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Agriculture for Food Security

Textbook for Class XII

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Department of Curriculum and Professional Development
Ministry of Education
Thimphu

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We would like to sincerely acknowledge the retrieval and use of ideas and pictures from various sources. We reaffirm that this book is purely for educational purposes.

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We are confident that with this modest effort of the two ministries "agriculture education" will progress in a more dynamic manner.

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Preface

Understanding the AgFS Curriculum Design

The AgFS is a vocational curriculum specifically designed for Bhutanese students studying in classes IX to XII. AgFS is also used as the title of text book for classes IX to XII; as an optional subject for IX and X and an elective subject for classes XI and XII. The AgFS Curriculum has been designed by the Ministry of Education in its attempt to improve the relevance of Secondary Education through curriculum diversification project of the 9th Five Year Plan of the Royal Government of Bhutan. The technical concepts, procedural skills, and values and attitudes of AgFS, demands students to apply their prior knowledge and skills of Scientific and Geography understand Agriculture. The AgFS provides students with opportunities for self-employment entrepreneurship that can address the growing unemployment of the literate youth in our society. It is also intended to reduce our import of huge quantities of agriculture produce all the year round threatening our food sovereignty and depletion of economy.

Aims of AgFSC

The Agriculture for Food Security (AgFS) XII is designed to provide learners with the concepts of Agriculture as a dynamic industry with multiple avenues of entrepreneurship for literate Bhutanese in realizing the national goals of self-reliance in terms of food security required for the sovereignty of a GNH nation. The AgFS XII provides foundation for understanding the good practices of Agriculture and its activities based on research for sustenance, especially in the changing environment impacted by the phenomenon of global warming. The AgFSC aims to equip students to be patriotic and scientific future farmers serving the nation. On the hind side, this curriculum provides foundations for Agriculture degree studies in the universities of the SAARC and beyond.

Content of AgFS

The educational experiences identified through which learning outcomes are expected to attain are developed and made available in the textbooks AgFS XII. This provision is made with the idea that AgFS is a new and a technical subject. It is also for a firm belief that students at this stage, need have all the information to learn AgFS and spend time on experimenting the critical application of ideas rather than wasting time on searching for information. The themes of the chapters are organised logically to make sense that can help students learn better.

The first chapter emphasizes on the good practices of sustainable Agriculture to the divers of change threatening Bhutanese agriculture, which future farmers can support government adapt and adopt policies changes. The introduction to Advance Horticulture in Chapter two, brings another dimension of enhancing horticulture entrepreneurship for the literate youth, a scientific method and different from the traditional farming experienced by many students coming from rural communities. A new idea of farming to produce more and in different seasons.

The Organic Farming of Chapter three connects and values the Bhutanese traditional farming in harmony with nature is advocated in the 21st century scientific farming facilitated by the use of chemical fertilizers and other science of producing more. This chapter provides great details of how alternative farming can be carried out that is ecologically friendly which is gaining popularity in Bhutan and in other parts the world as its products are good for human life. Organic Farming emphasizes on producing food and medicine, etc. organically scientific way but without using chemicals – a choice for the consumers. 'Plants and Animal breeding Practices' of chapter 4, discusses on the 'fundamentals of genetics', units of inheritance, principles of breeding in plants and animals, which are further elaborated and applied, specific to specific to animal application of Livestock in chapter 5, and to plants of 'Seed Production and Marketing' in chapter 6.

Mushroom cultivation concepts and procedural skills are provided in chapter 8, which can a viable entrepreneurship option for students. Mushroom is valued for its food quality and medicine in the market.

The Chapter on Farm Mechanization, discusses on the efforts made by the Ministry of Agriculture and Forests on addressing the drudgery of farm work in Bhutan. It emphasizes on the importance of mechanization of farm work especially in view of addressing shortage of manual workers required in the Agriculture sector in spite growing unemployment of literate youth in the country. Different type of mechanization in relation to different farming activities of growing food crops, livestock and horticulture, etc. is a way forward to encourage literate youth to take up farming which can address food security of the GNH nation. This book ends with the chapter on 'Agro-meteorology' providing ideas of climatology, weather and weather forecast and its utility to farmers –farmers using the weather forecasting for planning of farming activities

Implementation of AgFS

The AgFS subject is to be offered to the students who are interested in the subject and not necessary to the ones who are academically not inclined. However, preference may be given to students who are likely to discontinue studies after the basic education – after X or XII.

AgFS is a technical subject and what students learn in theory is expected to practice in the school or observe what others do in their fields. Therefore, AgFS is not expected to be taught like any other academic subject. Both the teachers and the students opted for AgFS need to read independently, understand and discussed in the class or at the site on the concepts and procedural skills of AgFS, share experiences of agriculture – growing and caring of vegetables, fruits, livestock, nutrition, horticulture, forestry and farm management critically for betterment in near future with changing climate and environment. The ideas from the book are to be taken as a starting point for discussions and not as absolute knowledge and skills procedures. Future modern farmers need to be experimental to do anything that will work better.

Considering the AgFS is a vocational subject is practical based, which students have to do within the school campus. If practical work cannot be done in the school, the teacher need to organize field trips to the place or farm nearby where vegetables, fruits, livestock and forestry activities are being carried out. Based on the field trip students need to write how such activities are being carried out individually or in small group.

It is also envisaged that students will be provided with ample opportunities to visit RNR Research and Development Centres and interact with researchers. It is recommended that RNR staff of the 'gewog', dzongkhag and regional RNR RDC of Ministry of Agriculture and Forests are consulted for their technical expertise and seek support of their services to be fully utilized, especially while assessing practical work.

Although this book provides production and management recommendations for whole range of vegetables, fruits and livestock, it is expected that subject teacher will select the most relevant crop/livestock that is popularly grown/raised in the locality. This will also allow students to relate their studies with the farms around.

Mode of Assessment

The assessment of student's performance in AgFS theory and practical work is to be based on the principle of (a) 'assessment as learning', (b) 'assessment for learning' and (c) 'assessment of learning'. The tools design for different aspects of teaching and learning processes are to be used for objective assessment of student's performance in 'assessment of learning' while being prepared for external examinations (BCESA) and records of assessment for submission to Bhutan Council for School Examination and Assessment (BCSEA). The students of XII will need to appear external examinations of BCSEA for 30%.

Resources required for AgFS curriculum implementation in schools

All Schools need to:

1. Advocate on the awareness of AgFS as a vocational/technical subject available for students from Classes IX to XII, which provides employment for the literate youth and enhance food security for the sovereignty of the GNH nation.
2. Encourage teachers to teach AgFS, reduce work load of teaching other academic subject (s) and school administrative work.
3. Offer AgFS subject to the students who are interested in the subject.
4. Establish institutional linkage with ARDC, Gewog RNR centres, School Agriculture Programme (SAP) unit of Department of School Education, Ministry of Education, and the SAP focal department of Department of Agriculture, MoAF, Dzongkhag Livestock Officer, and Dzongkhag Agriculture Officer for collaboration to implement AgFSC in schools.
5. Budget to implement AgFSC in schools.
6. Provide resources for AgFS curriculum implementation such as:
    a. Land for AgFS for practical work include space for gardening, space for constructing shed for livestock and horticulture, proper fence,
    b. Agriculture Tools for different agriculture activities such as:
        i. Spades, pick axes, crowbars, racks, weeding hoe, shovel, sickle, knives, water pipe, watering can, knapsack, wheel barrow, and any other tools required for AgFS students proportionately.
        ii. Horticulture – pruning and grafting tool sets.
7. Facilitate AgFS Class to use the services of Agriculture experts available in the locality through field trips and guest speakers.

Foreword

For the children of a predominantly agricultural land that our country is, there ought to be a natural link between their hands and the soil. Thankfully, this is largely the case especially in our ^{0}ore rural areas. In the more urban parts though, the human-nature bond is coming under increasing pressure owing to the onslaught of modernisation. The humanising influence of working with the hand is, therefore, getting weaker with the passage of time.

Our seats of learning have had a long tradition of school agriculture that has provided excellent opportunities for our students to work the land, raise garden, grow fruits and vegetables and generally tend the surroundings under the auspices of the Socially Useful and Productive Work programme and . With the initiation of a more structured School Agriculture Programme as a joint effort between the Ministry of Education and the Ministry of Agriculture & Forests, we have witnessed a visible improvement both in the process as well as the outcome of students' work.

The launch of the all-out educational reform initiative through the nurturing of Green School concept is expected to restore, among others, the vital link between human beings and the natural environment both as a science and as an art. We expect our students to experience the joy of sowing the seeds, see them germinate and emerge above the soil, follow the changes in shape and size, fruit and flower, mature and complete the cycle. We want our children and youth to feel the soil, understand the effect of sun and rain on plants as well as notice the impact of wind and drought.

A happy consequence of this engagement with the soil will be the production of much-needed food items, organic and nutritious, satisfying because self-produced, nurtured through love and care. The otherwise dreary-looking bare land dons multiple colours as seasons change and beautify the campus and elevate it as a seat of learning. The different sights, sounds and smells that a rich campus produces sharpen and sensitise our senses and awaken us to our full sensibilities.

