth cycle using improved crop management practices.

THE ECONOMIC IMPORTANCE OF PEARL MILLET

FOOD: Pearl millet is an important part of the diets of people living in dry areas. Pearl millet provides 353 kcal of energy, 67.5 g of carbohydrate, 11 g of protein, 5.4 g of fat, and 12 g of fiber per 100 g of seed. It is also a good source of vitamins, bioactive compounds, amino acids, and micronutrients such as calcium, iron, iodine, and zinc. Research has shown that pearl millet consumption per capita per day is about 2-19 kg per year in areas where the crop is widely used.

SUPPORTING HEALTHY EATING: Pearl millet is gluten free and a good substitute for wheat. It has been recommended for people with diabetes and cancer. Similarly, problems such as cardiovascular diseases, anemia, and calcium deficiencies can be resolved with the consumption of pearl millet-based foods.

BEVERAGES: Malting Pearl millet is used in the production of beer and other non-alcoholic beverages. Malt is important in the production of Pearl millet beer.

CLIMATE-HARDY CROP: Pearl millet is tolerant of extreme and unfavorable weather conditions such as low rainfall and high temperature.

PEARL MILLET DEVELOPMENT STAGES:

Three growth phases making up a total of ten stages have been described for pearl millet. Phase 1 includes emergence, 3- and 5-leaf stages, and panicle initiation. The second phase combines flag-leaf development, booting, and half-bloom stages. Phase 3 is made up of the milk, dough, and black layer stages of pearl millet development (Fig. 3.2).

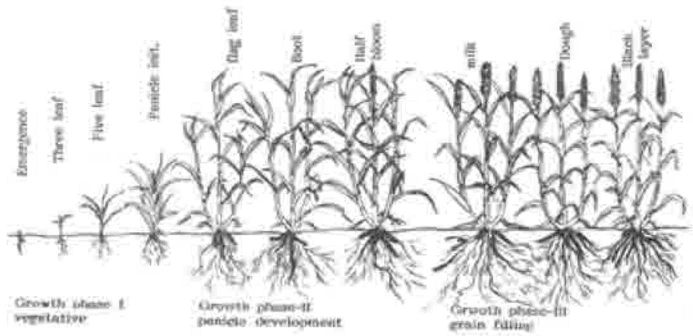

Fig. 3.2. Detailed illustration of pearl millet growth and development stages. Sources: Maiti and Bidinger (1981); Powers et al. (1980).

3.2 Crop requirements

SOIL REQUIREMENTS: Pearl millet can grow in a wide range of soils. The highest yields are usually obtained on fertile, well-drained loamy soils. Indeed, pearl millet can grow successfully on clay, clay loam, or sandy loam soils. The optimum soil pH is 5.5-6.5, but pearl millet tolerates acidic soils with a pH of 4 and those high in aluminum content.

WEATHER CONDITIONS: Pearl millet can grow in areas receiving less than 600 mm of rain. This makes pearl millet one of the most drought-tolerant cereal crops. Pearl millet is also a warm-weather crop that grows best at a temperature ranging from 20 to 28 °C. This crop can tolerate higher temperatures than other major cereal crops. However, poor emergence and seedling growth may result if the crop is planted in soil with temperatures lower than 20 °C.

Pearl millet is tolerant of drought due to its well-developed roots (which can reach 3.6 m in depth) and specialized cell walls that prevent desiccation. In contrast, it cannot tolerate waterlogging (see the section on Land preparation for barley).

3.3 Crop management

LAND PREPARATION: Land preparation can be started by the end of the dry season. Sowing can be timed to coincide with the onset of rains. The field should be ploughed once or twice, followed by harrowing to make a good soil tilth. Appropriate use of tillage equipment is recommended to avoid soil compaction. A consolidated horizon with loosened and aerated soil at depth will allow for good root development.

PLANT POPULATION: The recommended number of plants per hectare for pearl millet, under normal conditions, is about 180,000. Under irrigation or improved management and on very productive soils, a population of 225,000 plants/ha can be targeted. On soils that are sandy and dry, a population of about 90,000 plants/ha is deemed suitable. For a better estimation, the formula presented in Chapter 1 (Seed rates) can be used to determine the seed rate. Sowing density and distribution can be as follows:

- ✓ Sowing density: 6–10 kg of seeds/ha.
- ✓ Interrow spacing: 75–90 cm; in-row spacing: 15–20 cm.
- ✓ Sowing at 2–3 cm deep.

Pearl millet can also be broadcast and rolled or packed to gain seed-to-soil contact. This can be done with rotary-hoe-type tools. In rainfed systems, sowing can be conducted at the onset of rains. When irrigation infrastructure is available, sowing during the dry season is an option.

WATER MANAGEMENT: An annual water requirement of 450 to 650 mm has been used as a general guide for pearl millet production. During mid-season water shortage, irrigation can be used to supplement the crop water needs throughout the growing season. Irrigation during the bloom and soft-dough stages has been found to be beneficial because of the critical crop water need that occurs during these phases. Pearl millet is generally better suited than most other crops to dry and less fertile soils and is more drought-tolerant than crops such as sorghum. A deep root system makes pearl millet tolerant of short-term drought.

IRRIGATION METHODS: For small areas, it is advisable to use drip irrigation. Sprinkler irrigation is not recommended for pearl millet. Surface irrigation (furrows) and submersion irrigation are also not recommended as they consume much water. The use of saline water (≤7 dS/m) has almost no adverse effect on the crop.

FERTILIZATION: As a general guide, application of 100 kg/ha N and up to 60 kg/ha P_2O_5 is recommended for pearl millet. Also recommended is 50 kg/ha N in the ratoon crop after each cut. To avoid micronutrient deficiencies (e.g., in zinc-deficient soils), the application of 10 kg/ha $ZnSO_4$ is recommended.

- Split application of nitrogen in three proportions is recommended during the moist periods of the season. Otherwise, nitrogen could be lost to the environment through vaporization or leaching from sandy-loam and sandy soils following heavy rains. Thus, only a fraction of the recommended rate of nitrogen should be applied before sowing.

- Pearl millet seeds are sensitive to fertilizer burn. Applying fertilizer in furrows in contact with the seed or very close to the seed is not recommended

WEEDS, PESTS, AND DISEASES: Chemical weed control can be used with herbicides through the pre-emergence application of atrazine at 0.5 kg/ha. However, two hoe-weedings at 15 and 30 days after sowing are sufficient for controlling weeds effectively. Another manual weeding during the season helps conserve soil moisture.

3.4 Harvest, postharvest, and forage storage

GREEN BIOMASS: Fresh pearl millet is often used in the form of hay, silage and grazed.

Hay: Cut at the early boot stage for faster drying and leave a short, 20-cm height for optimal regrowth.

Silage: Cut at the boot stage and leave a short spike of 20 cm if you plan to make multiple cuts. Cut in the middle of the dough if you are planning to harvest one time.

Grazing: Start when the plants are still vegetative and graze to a height of 15 cm to allow regrowth before the next grazing. Use a rotation system to achieve the best in-season use by livestock or allow grazing for growing in fall and winter.