These multiple benefits of keeping ourselves close to the life-affirming soil have inspired us to introduce School Agriculture as one of the optional subjects for classes nine and above from the 2013 academic session. We commend the excellent work done by our colleagues in the Royal Education Council (REC) , Ministry of Education (MoE), and the Department of Agriculture (DoA) , Ministry of Agriculture and Forests (MoAF), and all other contributors for their inputs in the production of this document.

We trust that our students will find the contents as appealing and educative as our educators and instructors bring to our schools the joy of farming both as a hobby and as an occupation and help in building a healthy and food-secure Bhutan of Gross National Happiness.

Tashi Delek!

Dr. Pema Gyamtsho,
Minister,
Ministry of Agriculture and Forests.
Year 2013

Thakur S Powdyel,
Minister,
Ministry of Education.
Year 2013

Table of Contents

1

CHAPTER

Good practices of Sustainable Agriculture

Bhutanese agriculture is still largely based on the traditional subsistence oriented mixed farming systems that integrate cropping, livestock rearing, and use of forest products. This integrated system may be described as open systems, receiving inputs from outside and losing energy and matter as outputs. Inputs to the system come from various sources like nutrients from weathering of rocks, energy from solar radiation, water and nutrient from precipitation, water and humus/soil by erosion, and by inputs like seed, irrigation, fertilizers, and chemicals.

The ever increasing population that exerts pressure on food production has led to exploitation of agro-ecosystems by excessive use of chemicals, loss of biodiversity, depletion of water and soil, deforestation and land degradation. The mounting pressure to produce more and maintain the production proportionate to the demand has always been a challenge. The pressure will continue. This is what brings in the idea of sustaining the development. For centuries, the people of Bhutan have preserved their natural resources and lived in balance with nature. Ensuring the integrity of forests, rivers and soil was vital for the survival in the high valleys of the Eastern Himalayas. The relationship between the Bhutanese people and the environment has been forged over centuries within moral, cultural and ecological boundaries. Respect for these natural resources was ensured historically through a set of formal and informal rules and norms. Traditional and local beliefs promoted the conservation of the environment, and key ecological areas were recognized as the abodes of gods, goddesses, protective deities and mountain, river, forest and underworld spirits (NEC, 1998). This traditional respect for the natural world ensured that Bhutan emerged into the 20th century with an intact natural resource base.

Over the centuries, the symbiotic relationship that once coexisted between humans and nature seem to gradually fade away. It has become inevitable to bring in democratic process that seeks to bring together action and reflection, theory and

Reprint 2022

practice to identify durable practical solutions to issues. Amidst this general respect to nature, agricultural production is closely linked to trends in weather or climate change, policy environment and socio-economic situations. The range of weather conditions shapes the agricultural production. The dynamics of weather makes agriculture highly vulnerable for which agricultural practices needs to be adapted to local climatic conditions.

This chapter attempts to relate the relevance of agriculture to the changing environment that affects agriculture and suggests some research approaches to better understand the dynamics of change and be engaged in the change or adaptation process. Information provided under different topics and sub-topics are not to be learned as absolute knowledge but as bases for more exploration of higher knowledge and above all to facilitate thinking of alternative knowledge that can generate appropriate activities for prosperous and sustainable agriculture in Bhutan in this changing environment.

The agriculture and its activities need to be sustained through a continuous research of adapting agriculture practices, adopting sustainable agriculture systems fulfilling food sustainable systems; genetic engineering; use of modern technology; etc., by the new breed of Bhutanese literate farmers and farm workers. It is important for the literate farmers and farm workers to adopt research approach to adapting good practices of Agriculture – integrate farming, livestock and horticulture in Bhutan. However, all these activities to sustain agriculture need to be entrenched with the fundamental belief in the purposes of sustainable agriculture. Let us revisit sustainable agriculture and sustainable agriculture system to derive good practices.

1.1 Sustainable Agriculture

Sustainable Agriculture is the basis for sustainable production system in which the fertility of soil is maintained and improved; the availability and quality of water are protected and enhanced; biodiversity is protected; farmers, farm workers, and all other actors in value chains have livable incomes; the food we eat is affordable and promotes our health; sustainable businesses can thrive; and the flow of energy and the discharge of waste, including greenhouse gas emissions, are within the capacity of the earth to absorb forever. For SA, there is the need for sustainable agriculture system (SAS).

Sustainable agricultural systems aim to maintain and enhance biological and

Reprint 2022

economic productivity, enhance the efficiency of use of input, lessen adverse environmental impacts, minimize the magnitude and rate of soil degradation and to enhance soil quality and resilience so that crop productivity can be sustained. Sustainable agriculture system principally aims at five purposes as shown in Figure 1.1, and one of the first goals is to satisfy food, fibre and natural resources.

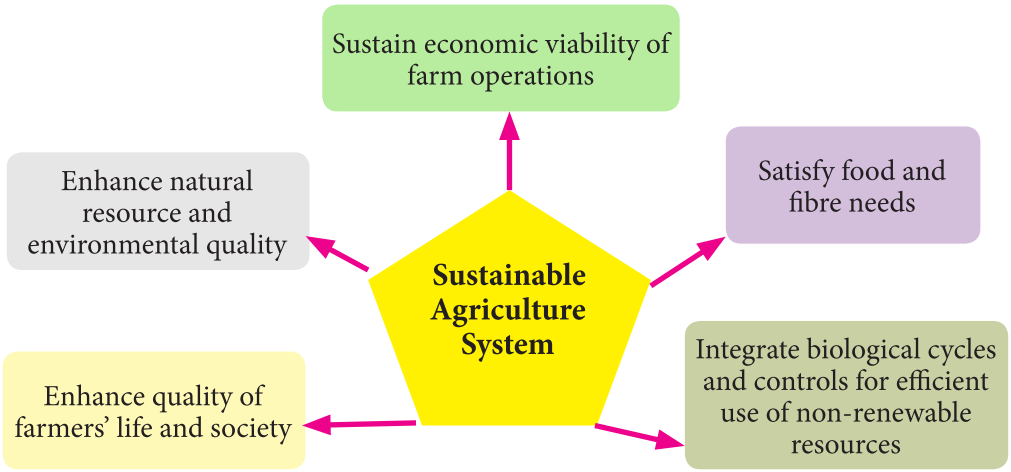

Figure 1.1 Purposes of sustainable agriculture system

Sustainable Agriculture requires 'a sustainable food system'. It is a collaborative network that integrates several components in order to enhance a community's environmental, economic and social well-being. It is built on principles that further the ecological, social and economic values of a community and region. Characteristics of a ***sustainable food system*** (based on Pothukuchi and Jufman, 1999) are:

- secured food, and therefore reliable and resilient to change (including climate change, rising energy prices, etc.) and accessible and affordable to all members of society.
- energy efficient.
- economic generator for farmers, whole communities and regions.
- is healthy and safe.
- environmentally beneficial or benign.
- creative use of water reclamation and conservation strategies for agricultural irrigation.
- balanced food imports with local capacity.

Reprint 2022

- has regionally-appropriate agricultural practices and crop choices.
- work towards organic farming.
- contribute to both community and ecological health.
- build soil quality and farmland through the recycling of organic waste.
- support multiple forms of urban as well as rural food production.
- ensure that food processing facilities are available to farmers and processors.
- preserve biodiversity in agro-ecosystems as well as in the crop selection
- has a strong educational focus to create awareness of food and agricultural issues, and
- fairly traded by providing a fair wage to producers and processors locally and abroad.

A food system is therefore the sum of all activities required to make food available to people. This includes: production, processing, distribution, consumption, and waste. A sustainable food system integrates all of these elements to enhance economic, environmental, social, and nutritional health for all (Figure 1.2).

a) Good practices of agriculture

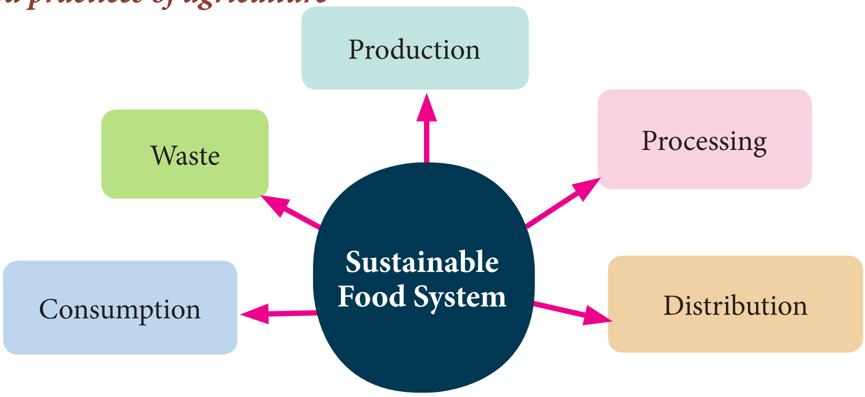

Figure 1.2 Elements to enhance environmental, economic, social and nutritional health for all.

Building a sustainable food system must be a collective effort of all and thus good practices of agriculture need to be derived from a sustainable food system with specific actions under broad themes as listed hereunder.

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Table 1.1 Themes and specific actions of good practices

Sl No	Themes	Specific actions of good practices
a.	Sustainable agriculture	Multiple cropping, Integrated pest management, climate smart agriculture, organic agriculture, judicious use of pesticides and fertilizers.
b.	Environmental science and land use	Integrated watershed management, forest management, sustainable land management, biodiversity conservation, environmental management.
c.	Personal and public health	Food safety and nutrition
d.	History and culture	Traditional food systems, food sovereignty
e.	Political economy and sociology	Trade and economy, poverty and malnutrition
f.	Policy and education	Food policy at different levels, integrating food system and food science in curriculum
g.	Agricultural economics and international trade	Regional and international trade
h.	Supply chains and processing	Product development and efficient supply chain, reduced waste
i.	Rural and urban development	Rural-urban migration, changing food preferences

Good practices of agriculture alone may not be adequate. The farming community needs to understand the global food chain system to be competitive. Some ideas are discussed hereunder.

b) Ecological footprint of the global food system

The ecological footprint can be defined as the impact of human activities measured in terms of the area of biologically productive land and water required to produce the goods consumed and to assimilate the wastes generated. More simply, it is the amount of the environment necessary to produce the goods and services necessary to support a particular lifestyle.

Reprint 2022

To produce food to feed ever increasing population, enormous areas of productive land and sea are needed for animals to graze on, fish to live in and for growing the fruit, grains and vegetables. With the globalization of the food market, the food item can be produced in different parts of the world, e.g. coffee plantation in Brazil, wheat from USA, rice from Vietnam. This means that our food choices have an impact on our ecological footprint. The process of producing food and delivering to consumers in different parts of the world, a huge quantity of energy is used. This energy mainly comes from fossil fuels which release carbon dioxide when they are burnt. The more carbon dioxide we release, the bigger our greenhouse gas footprint will be. The main energy inputs in the food production process include:

» *Energy for growing* – tractors run on diesel; irrigation systems need electricity to pump the water; fertilizers and pesticides are produced using energy; and greenhouses use gas to stay warm.

» *Energy for processing* - washing, chopping, preparing, cooking and freezing food uses lots of energy, both in terms of electricity to run all the machinery in the factories, but also gas to keep the factories warm. Ready meals have used up enormous amounts of energy by the time they get to a table.

» *Energy for packaging* – mining, growing, making and transporting packaging (tins, packets, bags, bottles, sachets, cartons and ready meals) uses lots of energy. Many food items are often over packaged, and some packaging is a 'once only' use of resources.

» *Energy for transporting*–the Lorries, ships, planes and cars which carry food from farms to factories, shops and our homes mainly use diesel and petrol. The distance they travel is often referred to as 'food miles'.

A simple way to understand this concept better is to ask oneself 'why is imported food or food product expensive?' An example 'potatoes' grow in Bhutan is being sold to Indian businessmen (Phuntsholing) at Nu. 5.00 per kg and later the same potatoes are sold in Paro or Thimphu at Nu 30.00 per kg. The more cost is due to handling and transportation charges. Why do we import (example potatoes)? What happens when we sell at low price and buy at high price? What good practices can we adopt? Good practices are: grow our own food, store or stock them and sell at affordable price that is good for all.

Reprint 2022

1.2 Agro-ecological systems

The term "agro-ecology" was first used in the 1930s by Bensin, a Russian agronomist, initially in reference to applying ecological methods to research on crops. In 1965, German ecologist and animal scientist Tischler published what is most probably the first book titled Agro-ecology.

Agro-ecology is a scientific discipline that uses ecological theory to study, design, manage and evaluate agricultural systems that are productive but also resource conserving. In a broader sense, agro-ecology encompasses the whole food system linking production with the food chain and consumers. It considers interactions among biophysical, technical and socio-economic components of farming systems. Agro-ecology therefore provides a framework by applying ecological theory to the management of agro-ecosystems according to specific resource and socio-economic realities of the community.

Agro-ecology goes beyond a one-dimensional view of agro-ecosystems - their genetics, agronomy, edaphology, and so on, to embrace an understanding of ecological and social levels of co-evolution, structure and function. Instead of focusing on one particular component of the agro-ecosystem, agro-ecology emphasizes the interrelatedness of all agro-ecosystem components and the complex dynamics of ecological processes (Vandermeer, 1995).

Agro-ecology is the application of ecological principles to agriculture (Altieri, 1983). Later agro-ecology was expanded to include food system linking production with the food chain and consumers. It actually allows inclusion of socio-economic and political dimensions in food system. As such agro-ecology is understood as a scientific discipline, agricultural practice, or political-social movement, which can be defined as follows:

Agro-ecology as a science in its simplest form is seen as the "application of ecological science to the study, design and management of sustainable agro-ecosystems". This can apply not just at the farm-level, but also across the global network of food production, distribution and consumption including food production systems, processing and marketing, the role of the consumer, and the policy level. As such, it uses knowledge from a range of disciplines, including agricultural and ecological science, and traditional knowledge systems. It questions conventional approaches which are centred on the use of science to promote economic growth.

Reprint 2022

Agro-ecology as practice seeks ways to enhance farming systems by mimicking natural processes, using biological interactions and synergies to support production.

Agro-ecology as a social and political movements about how individuals, communities and societies contribute to building sustainable, fair food models through what they buy, but also in the ways in which they shop and organize food distribution. Agro-ecological movements seek to influence national and international policies through grassroots cooperation, participation and action to create more sustainable management systems for food and seeds.

The concept of agro-ecology can be better appreciated by exploring its principles. The following list proposes such a set of principles, however not to be understood as a closed framework.

- ✓ Recycle biomass, optimize and close nutrient cycles.
- ✓ Improve soil conditions. This means in particular improving organic matter content and biological activity of the soil.
- ✓ Reduce dependence on external, synthetic inputs.
- ✓ Minimize resource losses (solar radiation, soil, water, air) by managing the micro-climate, increasing soil cover, water harvesting...
- ✓ Promote and conserve the genetic diversity of crops and animals.
- ✓ Integrate protection of biodiversity with production of food.
- ✓ Integrate short-term and long-term considerations in decision making. Aim at optimal yields rather than maximum yields. Value resilience and adaptability.
- ✓ Give value to the diversity of knowledge (local / traditional knowhow and practices, common knowledge and expert knowledge) in the definition of research problems, the definition of people concerned, and in finding solutions.
- ✓ Promote participatory research driven by the needs of society and practitioners, while at the same time guaranteeing scientific rigor.
- ✓ Develop knowledge and innovation systems that conserve and allow exchange of agro-ecological knowledge. Special attention should be paid to local knowledge, which is a scarce resource in itself and due to its specificity is difficult to disseminate.

Agro-ecological principles can contribute to creating a more sustainable, socially just, and secure global food system. "How to feed the world" is an increasingly urgent and looming concern voiced by many people, from local community groups to national and international governing bodies.

Reprint 2022

The design of such systems is based on the application of the following ecological principles:

1. Enhance recycling of biomass and optimizing nutrient availability and balancing nutrient flow.
2. Securing favorable soil conditions for plant growth, particularly by managing organic matter and enhancing soil biotic activity.
3. Minimizing losses due to flows of solar radiation, air and water by way of microclimate management, water harvesting and soil management through increased soil cover.
4. Species and genetic diversification of the agro- ecosystem in time and space.
5. Enhance beneficial biological interactions and synergisms among agro biodiversity components thus resulting in the promotion of key ecological processes and services.

Table 1.2 Principles and specific action of good practice

Principles	Specific actions of good practice
Use Renewable Resources	• *Use renewable sources of energy instead of non-renewable sources.* • *Use biological nitrogen fixation.* • *Use naturally-occurring materials instead of synthetic, manufactured inputs.* • *Use on-farm resources as much as possible.*
Recycle on-farm nutrients.	• *Reduce or eliminate the use of materials that have the potential to harm the environment or the health of farmers, farm workers, or consumers.*
Minimize Toxics	• *Use farming practices that reduce or eliminate environmental pollution with nitrates, toxic gases, or other materials generated by burning or overloading agro-ecosystems with nutrients.*
Conserve Resources	• *Soil, Water and Energy,* • *Genetic resources* • *Capital*

Reprint 2022

Manage Ecological Relationships	• *Reestablish ecological relationships that can occur naturally on the farm instead of reducing and simplifying them.* • *Manage pests, diseases, and weeds instead of "controlling" them.* • *Use intercropping and cover cropping* • *Integrate Livestock* • *Enhance beneficial biota* • *Recycle Nutrients* • *Minimize Disturbance*
Adjust to Local Environments	• *Match cropping patterns to the productive potential and physical limitations of the farm landscape.* • *Adapt Biota - adapt plants and animals to the ecological conditions of the farm rather than modifying the farm to meet the needs of the crops and animals.*
Diversify	• *Landscapes, Biota and Economics*
Empower People	• *Ensure that local people control their development process.* • *Use indigenous knowledge* • *Promote multi-directional transfer of knowledge, as opposed to "top-down" knowledge transfer.* • *Engage in people-centric development.* • *Increase farmer participation.* • *Strengthen communities.* • *Guarantee agricultural labor.* • *Teach principles of agro ecology & sustainability.*
Manage Whole Systems	• *Use planning processes that recognize the different scales of agro ecosystems (Landscapes, households, farms, communities, bioregions, and nations)* • *Minimize impacts on neighboring ecosystems.*

Reprint 2022

Maximize Long Term Benefits	• *Maximize intergenerational benefits, not just annual profits.* • *Maximize livelihoods and quality of life in rural areas.* • *Facilitate generational transfers.* • *Use long-term strategies-develop plans that can be adjusted and reevaluated through time.* • *Incorporate long-term sustainability into overall agro ecosystem design and management.* • *Build soil fertility over the long-term (build soil organic matter).*
Value Health	• *Human Health, Cultural Health,* • *Environmental Health, Animal Health, Plant Health*

Agro-ecosystems are overwhelmingly complex. The numerous ecological processes that tie people, crops, weeds, animals, micro-organisms, soil, and water together into a functioning, on-going ecosystem are so intricate that they can never be fully described, nor can they be fully comprehended. Simplification is a practical necessity of analysis and essential for effectively communicating the results of analysis to agricultural practitioners. One approach to simplification is system properties, which combine large numbers of agro ecosystem processes into single, highly-aggregated measures of performance that suggest how well an agro-ecosystem is meeting human objectives. There are five properties of agro-ecosystems such as:

1. *Productivity* – the quantity of food, fuel or fiber that an agro-ecosystem produces for human use.
2. *Stability* – consistency of production.
3. *Sustainability* – maintaining a specified level of production over the long term.
4. *Equitability* – sharing agricultural production fairly.
5. *Autonomy* – agro-ecosystem self-sufficiency.