Pearl millet is susceptible to sprouting in the ear and harvest should not be delayed if the weather is likely to be unfavorable. Larger fields can be harvested by combines. Combines must be adjusted to properly thresh the small seed of pearl millet. For smaller areas, hand harvesting is common.

Anti-nutritional factors: Pearl millet that is stressed to the point of stunted growth or plants that were fertilized with high rates of nitrogen can cause nitrate accumulation at the plant's base and these plants should not be grazed or adopted during these stressful periods.

There are no concerns about hydrocyanic acid with pearl millet.

DRY BIOMASS: Dry matter (DM) yields are approximately 20 t/ha but can be as high as 40 t/ha under ideal conditions. The grain harvest can occur at physiological maturity when the grains are sufficiently rigid and contain about 20% water. Threshed grain should be clean and sun-dried to decrease grain moisture content to 12–14% for safe storage. Under wet-season conditions or irrigated conditions in the dry season, grain yield can reach 5 t/ha.

YIELD UNDER HIGH SALINITY: With salt-tolerant genotypes selected by ICBA, under a multi-cut system with saline irrigation water, a maximum DM yield of 43.4 t/ha was obtained at low salinity (5 dS/m) and 26.8 t/ha at high salinity (15 dS/m).

NUTRITIONAL VALUE: Pearl millet is regarded as a high-quality feed. It is high in protein and energy and low in fiber and lignin concentration. Crude protein can range from 9% to 11% in unfertilized soils and from 14% to 15% under nitrogen-fertilized conditions. The fresh forage is fairly well digested by ruminants, with dry matter digestibility (DMD) being 66–69%. In pearl millet silage, crude protein content is low (4–10%) because of protein losses and the rumen degradable fiber fraction is also low.

4. SUGAR BEET (*Beta vulgaris* L.)

4.1 Introduction

Sugar beet (*Beta vulgaris* L.), a crop of temperate regions, is spreading to subtropical countries in which it can be grown successfully during the wet season. Its growth period is about half of that of sugarcane, but it has a higher productivity per unit time and requires less water. It is a biennial herbaceous plant from the Amaranthaceae family. The origin of sugar beet is the temperate zone of Europe. It is believed to have originated from a cross between beet and white beet and was probably first cultivated in Germany. Forage beets were cultivated across Europe, at least from the mid-1500s primarily as fodder for livestock, but were also consumed by humans, especially during food shortages.

A glomerulus has one or more seeds, depending on the beet variety. The leaves are well developed and numerous, which form during the first year in the shape of a leaf "bouquet."

Fodder beet is considered a more drought-tolerant root crop and is less sensitive to weather fluctuations. Fodder beet is an excellent alternative to grains in regions where grain or silage yields are uncertain because of seasonal weather fluctuations.

It is more economical for farmers who have just a few animals to cultivate fodder beet than to build a silo for grain or silage storage.

Fodder beet is a highly cross-pollinated crop. The plant has the following:

- ✓ Taproot, very developed, rich in sugar (energy).
- ✓ Stem fairly long, relatively thin, appears during the second year of vegetation.
- ✓ Inflorescences gathered in glomeruli at the top of the stem.

Production starts with seeding and market-ready sugar beet is harvested at maturity (Fig. 4.1).

Fig. 4.1. Illustration of sugar beet growth stages from seeding to maturity.

4.2 Crop requirements

SOIL REQUIREMENTS: Soil: deep and rich in organic matter. Field preparation: For healthy and good root production, fodder beets need fine, deeply ploughed, and well-drained soil free from clumps or rocks. Prepare the soil for a period before planting if possible.

A soil pH of from 6 to 8 is needed; if your soil tests show lower than pH 6, apply lime to reach pH 7.

WEATHER CONDITIONS: Fodder beet is productive and is a high-yielding crop grown under temperate climates. It is a water-demanding plant and can be grown in dry regions/seasons that receive more than 500 mm of rain per year. Otherwise, it could be cultivated using irrigation water. Sugar beet is not sensitive to cold.

CROP CULTIVATION AND MANAGEMENT: Considering that fodder beet is a root crop, the soil should be well drained with no subsoil compaction. Indeed, a fine tilth is required, which can be achieved by deep ploughing (ploughed twice to a depth of 30 to 40 cm), followed by two harrowings.

(See Soil Preparation in Chapter 1.)

4.3 Sowing

Varied choices can be made according to the richness of the root in dry matter and, above all, its ease of being pulled out (harvested). Farmers should also use salt- or drought-tolerant varieties for saline areas and dry seasons.

(See How to measure plant populations in Chapter 1.)

SOWING DENSITY: Seeding rate: 60,000 to 80,000 plants/ha. Sowing is done in rows 30 to 40 cm apart at a depth of about 2 cm. For an even distribution of seeds on the line, precision seeders are used on large farms, with one seed every 30 cm. Plant emergence is influenced by soil temperature, moisture, and aeration, plus physical impedance from the soil. Physical impedance relates to the distance seedlings move through the soil to emerge and the soil structure that the seedlings have to move within. Therefore, it is imperative to sow seeds at the optimum depth to achieve a good percentage of emergence.

SOWING TIME: Wet season: Sowing can be performed at the beginning of the wet season (early March to April) for West African countries and in early November for Mozambique, Namibia, and Botswana (see Cropping Calendar in the Annex). Dry season (with irrigation): Sowing can be done after the harvest of wet-season crops and land preparation.

4.4 Maintenance and weed control

Severe weed infestations in sugar beet crops can decrease yield by more than 50% unless a good control plan is used. Chemical weed control is beneficial. Also, manual weeding is necessary at the same time to complete thinning and then transplanting removed parts to replace missing parts.

IRRIGATION: Sugar beet is a water-demanding crop. Irrigation should be used to grow it in dry areas or during a dry season with rainfall less than 500 mm.

FERTILIZATION: Chemical fertilizer and compost requirements for sugar beet:

- ✓ 20 to 30 t/ha of manure in sandy areas.
- ✓ 80 to 100 kg/ha of P2O5.
- ✓ 50 to 60 kg/ha of K2O.
- ✓ 100 to 120 U/ha of N in two "cover" fractions at 30 and 50 days after sowing.
- ✓ Approximately 20 kg of borax (Bo).
- ✓ Zinc (according to need).

4.5 Harvest, postharvest, and forage storage

Yields of 50–75 t/ha of fresh roots are expected and up to 100 t/ha of fresh roots can be obtained by using improved technology. The crop also produces 10–20 t/ha of leaf material that can be used as green fodder. The sugar beet's root has a high nutritional value and is well accepted by animals, especially cows. Fodder beet is harvested when well developed, which results in excellent dry-season greens, which significantly improve animal milk production.

NUTRITIONAL VALUE: Fodder beets are mainly an energy feed because of their high content of water-soluble carbohydrates (55% to 70% DM, mostly sucrose). The DM contains about 20% NDF and crude fiber content is relatively low (5–8% DM). Protein content is also low at 6–10%. Metabolizable energy (ME) is 13.5 MJ/kg of dry matter. Cleaned roots and leaves can be fed directly to animals at the rate of 10–15 kg/animal/day (3–5 kg DM) with other green or dry fodder. The leaves contain a large amount of oxalic acid (calcium oxalates) and should not be fed in large quantities to livestock. However, oxalic acid content in roots varies from 3.0 to 6.0 g/kg DM, far below the 100 g/kg content that is considered dangerous.

STORAGE METHOD: Storage of the roots in fields is possible when needed, with conservation on-site throughout the dry season.

5. BLUE PANIC GRASS
(*Panicum antidotale* Retz)

5.1 Introduction

Panicum antidotale is commonly known as blue panic grass or blue panicum. Blue panic is a vigorous tufted perennial grass reaching up to 3 m (Fig. 5.1). It is deeply rooted and develops from short, thick, and somewhat bulbous rhizomes. Its stems are erect, rigid, almost woody, and swollen at the base, looking like sugarcane stems. The leaves are smooth and bluish (hence the name blue panic). The sheaths are 4–8 cm long and glabrous. The inflorescence is a 13–30-cm-long panicle with 3-mm-long spikelets borne on 2.5-mm-long woody stalks. *Panicum antidotale* is used for fodder and grain production. Several commercial varieties are available in the market.

Crop requirements

SOIL REQUIREMENTS: Blue panicum requires more fertile soil than many other grasses for higher yield. It prefers heavy loams or dark clay soils rich in limestone and does not grow well in acid sandy soils with low organic matter content.

WEATHER CONDITIONS: Blue panicum originated from the Indian subcontinent and West Asia and is adapted to tropical, subtropical, and arid regions with appropriate management. Blue panic is a summer grass that benefits from seasonal rains. It grows in several areas such as open fields, irrigated areas, field borders, sandy dunes, dry riverbeds, and disturbed areas such as wastelands and flooded areas. It is susceptible to frost but can survive mild winters, often retaining a greenish color during this period.

Fig. 5.1. Blue panic grass.

SOWING: Blue panicum can grow where rainfall is less than 130 mm/year. It is a drought- and salt-tolerant crop (up to 10 dS/m) even though it can grow with EC up to 15 dS/m. It is mildly tolerant of temporary flooding. Blue panicum can grow in saline, alkaline, and black cracking clay soils. However, it grows better in fertile heavy loams or dark clay soils. In a sandy soil such as those found in UAE, blue panicum requires organic manure incorporation. The addition of organic or animal manure will improve soil fertility and water retention capacity. Blue panicum is a full-sunlight grass and can tolerate partial shading. It is fire-resistant. A fine seedbed is preferable, either from mechanical preparation or harrowing or by scrub burning and sowing in the ashes. Higher yield is achievable with good crop management practices (Fig. 5.2).

Eight (8) growth stages of Blue panic

Bales at Harvesting

Fig. 5.2. Diagram illustrating the production stages and baling of blue panicum grass

Blue panicum can be sown alone or intercropped with buffelgrass (*Cenchrus ciliaris*) or Guinea grass (*Megathyrsus maximus*) in pastures.

SOWING TIME AND DENSITY: Blue panicum can be propagated by seed (drilled in rows or broadcast). It can be sown in rows with 50 or 100 cm between rows. It is recommended to sow just before the expected rainy season and use 5–6 kg/ha for broadcast sowing or 2 kg/ha if the seeds are placed in rows at 50-cm distance. If the rows have a distance of 100 cm, it is recommended to use 1 kg/ha of seed.

After sowing, cover the seeds with a maximum of 1-cm-deep soil. When seeds are broadcast, it is recommended to sow them on the surface and, if possible, provide a light cover..

SEEDLING VIGOR: Seeds germinate well, but plant development is slow for the first 6 to 8 weeks.

CROP MANAGEMENT (RAINFED): If the system to produce seed and forage is based on rainfed conditions, it is recommended that the seeds should be drilled in rows with a distance of 50–100 cm or the seeds can be broadcast before the rainy season.

Grass development is relatively slow during the first 6 to 8 weeks, but it becomes brisk once the plants are well established. As blue panic may become woody with maturity, it is recommended that grazing be done at the right time to maintain the crop's nutritive value.

DRIP IRRIGATION: Blue panicum can be grown in sandy or loamy soils. In sandy soils with low organic matter, it is recommended to incorporate 20–30 t/ha of compost (dry and decomposed animal manure). If water is a limiting factor, it is recommended that irrigation provide 300 mm of water. The water requirement can vary according to the season and period for forage production. If the water is saline (10 to 15 dS/m), an additional quantity should be applied as a leaching fraction to avoid salinity buildup in the soil (Fig. 5.3).

Fig. 5.3. Manual sowing under drip irrigation system in a conditioned sandy soil (left). After cutting and re-emerging, blue panic in a drip irrigation system plot (right) in Dubai, UAE.

IRRIGATION: Blue panicum is a best-adapted grass in areas with annual precipitation of 500–700 mm or on irrigated land. It can grow in areas with less than 130 mm of rain, such as in the southern Altiplano of Bolivia. Irrigation with saline water (up to 15 dS/m) can be another option.

FERTILIZATION: The following fertilizer doses should be applied to obtain optimum yield of blue panic:

- ✓ 30 kg/ha of P_2O_5 (phosphate, P fertilizer such as DAP, 46% P_2O_5, but 42% water-soluble that is easily available to the plant) applied as a basal dose and
- ✓ 20 kg/ha of N (nitrogen in the form of urea) after each cut to improve forage production.

Blue panicum field preparation also needs to incorporate organic matter to enrich poor soil with manure at 20 to 30 t/ha (based on local livestock goat, sheep, poultry). Blue panicum requires more fertile soil than buffelgrass to obtain high productivity. It prefers heavy loam soils and does not grow well on acidic sandy soils with low organic matter. Blue panicum responds significantly to N fertilizer. On the other hand, P and K fertilizer are needed according to soil composition. It is recommended to apply 30 kg N + 30 kg P2O5 + 20 kg K per hectare to increase forage yield. In poor sandy soil, these recommendations can enhance yield by 270%.

5.3 Weeds, pests, and diseases: responses to defoliation

The blue panic plant is resistant to fire and has no significant diseases and pests. By cutting more frequently in a multi-cut system, weeds can be well controlled; manual weeding can also provide benefit (Fig. 5.4).

Fig. 5.4. Manual weeding in a blue panic plot under drip irrigation in sandy soils in Dubai, UAE.

5.4 Harvest, postharvest, and forage storage

BIOMASS YIELD: Blue panicum can yield 10-50 t/ha of fresh biomass. Hay yields vary from 2.5 to 6.0 t/ha under rainfed conditions to almost 5.0 t/ha under irrigation (Fig. 5.5).

Fig. 5.5. Close-up of blue panic plants ready for harvesting (left); in this situation, a manual cut of plant leaves is recommended because of drip irrigation and to avoid damaging pipes. The cultivation of the plot is for green biomass and seed production (right). The plot has sandy soil and is irrigated with saline water (15 dS/m).

Blue panicum cannot withstand heavy, close grazing. It needs to be cut and used before seed formation stage because, at the flowering stage, the lignin and cellulose content in the stems increase and it becomes hard and woody and less useful for animal feeding.

It is recommended to cut the crop at 20-day intervals in the wet season, at a height of 10 cm from the soil, and at 30-day intervals to a height of 15 cm during the rest of the year.