Agro-ecological concepts and principles embrace a wide range of practices and have broad scope for implementation. This means that they have considerable resonance with other concepts, principles and practices in the field of sustainable agriculture that also offer alternative structures to the mainstream paradigm of industrial agriculture.

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1.3 Drivers of change in Bhutanese Agriculture

Land use in Bhutan is predominantly forests and agriculture. Land use under forest accounts for 70.46% and cultivate agriculture land for 2.93% of the total land area (Table 1.3). The pasture and alpine meadows cover 4.10%. A significant proportion of 13.63% of the total area is under shrubs and barren land. Snow/glacier and rock outcrops combined constitute about 7.44%. Settlement accounts only for 0.16% but it is fast growing due to urbanization.

Table 1.3 National land use as percentage of total area (Source: NSSC, 2010)

Land use type	Percent coverage
Forests	70.46
Shrubs	10.43
Meadows	4.10
Cultivated agriculture land	2.93
Built-up	0.16
Non-built up	0.01
Snow/glaciers	7.44
Barren area	3.20
Water bodies	0.72
Marshy area	0.01
Degraded area	0.54

The assessment of change over time is difficult due to the lack of compatible and consistent data sets across source, time, space, scale and classification systems. Nevertheless, certain trends are visible from the table. There is an increasing trend in the major land uses - forest, pastures and settlement. While the natural forest has increased over the years, there has been an increase of the scrub forest which is reflective of the declining forest quality. Similarly, land use under pasture has gone up over the years. It is surprising to observe a drastic decline in the area used for cultivation, which could be due to fallowing of land and also encroachment of land by urban development. Should Bhutanese questions themselves as to why such a development takes place in Bhutan?

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Table 1.4 Changes in land use between 1990 and 2010 Sq. Km. Source: NSSC, 2010

Land use type	1990	2010
Forests	25787	27052.9
Shrubs	3258	4005.26
Meadows	1564	1575.69
Cultivated agriculture land	3146	1125.55
Built-up	31	61.51
Non-built up	0	3.30
Snow/glaciers	2989	2854.79
Bare area	2008	1229.75
Water bodies	304	275.69
Marshy area	35	3.19
Degraded area	954	206.36
	40076	38393.99

The drastic reduction in the cultivated agriculture land is a great concern and it is indicative that Bhutanese cultivate less as the population grows, especially with growing literate population. *Can Bhutanese education prepare youth to grow food, fibre, medicine and other needs of Bhutanese population?* Hopefully, this question will be answered sooner or later but before it is late for Bhutan. As the land for agriculture, meadows and pastures declines, agricultural production is affected. Further, pushing agricultural production to peripheries and hostile environments, will limit the production of food. It implies that Bhutan will become more dependent on imported food that can threaten the nation's food security and sovereignty.

a) A good practice for gaining food security and sovereignty

Bhutan has a wide range of agro-ecological zones ranging from the sub-tropics to the cool temperate on which a large number of horticultural crops such as fruits, vegetables, potato, tuber crops, mushroom, ornamental, medicinal and aromatic plants, plantation crops and spices are grown. However, Bhutan has not been able to exploit its agro-ecological zones for agro-industries for food security and food sovereignty. The growing service sector (civil service and private) of the growing urban centres import food, fibre and medicine widening the trade deficit making

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Bhutan economically venerable. *Would a step towards good practice to:*

1. *be critical of Bhutan's land use for different socio-economic development plan?*
2. *reserve Bhutan's limited arable land for agriculture for food security and food sovereignty?*
3. *support Bhutanese entrepreneurs with arable land, capital fund free of interest and technical support to start agriculture industries instead of sending Bhutanese youth abroad ?*
4. *regulating import of food items in favour of Bhutanese farmers?*
5. *expand urban centres and industries on the non-arable land?*

b) Biodiversity

Biological diversity is vital for every sphere of human existence and provides us with a vast range of products and services. It is the foundation of agriculture that supports production, food security and sustainability. It provides services such as food, water, timber, fibre, genetic resources, and medicines; regulating services such as regulation of climate and, water and soil quality, and pollination; cultural services such as recreational, aesthetic, and spiritual benefits; and supporting services such as soil formation and nutrient cycling. Approximately 7,000 plant species have been collected and cultivated for food ever since agriculture began some 12,000 years ago.

Located in the eastern Himalayas, Bhutan has an incredible range of habitat type and is considered the most bio-diverse country in the world. The biodiversity in Bhutan ranges two major bio-geographic realms, the Indo-Malayan and Palearctic (Figure 1. 3) and is part of the Eastern Himalayan region which contains parts of three global biodiversity hotspots, 60 Eco regions, 330 important Bird Areas, 53 Important Plant Areas, and a large number of wetlands and 29 Ramsar sites. Bhutan is home to a diverse array of flora and fauna. Bhutan falls under one of the ten global biodiversity 'hotspots' with many animal and plant species.

Today only about 15 plant species and 8 animal species supply 90% of the global demand for food. Loss of biodiversity is caused by several factors such as changes in land use, over exploitation of natural resources, destruction of natural habitats, urbanization, human, wildlife conflict, forest fires, hydropower development, industrial development, and invasive species

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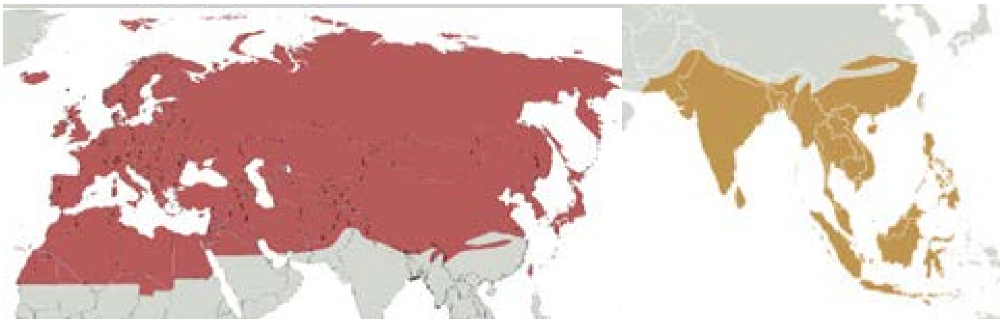

(a) Palearctic (b) Indo-Malaya

Figure 1.3 Eco zones

Climate change will further exacerbate the effects of other stressors and is likely to become the primary driver of biodiversity loss by the end of this century. Key factors causing the decline in biodiversity include habitat disturbance and changes in the food chain. In general, there are fewer species in intensive plant production regions with little diversity in the landscape structure as compared with mixed farming and livestock production regions. Living in harmony with nature as per the Buddhist philosophy of co-existence is way of a good practice of Agriculture.

Should Bhutan continue import of food to preserve biodiversity or convert forest into cultivable land? Can mixed farming with organic farming approaches be viable? How can conservation of forest resources be part of your mix farm?

c) Water availability and competition

Water is essential for human survival and well-being and important to many sectors of the economy. Every living organism needs water to survive. Plants need water to make food. All animals depend on plants for food either directly or indirectly. Therefore, without water, all life forms will cease to exist. However, water resources are irregularly distributed in space and time, and they are under pressure due to human activity. Water is one of the renewable natural resource that is vital for agricultural growth. Globally the availability of fresh water for agriculture is declining and could become a rare resource. Compounded with the changing rainfall patterns, temperature, management regimes and increasing demand water resource is under critical threat of becoming the most contested natural resource.

Situated in the Eastern Himalayas, the northern part of the country is under snow cover almost year round. The glaciers which feed rivers in Bhutan cover

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around 10% of the total land area. There are 2674 glacial lakes (Mool et al., 2001) that serve as a perennial source of water for the four major river systems in the country: the Drangme Chhu; the Puna Tsang Chhu; the Wang Chhu; and the Amo Chhu (Figure 1.4).

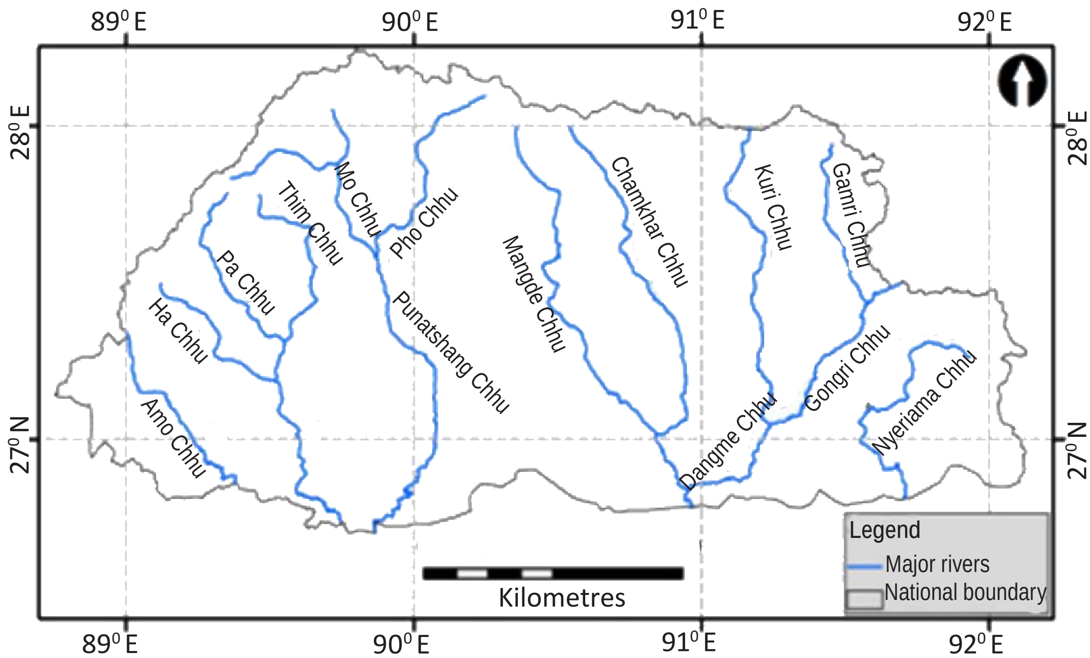

Figure 1.4 Main river systems and in Bhutan

All these river systems swiftly meander through deep gorges and narrow valleys to drain into the Brahmaputra in India, dropping from an altitude of above 5500 m to 200m within a distance of 250 km (Figure 1.6).

The quick drop within a short distance provides tremendous hydropower potential of around 30,000 MW (GNHC, 2008). The hydropower sector generates around 60% of the national revenue and contributed 19.1% of the GDP in 2008 (NSB, 2009). Apart from revenue generation, the electrical power sector has hastened the development in all sectors such as industry, education and health services. The rural electrification program which aims at the electrification of all settlements by 2020 (GNHC, 2008) will help in the reduction of fuel wood use, improve hygiene and health, increase working time in the evenings, introduce electrical appliances thereby support in poverty alleviation. It is estimated that agriculture utilizes 54% of the water for irrigating crops followed by domestic use accounting for an extra 36%, and industries which are gradually coming up takes up 10% of water volumes (EarthTrends, 2003).

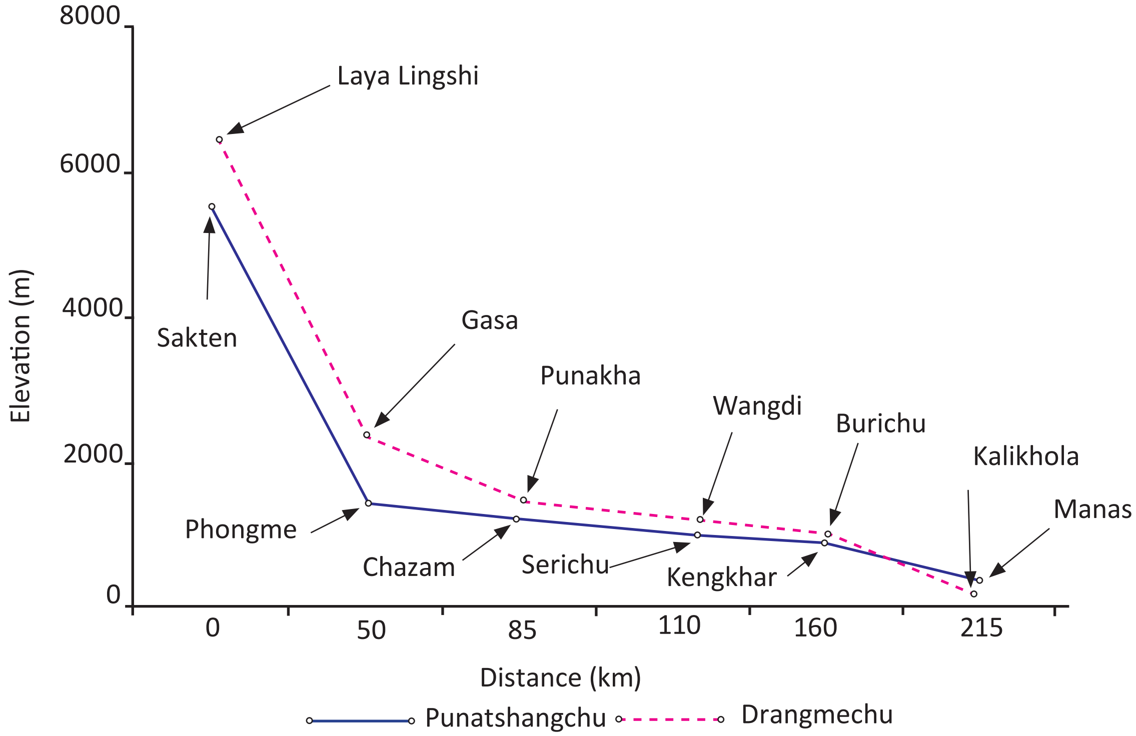

Figure 1.5 Schematic representation of the profile of two major river systems – Punatshang chu and Dangme chu – in Bhutan

As the main rivers flow swiftly down south at the bottom of deep gorges, their water is rarely used in agriculture. In addition to its accessibility problem, low temperature from glacial melt makes it harmful to crop production. As such small seasonal streams and spring ponds are used for domestic and agriculture purposes. The annual renewable freshwater resource per capita is estimated to be 58,930 cubic metres (PCS, 2007) and seems insufficient with increasing demand from rapid industrialization and urbanization. In agriculture, there are 19,522 hectares of wetland where irrigated rice is cultivated and only 40% of the wetlands are fed with 591 km of concrete lined irrigation canals built by the Department of Agriculture (GNHC, 2008). Remaining wetland fields are either irrigated with the help of earthen canals built by communities or depend on rainfall. Questions that we need to ask are *'What is happening or what we are doing sustainable?' What should the future farmers or farm workers do or need to do to avoid competition? Would building dams/reservoirs, harvesting rainwater, other technology, etc., be of some solutions or as good practices? What measures do you think you could do to protect water sheds?*

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d) Land degradation

The indiscriminate exploitation of land has undermined the importance of land and natural resources that thrive in it. The landscape in the Himalayas is prone to degradation and /or desertification because of its young soil, and climatic and physiographic variations. Natural causes like low rainfall, short period of heavy rainfall, high-velocity wind, steep slopes and unstable geology and flooding are responsible for land degradation. Alternatively, deforestation, inappropriate farming practices, intensive agriculture, overgrazing, and shifting cultivation have accelerated land degradation process. The socio-economic factors, i.e., socio-cultural and religious causes, poverty and food insecurity, population pressure, and gender inequality have compounded the problems. It has been estimated that about 1.8 million tons of plant nutrients (Nitrogen, Phosphorus, Potassium and calcium) are removed by crop harvesting (0.5 million tons) and soil erosion (1.3 million tons) each year.

Land degradation may be defined as long-term loss of ecosystem function and productivity caused by natural process or human interference from which land cannot recover unaided. Land degradation is increasing in severity and extent in many parts of the world, with more than 20% of all cultivated areas, 30% of forests and 10% of grasslands are reported to undergoing active degradation. According to FAO (2005), land degradation is a complex phenomenon and encompasses factors concerning soils, water, forests, grassland, crops, and biodiversity.

Land degradation in Bhutan is mostly anthropogenic (man-made). The major causes of land degradation are deforestation, overgrazing, construction works and unscientific farming in the hills. In Bhutan the two most common types of in situ physical land degradation is topsoil capping and subsoil compaction (Table 1.5). Loss of vegetation due to deforestation, over cutting beyond silvi-culturally permissible limits, unsustainable fuel wood extraction, shifting cultivation, encroachment into forest land, forest fire, over grazing, extension of cultivation onto lands of low potential or high natural hazards, non-adoption of adequate soil conservation measures and improper crop rotation are some of the important factors contributing to land degradation in Bhutan. Some reports mention that there are 7032 ha of degraded area (landslides and gullies) in Bhutan which represents 0.18 % of the country's total area (NSSC, 2015.