PALATABILITY: Young plants up to the flowering stage are quite palatable and become less edible as the stems become coarser. This tropical grass is well adapted to arid and hot climates and provides an alternative source of green forage to livestock in dry regions worldwide.

5.5 Other considerations

Blue panic is a salt-tolerant grass that can be grown in marginal lands with salinity problems. Some of its accessions have been cultivated on salt-affected soil and have proven their performance. It is recommended as a forage for irrigated pastures that receive moderately saline subsoil water (5 to 10 dS/m). Based on seed and forage yields, blue panic grass is more resistant to high salinity than other range grasses such as Guinea grass (Megathyrsus maximus). Since blue panic is a tall, coarse, woody perennial grass, it can be used as a windbreak. Planting it at the correct angle decreases wind speed to stop soil erosion, especially in arid regions.

6. BUFFELGRASS (*Cenchrus ciliaris* L.)

6.1 Introduction

This grass is known as buffelgrass (Australia), African foxtail (U.S., Kenya), dhaman grass, anjan grass, and koluk katai (India). The natural range of *C. ciliaris* is the hotter and drier parts of South and West Asia, the Mediterranean region, Central and southern Africa, and Australia. This saline-tolerant grass has been introduced into many areas where soils are affected by salinity.

Fig. 6.1. Buffelgrass at full flowering, insert are buffelgrass seeds.

Buffelgrass is a perennial grass growing to 20 to 120 cm tall. The leaves are linear, 3 to 25 cm long and 4 to 10 mm wide. The flowers are produced in a panicle 2 to 14 cm long and 1.0 to 2.6 cm wide.
The grass is cultivated to produce green and dry forage. Saline water (up to 10 dS/m) can be used for irrigation to grow this highly drought- and heat-tolerant plant. Both vegetative and seed propagation methods are used for its cultivation.

6.2 Crop requirements

SOIL REQUIREMENTS: Buffelgrass can grow in lighter textured soils with a high phosphorus content. Its establishment on black cracked soil is slow, but it does well once established.

- ✓ The optimum soil pH is 7 to 8. However, buffelgrass can grow on soil with low pH of approximately 5.5.
- ✓ High content of aluminium in the soil can affect the growth of buffelgrass.

Although buffelgrass grows well on sandy soils, it can be well adapted to a wide range of other soils. It establishes slowly on hard and heavy clay soils but, once established, it grows well there too.

WEATHER CONDITIONS: Buffelgrass is a short-day plant that can grow under

- ✓ Average annual temperature from 12 to 28 oC.
- ✓ The optimal temperature for growth is 35 oC and the minimum is from 5 to 16 oC.

PLANTING: Buffelgrass can be grown on well-prepared soil, very fine seedbeds, or hard-setting soil. On well-prepared seedbeds, the seed is broadcast on the surface and covered by soil to a maximum depth of 1 cm by light harrows. It can also be sown using a grass air-seeder, modified fertilizer spreader, or combine.

Mixing with fertilizer or cracked grain or using pelleted seed improves distribution through air-seeders and combines. Buffelgrass germination relies on adequate soil moisture after planting. The seed must maintain contact with wet soil for 4-5 days to produce a seedling. In dry areas, supplementary irrigation may be required. Buffelgrass can also be propagated vegetatively from "splits." For row planting, the row-to-row and plant-to-plant distance should be 50 cm.

WATER REQUIREMENT: Buffelgrass is one of the most drought-tolerant grasses found in regions with rainfall as low as 100 mm per year. Meanwhile, irrigation increases its production tremendously. In arid environments, irrigation requirements can vary from 1,800 to 2,500 mm per year depending on weather conditions (evapotranspiration) and soil texture.

DRIP IRRIGATION: A drip irrigation system can be used to grow buffelgrass. For that method, the distance between rows should be 1 m and between plants 0.5-1.0 m. In the case of saline water (about 15 dS/m), irrigation scheduling can be similar in loamy clay soils; whereas, for sandy soils, the irrigation water requirement can be more as those soils have less water-holding capacity. The irrigation water requirement can be more as those soils have less water-holding capacity.

FERTILIZATION: Buffelgrass requires immense fertilization, particularly for nitrogen, phosphorus, and calcium, to reach potential yield. Yield can increase 10-fold or more with N fertilizer

✓ usually at rates of 100–200 kg/ha of urea. If available phosphorus is low, phosphate should be applied at sowing at a rate of 50–150 kg/ha

WEEDS, PESTS, AND DISEASES: The most severe disease is blight caused by the fungus *Magnaporthe grisea*. Other fungal species causing damage are *Fusarium oxysporum*, *Bipolaris* sp., and *Claviceps* sp. Seed crops can be damaged by buffelgrass seed caterpillars (*Mampava rhodoneura*) that feed on seed, webbing the heads together.

6.3 Harvest, postharvest, and forage storage

BIOMASS YIELD: Green (fresh forage) production and dry biomass (Fig. 6.2) depend on available water sources. If the buffelgrass plot was irrigated with freshwater, a high amount of fresh biomass could be obtained. In contrast, using a saline water source, a yield decline can be expected.

Fig. 6.2. Mixing of dry mowed grass grown with saline irrigation. Bales are packed with many kinds of grasses and the grass is easy to store. Every year, this activity is carried out with many grass blades at the Experimental Station of ICBA, Dubai, UAE. It is recommended to cut for fresh forage before the beginning of flowering (Fig. 6.3). If the grass is cut at physiological maturity, the quality of the forage will not be good. Cutting can be done with a sickle if drip irrigation is used. If the plot is under rainfed conditions, grass cutting can be mechanized and the grass mixed with other grasses when making bales.

SEED YIELD AND PACKAGING: During physiological maturity, the seeds of buffelgrass are dispersed. Thus, propagation is easy when the soil has an adequate amount of moisture. The panicle shape of buffelgrass is like the tail of a fox. In small plots, seeds can be harvested manually by stripping mature panicles into paper bags. For a good harvest, the panicles need to be covered with bags before seed maturity.

To collect seeds, the panicles can be placed on a piece of plywood lined with corrugated rubber floor matting, and a rubbing board also covered with corrugated rubber moved back and forth across the seed heads. The threshed seed usually contains trash, which can be removed by winnowing or using air/screen cleaners.

Fig. 6.3. Close-up of manual cutting of fresh biomass with a sickle (left). As the plants are irrigated with dripper pipes, a manual cut is required to avoid damaging the pipes. The seeds are harvested when the spikes are soft and have a "small foxtail shape." They are easy to collect and save in paper bags. These buffelgrass plots are at the Experimental Station of ICBA, Dubai, UAE.

Depending on growing conditions and variety, seed yields range from 10 to 60 kg/ha. Freshly collected seed often has a high level of dormancy. The germination rate can be improved with storage of 6-18 months after harvest. Total viable seed content is usually 30–50%.

PALATABILITY: Buffelgrass is a highly nutritious grass because of its green and dry biomass quality. It is reported that feeding and using buffelgrass can enhance the milk production of minor livestock. The nutritional benefits from buffelgrass include high dry matter (4.5%), crude protein (8.3%), and fiber (NDF = 69.6% and ADF = 49.9%) contents (García Dessommes et al. 2003).