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Table 1.5 Land degradation classes, types and occurrence in Bhutan (Norbu et al. 2000)

Land degradation group	Types of land degradation	Occurrence in Bhutan
In-Situ Chemical	• Depletion of soil Organic Matter • Depletion of Nutrients • Soil Acidification • Over-fertilization	Most acute on chhushing and in kamshing or short fallow tseri, widespread (intensively cultivated areas), excess urea on some maize and rice , possible excess P fertilizer applied to apples in western Bhutan
In Situ Degradation-Physical	• Topsoil capping • Subsoil compaction • Water logging	Land freshly cultivated for kamshing vulnerable, chhushing land protected by surface water, widespread in chhushing, more common on logging roads
Water (+ gravity) erosion	• Splash erosion • Sheet erosion • Rill erosion • Gully erosion • Mass movements (landslips & landslides) • Ravines (Large long combined gullies & slides) • River Processes • Bank erosion • Flooding	Fine sandy - silty topsoil common in Bhutan are vulnerable, reported on some clay-rich soils in Eastern Bhutan , widespread when pre-monsoon rains are heavy, Some deep red clays, e.g. Lobeysa – Punakha, prolonged & deep saturation increase mass, reduce cohesion & increase landslide risk-highest in South, Radhi, many examples in South, But concentrated on productive valley areas, concentrated in productive valleys, e.g. 1968 flood in Paro
Tectonic natural hazards	• Earthquakes • Urban & industrial • Encroachment • Pollution	Bhutan mostly in slightly, lower risk zone IV, Mainly Thimphu, Paro, Jakar & in South, Mainly Thimphu & South

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Spoil tipping	• Riverbed mining for construction sand & gravel	Main area is Punakha – Wangdi stretch of Puna Tsang Chhu

Bhutan currently has only 2.93% agricultural land (LCMP, 2010) which has to sustain agricultural production. As most agriculture land is located in hills and slope a slow process of land degradation is always happening. As per the study finding of National Soil Services Centre (NSSC), about 29 MT /ac-1of top soils are washed away annually from dryland with slope ranging from 15 to 40 degree. The changing landscape and the capacity of the land to produce has remarkable influence of how we farm and manage the land. It also has direct impact on our life and livelihood.

Study Table 1.5 and ask yourself '*What should literate farmers or farm workers do as good practice of Agriculture to avoid land degradation?* The answers will be your good practice of saving land that can help expand agriculture in your localities.

Bhutan is highly vulnerable to the climate change impacts due to its size, physiographic location, and resource endowment. Geography coupled with high levels of poverty and inaccessibility has rendered Bhutan especially vulnerable to the impacts of climate change. Some of the prominent impacts are:

- Increased Glacial Lake Outburst Floods (GLOF), landslides, flash flood, and drought
- Drought- (due to temperaure rise and/or weather change pattern –longer intervals between rains)
- Forests and Biodiversity habitat degradation
- Agricultural Activities - crop loss, yield decline, pest emergence

Some of the adaptation strategies practiced in Bhutan as per the law of the land are:

- The conversion of wet land is prohibited to any other form of land use which safeguards the land for rice cultivation.
- The shifting cultivation which was quite rampant in the Eastern part of the country has been banned and such farmers are provided with incentives to convert such land into orchards and dry land farming.
- The promotion of organic program is vigorously pursued to reduce dependency on external inputs like chemical fertilizers and agrochemicals. In addition,

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use of bio- pesticides is being promoted.

- All persistent and very hazardous group of pesticides are banned. The removal of subsidy on all kinds of pesticides since 1995 has brought down the use of agro-pesticides.
- Sustainable Land Management program which provides support for participatory land management are given very high priority. Sustainable land management includes measures like hedgerow plantation using fodder species which serve dual purposes as a source of feed as well as protection against erosion.
- The Government has adopted the Zero grazing policy so that the utilization of animal waste are used properly which can be used to increase the yield of the agriculture crops.
- Land terracing, contour-bunding and building check dams to control soil erosion is also promoted.
- Management of Glacial Lake Outburst Flood (GLOF) in order to reduce the risk of washing away of arable land and properties due to downstream flood has been accorded highest priority.
- Implementation of pollution control strategies by the National Environmental Commission in the Industries to prevent the untoward effect on crops due to release of unwanted gases.

It is important that these strategies are adopted by farmers and farm workers as good practices of Agriculture seriously. Every farmer and farm work need to walk the talk of 'think globally and act locally'

e) Policy

Policies related to land, subsidy, production, and trade have far reaching effect on agriculture. Since the economy of Bhutan is dependent on agriculture, the dynamics and its effects transcend all sectors. According to International Food Policy Research Institute (IFPRI), protectionism and subsidies by industrialized nations cost developing countries about US$24 billion annually in lost agricultural and agro-industrial income. The figure below attempts to illustrate the area of development affected by different policies. Study the flow chart (fig. 1.6) and discuss how policy of a system can affect agriculture. '*What implication does such a policy have on Bhutan? What kinds of policy would Bhutan need to adopt and what would be farmer's responsibilities?*'

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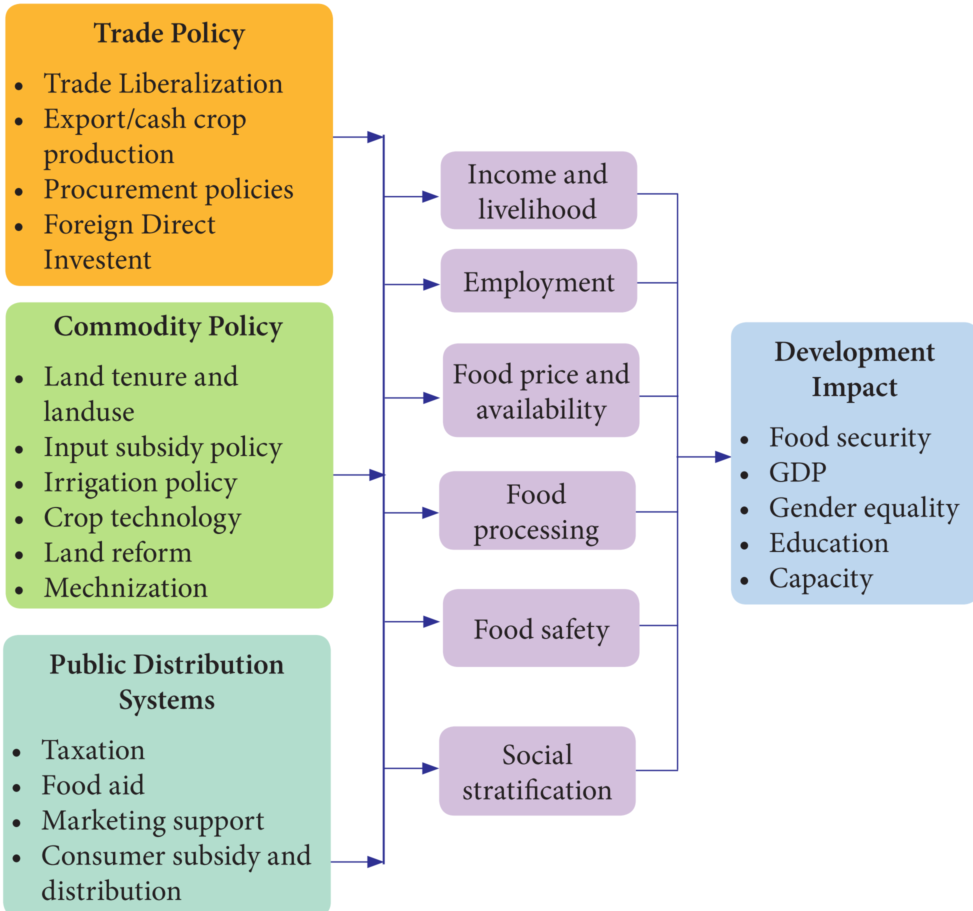

Figure 1.6 Effect of agricultural policies on overall development

1.4 Adaptation in Socio-Ecological Systems

The social-ecological landscape which is represented by three components of social, economic and environment show a very clear interaction between the three elements. In this interaction, it is the social factor that has a major role in changes that steer and shapes ecosystem dynamics from local environments to the biosphere as a whole. It is also now clear that patterns of production; consumption and wellbeing develop not only from economic and social relations within and between regions but also depend on the capacity of other regions' ecosystems to sustain them. Therefore, a major challenge is to develop adaptive forms of governance systems that make it possible to relate to environmental assets in a fashion that secures their capacity to support societal development for a long time into the future. In sustaining the development is the resilience of the capacity for renewal, reorganization and development. In a vulnerable social-ecological system even a small disturbance may cause dramatic social consequences. Vulnerability here it includes the attributes of persons or groups that enable them to cope with the impact of disturbances, like natural hazards. Such disturbances have the potentials to create opportunity for doing new things, for innovation and development. Such innovation and development will foster adaptation and shape change towards a sustainable desirable pathways of development.