6.4 Environmental considerations

USE IN SALINE SOILS: It is recommended to grow buffelgrass particularly in sandy soils affected by salinity. Once established, buffelgrass is an alternative forage for small farmers in arid regions. In addition, in clay and loamy clay soil with pH of 7 to 8, this grass can tolerate up to 10 dS/m of salinity for good production and can grow under up to 25 dS/m as well. With low rainfall, it is a source of fodder for minor livestock.

SOIL EROSION CONTROL: Buffelgrass propagation is easy in soil with lower moisture content. It has a deep, robust fibrous root system up to 2.0 m in length that stabilizes the soil. Once established, the grass can cover the ground and protect the soil from wind and water erosion.

AGROFORESTRY: Buffelgrass grows in deserts as in the Arabian Peninsula countries, particularly in the United Arab Emirates. This grass can survive harsh arid conditions and can be combined with trees, including Prosopis cineraria and Acacia ampliceps, to establish an agroforestry system in marginal lands.

7. COWPEA (*Vigna unguiculata* (L.) Walp.)

7.1 Introduction

Globally, about 9 million metric tons of cowpea are produced from a cultivated area of about 14 million hectares in a year. Cowpea is mainly cultivated for its food and feed value, especially in mixed crop-livestock systems (Fig. 7.1). Breeding programs have also developed cowpea varieties that can be used as a vegetables and browse for livestock. Cowpea stands out from other legumes because of its hardy characteristics that enable production in areas with lower than 400 mm of rainfall annually. However, both abiotic and biotic stress factors affect the yield of cowpea worldwide.

Cowpea (*Vigna unguiculata*) belongs to the family Fabaceae (Leguminosae). Three groups (cultivated, wild, and weedy) with genetic variations have been studied in cowpea. Of these, the wild relative (*Vigna unguiculata* var. spontanea) has shown higher genetic diversity than cultivated cowpea.

Fig. 7.1 Cowpea leaves and seed are good sources of proteins for humans and livestock

CULTIVATED COWPEA: Cultivated cowpeas within the *V. unguiculata* subspecies *Unguiculata* classification are commonly divided into four groups of cultivars: *Biflora, Sesquipedalis, Textilis,* and *Unguiculata*. The *Sesquipedalis* group develops long pods, which are used as vegetables, while the biflora group is used to produce pods and dry seeds.

CENTER OF ORIGIN: Cowpea's center of diversity has been identified as West Africa. Although the crop has wild relatives spread across the whole African region, with some high-diversity spots in southern Africa, the greatest diversity is found in the savannas of West Africa. Regions around Benin, Cameroon, Ghana, Niger, Nigeria, and Togo have been suggested as leading candidates. Its domestication could have started anywhere on the African continent.

THE ECONOMIC IMPORTANCE OF COWPEA

Cowpea is a leguminous crop of high economic importance. The whole crop has valuable uses. The leaves are protein rich and good vegetables. Fresh pods and dry seed contain more than 23% protein. The stems and leaves make high-nutrition fodder and hay for use alone or in combination with other high-roughage feed sources. Its roots are important in symbiotic relationships with both soil bacteria that help fix nitrogen in the soil.

FOOD VALUE: Cowpea is a good source of carbohydrate, protein (22-23%), thiamine (vitamin B1), riboflavin (vitamin B2), and niacin (vitamin B3). Many dishes with only cowpea and in combination with other grains are prepared for adults and children. The leaves provide a significant amount of ascorbic acid (vitamin C) and β-carotene. However, the presence of tannins, trypsin inhibitors, and flatulent sugar contained in cowpea seed lower its quality. Smoking or heat treatment decrease these compounds in the seeds.

FEED VALUE: Cowpea aerial parts can be used to support livestock production. Cowpea has been the basis of high-protein silages for smallholder dairy farms in sub-Saharan Africa. Cowpea-maize and cowpea-sorghum combinations are important sources of both protein and roughage.

Fig. 7.2 Cowpea can be used as a cover crop which can prevent wind and water erosion, reduce weed intensity and fix soil nitrogen.

SOIL IMPROVEMENT: There are three ways through which cowpea contributes to soil improvement. First, cowpea is an effective soil cover and protects the soil from direct raindrop action and dry sun baking (Fig. 7.2). Second, cowpea's non-grain biomass contributes to building soil organic matter, which is central to soil fertility management. Third, and most important, cowpea adds nitrogen to the soil by fixing it from the atmosphere. The indigenous bacteria (*Bradyrhizobium* spp.) found in soils infect roots of cowpea to form nodules leading to N fixation.

7.2 Crop requirements

SOIL REQUIREMENTS: Cowpea is a moderately salinity-tolerant crop, with a threshold of 4.9 dS/m. It is susceptible to salinity increases at the late vegetative stage and then during flowering or pod-filling stages.

Cowpea is well adapted to many areas of the humid tropics and temperate zones:

- ✓ It thrives from 20 to 35 °C, but not lower than 15 °C.
- ✓ Cowpea tolerates hot and dry conditions.
- ✓ Temperatures above 38 °C can adversely affect fertilization and pod-set.

Cowpea performs well on a wide range of soils and soil conditions but performs best on well-drained sandy loams or sandy soils where soil pH is in the range of 5.5 to 6.5. Seeds will decay if sown in cold and wet soils.

WEATHER CONDITIONS: Cowpea is cultivated for two purposes: seed and green forage for minor livestock. Cultivation varies from the tropical to subtropical, arid, semi-arid, and desert zones, preferring conditioned soil with an environmental temperature of 20 to 35 °C and optimal temperature of 20 °C. Cowpea grows under a photoperiod of 8 to 11 hours/day (long day). Cowpea can be cultivated from sea level to up to 2,500 meters. This leguminous crop can be grown in loamy clay, clay, and sandy soils. It shows good adaptation to diurnal temperature differences and it produces a decent amount of green biomass and seed.

SOWING: Select fields where cowpea was not grown in the previous season. The fields should be prepared well by deep ploughing and one or two harrowings, followed by leveling. Cowpea emergence can be adversely affected by soil crusting.

✓ The optimum distance between planting rows is 45-60 cm.

✓ The optimum distance between plants within a row is 25 cm.

✓ Seed should be planted at a depth of 3-5 cm.

For climbing and prostrate cultivars, seed should be sown in rows 75 cm apart, with approximately 15 cm between plants. Climbing types require the support of a 2-m-high stick. The recommended seed rate is 20 to 25 kg/ha for climbing and prostrate varieties and 45 to 50 kg/ha for plants with a small canopy.

CROP CULTIVATION (RAINFED): In clay soil with remnant water moisture, cowpea seeds can be sown at 3-5-cm depth with rows 50 cm apart and 25-cm distance between plants. If the soil moisture is 40%, this can help in seed germination and emergence. It is recommended to maintain this moisture for 1 week to obtain good results. Thus, it is advised to sow the plot during the onset of rains in certain regions as cowpea is a long-season crop (4 to 6 months). Rainfall of 500-800 mm during the crop growth cycle is adequate to obtain optimum seed and forage yield.

IRRIGATION: For cowpea cultivation using a drip irrigation system, the recommended distance between pipes is 50 cm, while it is 25 cm among drippers. If there is saline water for irrigation, up to 10 dS/m of salinity is recommended. Although 15 dS/m is the maximum salinity for cowpea, biomass yield will decrease by 50% vis-à-vis freshwater irrigation.

FLOWERING AND POD FORMATION: The most critical watering period is before and during flowering and pod formation. Also, ensuring that the crop is not over-irrigated is critical, as this will adversely affect plant growth by lowering soil temperature. The water requirement varies from 300 to 500 mm depending on climatic conditions and the length of the growing cycle.

FERTILIZATION: A soil analysis is the best option to determine how much and what types of nutrients need to be supplied for a specific site. The cowpea plant performs well under low-nitrogen conditions as it can fix nitrogen by itself. Sometimes, a nitrogen rate of 30 kg/ha is required for early plant development in low-N soils. Excess nitrogen promotes lush vegetative growth, delays maturity, decreases seed yield, and may even suppress nitrogen fixation.

It is recommended to use

✓ 30 kg/ha of phosphorus and

✓ 45 kg/ha of potassium on soils of medium fertility.

Place fertilizer 10 cm deep and 5 cm away from the seed or broadcast and disc in all fertilizer, including nitrogen, before planting.

WEEDS, PESTS, AND DISEASES: Adequate weed control is necessary for high yield and income. One or two hand-hoe operations followed by timely cultivation should be done when no herbicides are used.

Diseases: *Root rot, Southern blight*, and *Fusarium wilt* are the major diseases. Several viruses can attack cowpea, with the most common being cowpea mosaic. Root-knot nematodes, aphids, and weevils are important pests of cowpea. During pod formation and maturation, some cowpea cultivars can be attacked by weevils. It is recommended to check the pods and plants if there are holes in the pods.

Weevils can also attack the pods during drying and it is recommended to dry the pods in black plastic bags. The heat will kill the weevils.

7.3 Harvest, postharvest, and seed storage

Cowpea pods are ready for harvest when they turn yellowish brown and the seeds become firm depending on the variety (Fig. 7.3). Fruit formation extends over a long period. Therefore, the collecting of pods by hand is common. Depending on a cultivar's span of maturity, cowpea cultivars can be harvested (by picking) two times when necessary. It is recommended that cultivars that mature relatively uniformly be cut and left in windrows for further drying. Crops left in windrows can either be picked up with a combine or taken to a stationary thresher. Care must be taken during threshing to minimize mechanical damage to the seeds.

Fig. 7.3. Different cowpea varieties come in a range of colors and seed sizes.

For drying and storage, the seeds should contain 13% or less moisture. Drying can be done on a drying floor. The air temperature should not exceed 35 oC under artificial drying. Seed moisture should be further decreased to 8⊠10% for longer-term storage in vapor-proof containers. The seed yield of cowpea can be from 1.5 to 2.0 t/ha.

BIOMASS YIELD: Cowpea can produce from 4 to 7 t/ha of dry biomass. The direct use of fresh biomass involves cutting from growing plants and feeding to minor livestock. High biomass with tender leaves can be obtained up to flowering. During and after physiological maturity, fodder quality deteriorates as leaves and stems become hardened.

7.4 Other important considerations

Cultivation in saline soils will depend on salinity as cowpea can tolerate salinity up to12 dS/m in well-drained soil. Higher salinity can affect growth and biomass production. Seed production can be adversely affected in the case of irrigation with high-saline water. In contrast, cowpea can tolerate high temperatures. Cowpea is grown to maintain fertility and improve nitrogen in the soil. The plant has a deep root system (up to 2.4 m) that protects soil from wind and water erosion. For agroforestry systems, cowpea cultivation fits well with banana, cacao, and coffee trees to maintain moisture in the soil, improve nitrogen availability, and discourage other weeds.

8. QUINOA (*Chenopodium quinoa* Willd.)

8.1 Introduction

Quinoa production stands at about 161,000 tons annually from a cultivated area estimated to be 184,000 hectares. The current production figures are dominated by countries in South America, from where the crop originates. The crop is grown for its edible seed that contains protein, fiber, and minerals. The history of quinoa shows that the crop was first used as a livestock feed and later varieties were developed for human consumption.

Fig. 8.1. Quinoa diversity research trials at the ICBA research station, UAE.

SOWING: Quinoa (*Chenopodium quinoa* Willd.) is native to the Andes Mountains that cover parts of Bolivia, Chile, and Peru. Cultivated quinoa is an annual herb that grows from 1 to 2 m in height and matures in 3 to 6 months (Fig. 8.1). It produces seeds in large sorghum-like inflorescences. Although the seeds are very small, they comprise 30% of the dry weight of the plant.

CULTIVATED QUINOA: Cultivated quinoa (*C. quinoa*) was domesticated in the Peruvian Andes (Fig. 8.2). Wild quinoa plants (*C. quinoa* var. melanospermum) are prevalent in its center of origin.

Fig. 8.2. Cultivated varieties of quinoa exhibit a range of colors, a confirmation of the genetic diversity found in the crop.

THE ECONOMIC IMPORTANCE OF QUINOA

Quinoa is an important source of protein and carbohydrate. Its economic value has been increasing in recent years because of awareness. The seed harvested from the crop contains edible oil and is rich in other nutrients.

FOOD VALUE: Quinoa seeds can be served raw. Quinoa is a source of highly nutritious dishes. In terms of nutrition, processed quinoa seeds closely compare to milk products or other protein-rich grains. The essential amino acids, especially lysine, in quinoa are good for both human and animal health. The saponins found in the seed coat make the seeds bitter and unpalatable; hence, they need to be removed before consumption.

FEED VALUE: Aerial parts of the crop can be grown specifically to support livestock production. The energy and protein contributions of quinoa to livestock are highly valuable. The oxalic acid contents in quinoa leaves and stems prevent its consumption in large quantities.

8.2 Crop requirements

LAND PREPARATION: It is recommended to use lands where soils are wet and easy to till and plough to remove weeds, and it is much better if the area was previously cultivated. In dry areas, soil preparation must be practiced, allowing for adequate moisture. In addition, secondary tilling helps for better seedbed preparation and weed removal. Soil ploughing should be up to 30 cm in depth with a disc harrow and it is recommended to pass twice, in different directions. The soil clods need to be very small to achieve seed-soil contact considering the size of quinoa seed. The next recommended task is leveling of the ground. This can be done with a rail or plank tied behind the harrow.

SOWING: Quinoa seed sowing and seedling transplanting can be done according to the field size. Sowing in pockets and dripper lines should be done by hand, while in furrows it can be done using a tractor or with the help of draught power. Sowing in pockets is practiced when there is not enough soil moisture or no rainfall occurs. Usually practiced in the southern Altiplano (Bolivia), the distance between pockets is 1 m and several seeds (50–100) are deposited in a hole of 20–30 cm.

Furrowing helps in several cultural operations that are carried out during quinoa cultivation. It is crucial to prepare the soil considering the slope for better water distribution without eroding the soil. The distance between rows is determined according to the available agricultural machinery or animal traction equipment to be used. It could vary from 40 to 80 cm, with a depth of 15–30 cm. When the conditions are under "irrigation by gravity," the seeds should be in the ribs of the furrows at about 10 cm from the bottom.