The socio-ecological system in Lingmuteychu watershed in Punakha schematically represented in Figure 1.7 show how three elements (Social, economic and environmental) of socio-ecological system in a small community in Bhutan is interrelated and complex. Under the influence of both internal and external factors, the dynamics of the interaction changes to suit the local conditions. The dynamic process is the process of adaptation to change and transformations from one system to another with different viability and functions. If we make a similar

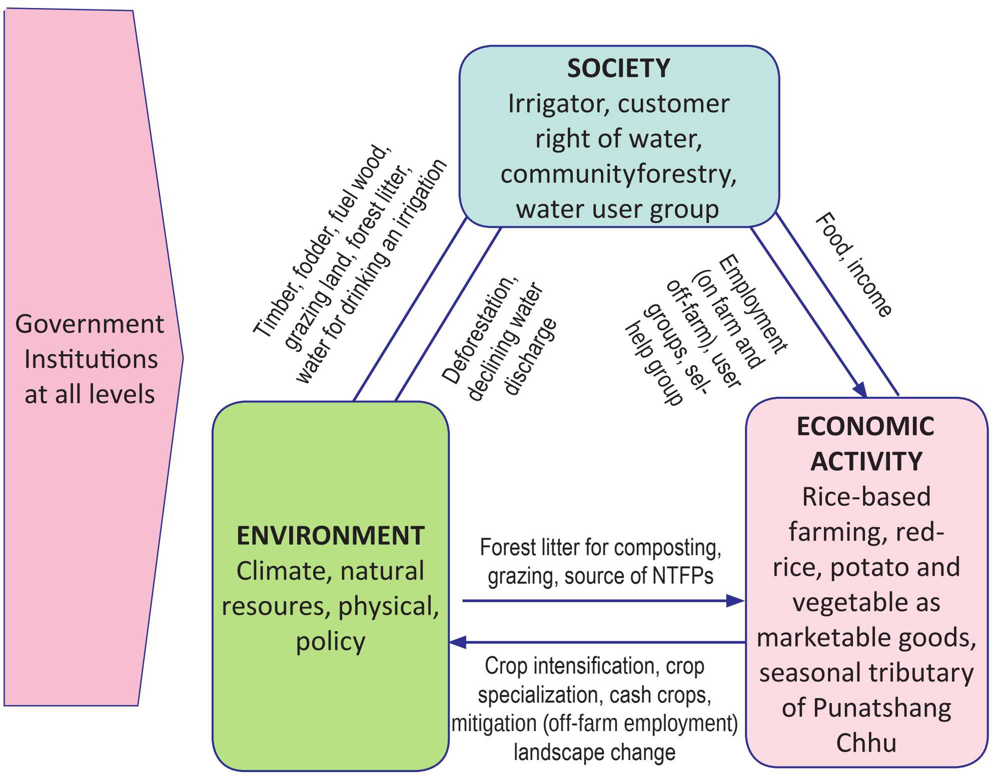

Figure 1.7 Components of the rural socio-ecological system and their interactions at Lingmuteychu, Punakha, Bhutan

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representation five decade ago, the interactions may be different.

The social-ecological system recognizes the fact that ecosystems are complex adaptive systems characterized by non-linear relations, threshold effects, historical dependency, and multiple possible outcomes. Ecosystem structures and processes are linked across spatial and temporal scales. Due to their complexity and the range of positive and negative feedback across scales, the predictability of these systems is limited. As shown in the earlier section, agriculture is probably the most vulnerable human enterprise to change in environment. The impact of change can vary in terms of scale but largely have similar effects in all countries. The disturbances are a natural part of the dynamics of ecosystem development. For example, a fire can seem devastating for parts of a boreal forest from a human perspective, but the forest tends to recover to the status of a functioning forest system after disturbance. In other cases disturbance can cause ecosystems to shift to other states with a corresponding alteration of ecosystem functions. Such phase shifts build on the notion that complex adaptive systems, such as ecosystems, tend to have multiple stable states or stability domains. The ability of ecosystems to remain within a stability domain has been referred to as ecological or ecosystem resilience defined as the magnitude of disturbance that can be absorbed or buffered before the ecosystem re-defines its structure by changing the variables and processes that control its functional characteristics. The diversity of functional groups of species and their capacity to respond differently to disturbances contributes to ecosystem resilience.

As explained earlier, it is the social mechanisms that have a strong link to maintaining ecological resilience. This implies that changes in key social mechanisms could affect the ecosystem state as much as changes in key structuring ecological variables. Hence, the loss of a key social mechanism like trust could not only jeopardize collaborative learning processes but also the ability to maintain a desirable ecosystem state. Therefore, a definition of resilience that incorporates social-ecological linkages has been developed and has the following characteristics:

- the amount of change a system can undergo and still retain essentially the same function, structure and identity (still be in the same state - within the same basin of attraction),
- the degree to which the system is capable of self-organization, and
- the degree to which the system expresses capacity for learning and adaptation.

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There are four critical factors that interact across temporal and spatial scales and that seem to be required for dealing with natural resource dynamics during periods of change and reorganization:

1. learning to live with change and uncertainty;
2. nurturing diversity for resilience;
3. combining different types of knowledge for learning; and
4. creating opportunity for self-organization towards social-ecological sustainability.

Sustainability is viewed as a process, rather than an end-product, a dynamic process that requires adaptive capacity in resilient social–ecological systems to deal with change.

As depicted in Figure 1.8, it puts the focus on the capacity of actors in a social-ecological system to cope with change without limiting future options. In a social-ecological system with high adaptive capacity, human actors have the ability to sustain the combined system of humans and nature in a desirable state, along a desirable trajectory, in response to changing conditions and disturbance events.

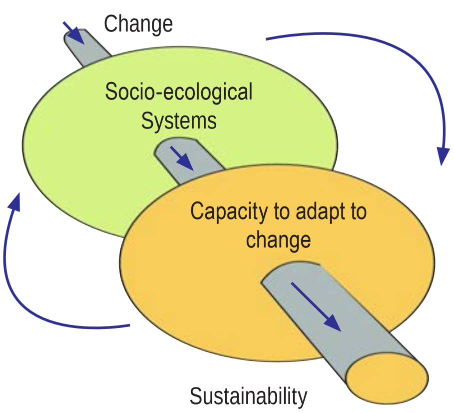

Figure 1.8 Adaptive capacity for sustainability

In short, adaptive capacity is the capacity to respond to and shape change. The social part of this capacity for ecosystem management can include the diversity of expertise and knowledge within organizations such as networks, which gather and store ecosystem knowledge and experience, create flexibility in institutions and problem solving, and balance power among interest groups change management has at least three different aspects, including: adapting to change, controlling change, and effecting change. A proactive approach to dealing with change is at the core of all three aspects. If adaptations are classified into three (autonomous, anticipatory, and reactive), agricultural technologies can also be classified accordingly for easy appreciating their purpose and benefits (Table 1.7).

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Table 1.7 Technologies for up scaling against three types of adaptations

Types of adaptation	Technologies/strategies for up scaling
Autonomous	• Adoption of agro-forestry concepts • Home gardening • Soil and water conservation measures in highlands • Adjustment of cropping patterns and crops • Community based management/support group
Anticipatory	• Agricultural advisory services (India), Early warning systems – engaging community • Use of shallow ground water for supplementary irrigation (Agro-wells) • Shifting of annual cropping lands to perennial fruit crops or plantation crops • Vertical agriculture in urban environments • Intensive agriculture in protected houses • Program and investment to establish seed bank at community level for seed security and crop/variety diversity at the time seed scarcity and • Develop new crop varieties and breeds resistant to heat, drought, new pests and diseases, • Introduction of weather-indexing crop insurance system by integrating micro-finance programs,
Reactive	• Bio-remediation and Integrated Farming • Micro-financing with reduced interest rates by the government's bank • Use of micro irrigation in both annual and perennial cropping systems • Aerobic Rice Production Technology • Plastic Film Mulching Technology • Community based early warning flood prevention systems

Good practices of sustaining agriculture need to be thought about globally but needs actions to be taken at individual levels. It is important for individuals or groups to be sustainable with good practices of sustainable agriculture learned from the sustainable agriculture systems of Sustainable Development chapter

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of class XI enriched with the wisdom from this chapter. An individual farmer's sustainable agriculture practices will support a community to be sustainable and different communities contributing to a nation's food security and sovereignty. 'Practice sustainable agriculture' for our GNH society.

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Student Activity

1. Discuss with the students and carryout a survey to educate school staff, students and local community members on the ideas of sustainable development and what entails 'sustainable agriculture' supported by the principles of agro-ecological system.
   a. Divide students into smaller groups and assign areas of sustainable agriculture practices, such as:
      - characteristics of sustainable food system,
      - themes with specific actions,
      - practices of agro-ecological principles,
      - good practice of gaining food security and sovereignty,
      - conservation of agriculture land degradation,
      - adaptation strategies practiced as per the law of the land, etc.

   b. Develop survey questionnaires of awareness and education in small group in their assigned areas, compile the questions, present and discuss compiled questionnaires to have same understanding.
   c. Discuss strategies of how survey is to be carried out, conduct survey, gather data, compile, analyze, write report on finding and display for people to read and learn.
2. Discuss, plan and implement sustainable agriculture practices (agro-ecology system) in the school campus while gardening for AgFS practice.
3. Discuss adaptation strategies of policies and plans of the government provided in the text, analyze and identify for practice in school gardening as responsible citizens of the GNH society.

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2

Chapter

Introduction to Advance Horticulture

Horticulture is a vast subject and encompasses many aspects of agriculture. However, topics such as types of soil required for horticulture, plant nutrition, crops, seeds production and tree training – apple orchard, etc. are discussed in other chapters of AgFS book from IX to XI and other chapters of AgFS XII. This chapter will focus on the general concepts of horticulture, its importance, scope of horticulture industry and current scientific understanding and progress in modern farming i.e. protected cultivation for sustainable horticulture – the current trend of horticulture industry in Bhutan, procedures of planning and constructing poly-houses/green houses at different climatic locations and use of recommended fertilizers for priority horticulture crops. A brief overview of the horticulture development strategy of the Ministry of Agriculture and Forests is provided, which will be of useful information for anybody opting to take up agriculture as a vocation in life. The horticulture knowledge, skills and values learnt from this chapter are expected to enhance development of good practices of Horticulture in Bhutan.