The seed rate in lines and dripper systems should be 1.0–2.0 kg/ha (use a distance between plants of 15 cm) and 3 kg/ha when the plants are at 25-cm distance (Fig. 8.3). Three seeds should be placed in the hole at a depth of 2 cm. The distance between lines/rows should be 50 cm.

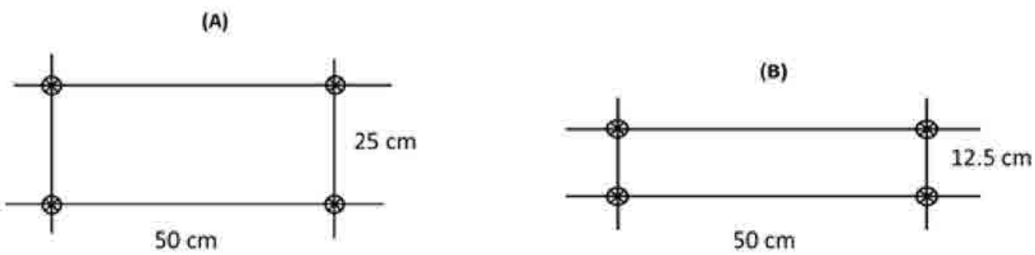

Fig. 8.3. Sowing of quinoa under rainfed conditions (left) and under drip irrigation system (right).

Sowing can be done by hand or with a seeder regulated to sow at distances of 12.5–25.0 cm. The seeds should be covered by moist sand or soil to help with germination and emergence. Under rainfed conditions, if the region receives low rainfall, the seeds should be placed at the furrow's bottom. In a high-rainfall zone, place the seeds over the furrow. For this type of manual sowing, the seeds should be placed in a continuous stream, manually with a dispenser, which can be homemade or made by a small sowing machine for vegetables.

For the drip irrigation system, place the seeds in a 2-cm-deep hole next to the dripper with moist soil. Three seeds should be deposited and slightly covered. Irrigation in this system should take place two times a day. It is recommended to cover the field after sowing with dry grass to avoid water evaporation and bird attacks.

CROP MANAGEMENT: If the sowing was direct and done with good-quality seed (high germination and emergence), this will result in a higher number of seedlings than required. Thinning of the seedlings will decrease and avoid competition for light and nutrients. This task involves removing seedlings that are close to one another to provide space for others.

Hilling, an activity done in potato plants to strengthen plants and avoid lodging, is also recommended for quinoa plants. Hilling allows the anchoring of the roots and protects the plants from falling, as quinoa plants are tall. It is recommended to do thinning and hilling when the soil moisture is optimal (field capacity). This work can be done by hand or tractor with field tools (pickaxe, shovel, harrow).

Variety purification based on plant color is an important task and should be done manually before flowering. The preferred color of the variety must be noted first. Plants of different colors should be eliminated to avoid mixing.

IRRIGATION: Quinoa grows well with a minimum rainfall of 200–250 mm/year and provides a good seed yield. Irrigation can support plant growth and development. Flooding (excess of irrigation or lack of drainage in loamy and loamy-clay soils) can affect plant growth and damage the crop.

Under 150 to 1,000 mm of rain, quinoa grows well and produces an excellent seed yield. Water demand varies by season (winter, spring, summer), soil (sandy, loamy, clay), variety (early or late), and irrigation system used. Quinoa cultivation uses three irrigation systems:

- ✓ Gravity irrigation in a furrow
- ✓ Drip irrigation
- ✓ Sprinklers

Irrigation must be applied before crop establishment. This means that soil moisture should be adequate at the time of sowing. If necessary, light irrigation could be given after sowing to help with germination and emergence. The irrigation time can be 10, 15, or 20 days depending on the soil type and climate of the region.

FERTILIZER MANAGEMENT: Quinoa requires fertilization based on nitrogen with 150 kg/ha of N and phosphate (PO_4) and potassium at a rate of 50 kg/ha to obtain good seed yield. Phosphate and potassium and half nitrogen should be applied in the soil before seeding. Then, the rest or half nitrogen can be applied during crop growth. Production of quinoa requires less fertilizer than other crops. Nevertheless, it is recommended to apply fertilizer after sowing and during crop growth.

CROP ROTATION: This activity is essential and is recommended not only for growing quinoa but also for other crops. Crop rotation helps to avoid weeds, insects, pests, and diseases. Crop rotation will improve water availability for the crop. In most cases, quinoa is cultivated after potato in the same plot. It is recommended to cultivate leguminous crops, including fava bean, pea, chickpea, and cowpea, in rotation with quinoa in the same field. The leguminous crops help in improving soil fertility by fixing nitrogen.

8.3 Weeds, pests, and diseases

WEED MANAGEMENT: Weed control must be done between branching and flowering stages. Quinoa needs two to three manual weedings (Fig. 8.4). It is advised to use well-decomposed animal manure without odor. If fresh manure is used, it could bring many seeds of weeds that will propagate unwanted plants in the field.

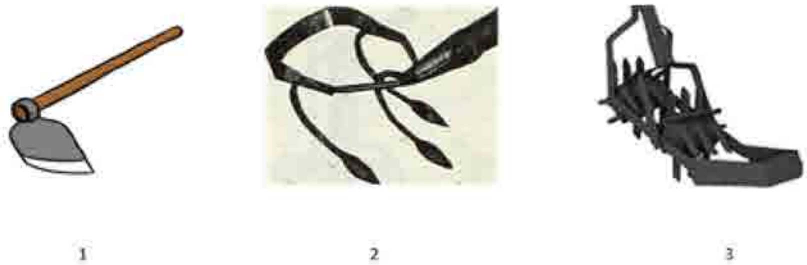

Fig. 8.4. Commonly used hand tools used in weed management on smallholder farms; (1) hand hoe, (2) hand harrow, and (3) hand weeder.

INSECT CONTROL: Pest and disease control should be carried out during the growth of quinoa. The primary pest present in quinoa recorded in some regions of Latin America such as the Altiplano or Puna (Bolivia and Peru) and the coastal region (Chile) is the larvae of *Eurysacca* sp. (quinoa moth, known locally as Kcona). In the coastal region, aphids can affect quinoa production if they are not controlled on time.

In the case of Eurysacca sp., the stage of the biological control must be kept in mind. It is recommended to control the larvae of *Eurysacca* sp., *Spodoptera* sp., *Copitarsia* sp., *Feltia* sp., and *Agrostis* sp. with products based on metabolic action such as vegetable oil to support the application and allow the product to adhere on the leaves. This application should be made when the larvae attack is strong on the panicles at the grain-filling stage (milky and pastry grain stage).

DOWNY MILDEW: The most harmful disease of quinoa is downy mildew (caused by *Peronospora variabilis*). The attack of downy mildew depends on the humidity and it is more prevalent in areas where the relative humidity surpasses 40%. In contrast, in regions such as the southern Altiplano (Bolivia), where the relative humidity is below 20%, downy mildew attack is non-existent. To control downy mildew, use a fungicide. Apply it in the branching and panicle formation stages of quinoa.

Monitor the plants after the branching stage and during panicle development. When relative humidity is high, it is recommended to assess the plants for downy mildew. There is only chemical control for a downy mildew attack in the first stages of the plant.

Sustainable management of pests and diseases is extremely important as this determines the quality of the produce from farms. Farmers use several methods to keep the pest and disease pressure low on their farm (Fig. 8.5).

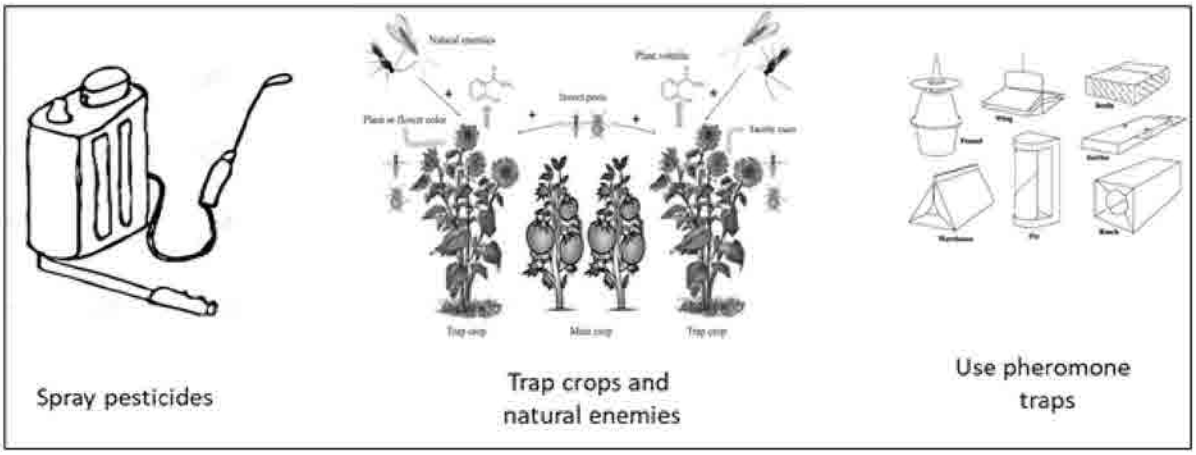

Fig. 8.5. Feld management practices for pest control on quinoa: spraying, natural enemies, and application of pheromone-based biological control traps.

8.4 Harvest, postharvest, and seed storage

MANUAL HARVESTING: Quinoa seed yield varies depending on harvest techniques. Manual harvest using a sickle can decrease seed loss, but it needs intensive labor. Where the production area is large, many labor days will be required to complete the task.

When quinoa is grown using a drip irrigation system in a smaller area, manual harvesting is recommended. If the plot has a large area, the pipes can be removed, followed by harvest with a portable disc grass cutter. This activity is recommended for the afternoon when the relative humidity will be low, around 40%.

MECHANICAL HARVESTING: New agronomic methods can boost quinoa seed yield to 1-2 t/ha vis-à-vis traditional techniques that produce 500 to 600 kg/ha. In South and North America and Europe, quinoa is harvested using large machines, or small harvester combines increase efficiency and effectiveness.

The suitable time for harvesting quinoa is at the physiological maturity stage. At this stage, leaves change from green to red, orange or yellow depending on the variety, and the panicles also change their color.

POST-HARVEST THRESHING: Threshing is done after the plants are dry and seed moisture is from 12-15 %. Threshing is done by hand using wood sticks when the number of plants is small. In case of many plants, a thresher is used.

WINNOWING: Winnowing is required to separate the seeds from the hulls. Nevertheless, if a mechanical harvester is used, the plants must be very dry to avoid crushing the seed. For a more extended period of storage, seed moisture content should be 10-13%.

Seeds can be graded according to their size (large, medium, and small). Quinoa seeds can be stored in plastic or polypropylene bags or in metallic containers to avoid insect and rodent damage.

CLEANING: Traditionally, cleaning is done manually in water. The process removes the saponin from the seed. Rubbing the seeds in water for few minutes produces foam. The amount of foam is commensurate to the amount of saponins removed from the seed. Washing can be repeated three to four times until water clears and has very little foam produced.

After drying, rubbing separates the powder from the seed. Use of mechanical methods reduces the time of processing quinoa seed. Saponin has industrial value for the soap and cosmetic industry.

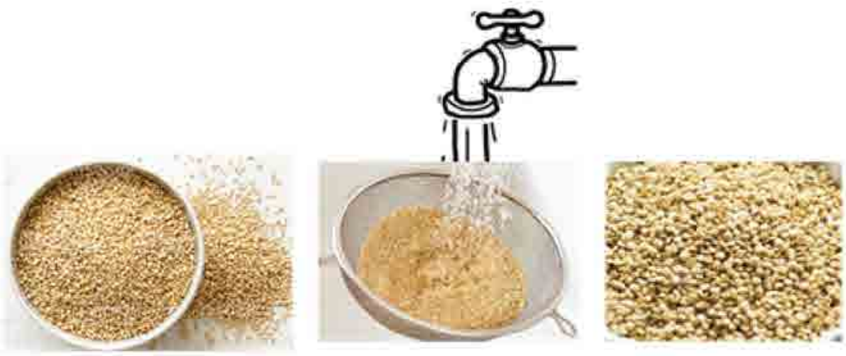

Figure 8.6 Three steps in removing saponins from Quinoa which, depending on the scale, the steps can be manual or mechanical.

8.5 Seed packaging and storage

Seed storage and conservation are important steps of the postharvest process for quinoa. Insects and rodents can damage quinoa seed when it is inappropriately packaged. The seeds can be stored at low temperature (10 °C) and low humidity for about two years. Nevertheless, if the seeds are stored for a longer time, they will lose viability. In the case of conservation for extended periods, standard genebank keep seeds with moisture content of 8%, use of aluminum bags, and storage temperature of -18 °C.

SEED STORAGE FOR COMMERCIAL PURPOSES; sealed containers, stocked in ventilated rooms, and protected from insects and rodents are important. When large seed quantities are involved, the seeds should be stored in large metallic silos at 10-13% moisture content under very clean conditions.

RETURN ON INVESTMENT

A price of between US$4 and US$5.2 per kilogram of processed quinoa reported by Rafik et al. (2021) show that the crop is acceptable to consumers and potential benefits to producers are high. Cost-benefit analysis of high yielding quinoa production scenarios showed high profitability under water managed systems, both manual and mechanized harvesting systems (Hirich et al. 2021).

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ANNEX 1: CROPPING CALENDAR FOR RESADE COUNTRIES IN SUB-SAHARAN AFRICA

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Gambia						Sowing					Harvesting	
Liberia			Land preparation	Sowing							Harvesting	
Togo (Maritime region)			Sowing					Harvesting	Sowing			Harvesting
Togo (Plateau and Northern region)					Sowing					Harvesting		
Sierra Leone												
Mozambique				Harvesting						Land preparation	Sowing	
Namibia				Harvesting							Sowing	
Botswana				Harvesting							Sowing	

	Wet season
	Dry season

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