2.1 Horticulture

The word 'Horticulture' is modeled after agriculture, and comes from Latin words *hortus* means "garden" and *Cultura* means "cultivation". Therefore, the term horticulture means growing of garden crops.

Horticulture is a branch of agriculture that deals with the art, science, technology, and business of plant cultivation. It includes the cultivation of fruits, vegetables, nuts, ornamental plants, medicinal and aromatic plants, herbs, spices, sprouts, mushrooms, condiments, seeds and beverages. It also includes plant conservation, landscape restoration, landscape and garden design, construction and maintenances, and arboriculture.

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Horticulture involves nine areas of study, which can be grouped into two broad sections – edibles and ornamentals, and are listed as follows.

1. Pomology includes the production and marketing of pome fruits (e.g. apple)
2. Olericulture includes the production and marketing of vegetables
3. Viticulture includes the production and marketing of grapes
4. Oenology includes all aspects of wine and wine making.
5. Arboriculture is the study of, and the selection, planting, care, and removal of individual trees, shrubs, vines, and other perennial woody plants.
6. Turf management includes the production and maintenance of turf grass for sports, leisure use or amenity use
7. Floriculture includes the production and marketing of floral crops
8. Landscape horticulture includes the production, marketing and maintenance of landscape plants
9. Postharvest physiology involves maintaining the quality and preventing the spoilage of plants and animals.

2.2 Importance of horticulture

Among all sectors of development, agriculture is essential and major contributor to livelihood security of the people, because more than 70% of the population in developing world is dependent on agriculture and the food security of world population is directly linked with the successful agriculture. The World Bank highlighted the critical role agriculture and rural development can play in helping people move out of poverty and that the sector has the powerful influence on economic growth, poverty reduction and environmental sustainability.

Development organizations involved in poverty alleviation, food and livelihood security issues, have adopted this concept and have moved away from a concern for regional and national food security to a consideration of household and individual food security issues. At the household level the concern shifted from "food first" or food production to a wider focus on the ability of households to secure the food that they required. This then led to a widening of the scope and recognition that food was just one of the ranges of factors that determined poor people's decisions. Thus the evolution of the concepts and issues related to household food and nutritional

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security led to the development of the concept of household livelihood security. In the present context, the main element of livelihood security considered are food security, nutrition security, health security and employment and income generation where horticulture is the lead contributor. It is also recognized that the food security and the livelihood security are inseparable, as also the income generation and the livelihood security. It need not be over-emphasized that nutrition and health have now assumed more importance than before in the life of the people. There is an observable shift in the food habits of people in the last two decades that is reflected as changing cropping pattern, away from cereal base to other commercial crops. During the same period, economic growth in horticulture has far exceeded than that in most agricultural goods. This trend is attributed largely to the changing consumer preferences, powered by increased income and general standard of living led awareness towards diversification and balanced nutrition.

Nath (2012) envisages that the development of horticultural crop production has potential for the developing countries the ability not only to meet their domestic food needs, but offer diversified income sources to their rural economies. Further, horticultural crop based products are proven supplements of human health, besides being sources of farmer household economic and social advancement. Thus, horticultural commodities on the whole seem to be ideally suited to accomplish the objective of providing "sustainable livelihood security".

The rapid urbanization of the developing world and associated changes in life-style will have significant bearing on food preferences and food demand. Hence, the semi-urban and urban agriculture will play an important role and horticultural crops will dominate because of un-parallel advantage of cultivation and production coupled with its nutrition values. The growing importance of horticulture lies in its significant support to food security; as major contributor to nutrition security; as promoter of health security and as an important source of employment and income generation all leading to livelihood security and economic growth (Nath, 2009).

Horticulture crops in the diet are of paramount importance especially from nutrition perspectives. Proper nutrition means the intake of many different kinds of food with a proper balance and in optimal amounts. Fruits and vegetables play an important role in providing vitamins, minerals, micro-nutrients, as well as proteins to obtain a balanced diet. Starchy vegetables and more specifically the root and tuber crops play an important role as a source of calorie to meet the energy requirement. When farmers have better yields by growing cereals, they are no longer poor and hungry. When they shift to horticulture, by growing fruits and vegetables, they can get more income and this will reflect on a better diet, education and livelihood of the family. To sum up, horticulture has important roles in lives of many not only in making a livelihood but also living a healthy life. Therefore, horticulture has immense potential for entrepreneurship but also to contribute to the wellbeing of human race. Let us see what scope horticulture has for young Bhutanese farmers or farm workers.

2.3 Horticulture industry in Bhutan

In the early sixties, major emphasis by the Government of Bhutan was laid on achieving self-sufficiency in food production especially in cereals. However, after mid-1980s it became clear that horticulture, for which the Bhutanese topography and agro-climate are well suited, is an ideal method of achieving sustainability of small holdings. The need for diversification was acknowledged to make agriculture more profitable, through efficient land use; create skillful employment for rural masses and women, and optimize the utilization of natural resources (soil, water and environment). Past efforts have been rewarding in terms of increased production and productivity of horticultural crops. Resultantly, horticulture has moved from rural confines to semi-commercial and commercial venture attracting youth since it has proved to be intellectually-satisfying and economically-rewarding. Horticulture industry in Bhutan has been dominated by potato, citrus, cardamom and apple as the main cash crops. It is however; rapidly changing and the other horticulture such as 'Floriculture and Olericulture' are gaining grounds in horticulture industry in the growing urban centers.

In a country like Bhutan where landholdings are fragmented and small and where access is difficult, horticultural crops is perceived to have a relatively higher comparative economic advantage over cereal crops. In this light, horticulture production is understood to have vast potential in improving the socio-economic conditions of the rural people. The demand for horticultural crops to meet nutrition, food and income requirement is growing in line with increasing population, urbanization and disposable incomes. Except for apple, citrus, cardamom and potato, Bhutan has a negative trade balance for most produce. The domestic production of vegetables (Table 2.1) is increasingly falling behind in meeting the demand. This is resulting in growing import and corresponding trade imbalances.

Reprint 2022

However, this indicates that there is opportunity to increase production to cater to the growing domestic needs. To be able to achieve this, it is not only necessary to enhance production but to produce the crops at a given season and at the reasonable costs. Even for crops like citrus, apple, cardamom and potato, though the price fluctuates yearly, there is established market in neighboring countries with the capacity to absorb as much as can be potentially produced.

The current productivity per unit land is low and the post-production losses are high; thus there are good opportunities to increase production and to reduce post-production losses. The measures refer to increasing productivity, increasing area under cultivation and improving product handling and processing across the entire chain from production to consumption. It involves systematic widening of all technical, institutional/ organizational and policy bottlenecks which prevent farmers from engaging in increasing productivity and expanding output of these commodities. Furthermore, the area under horticulture crop production is limited. However, the recent policy change where in State Reserved Forests can be leased by private parties for commercial production of horticulture, opens up huge potential for the growth of horticulture industry.

Table 2.1 Production, export and import of horticultural crops in million Ngultrum (MT). Source: Agriculture Statistics 2013 and Statistical Yearbook 2013.

Commodity	Production (MT)	Export (MT)	Import (MT)	Export	Import (Nu mil)	Trade Balance (Nu mil)
Potato	50390	25,658	5,285	326	61	26
Citrus	33469	24,432	163	453	8	44
Fruits & Nuts	23139	7,915	2,397	88	72	16
Vegetables	46468	2088	13,529	36	227	-19
MAPS	4918	2067	5	444	1	44
	Total	62,330	74,097	1,347	369	111

Look at the table 2.1, the production, export and import of Horticulture Crops and calculate the value difference between export and import. *Why do you think there is value difference in export and import? How would you as a Bhutanese farmer stop 227 million Ngultrum going across the border?* It is not impossible. We only have to commit ourselves and grow our own fruits and vegetables. Protected cultivation can help us greatly in mission.

Reprint 2022

2.3 Protected cultivation for sustainable horticulture

Since the late 19th century, population all over the world increased rapidly, which demanded more food. This made the food production as an important business. New scientific interventions and repeated cultivation of same or similar crops on the same land, gradually reduced the productivity. The incorporation of inorganic fertilizers and other chemicals degraded the soil health. As the population increases, the demand for quality and diversity of food remain high throughout the year whereas production of these fruits are seasonal and determined by weather conditions. To overcome these limitations, the concept of 'protected cultivation' came into existence. This also gained momentum as the pressure on agricultural land increased due to urbanization, industrialization, land division, etc.

Protected cultivation, poly-house cultivation and greenhouse cultivation are synonymously used. The protected cultivation is generally covered by transparent or translucent material such as glass or plastic. It works on the principle of greenhouse effect of the earth. It requires precision technical knowledge of poly-house designs, climate controlling systems and crop production techniques. The greenhouse cultivation under the glass houses has been popular in the cold European countries for many years but the momentum took place only recently after the introduction of plastics.

Protected cultivation is being used worldwide to produce more and good quality crops with varying levels of area under it. The structures vary from plastic tunnel types to fully automated system. All over the world, the area under protected cultivation is increasing at quite a fast rate. Holland and Israel are the two countries taking the best out of the protected cultivation for vegetable and flower production. In Asia, China, Japan and Korea are the leading users of protected cultivation and it is mostly used for extending the growing season. In Bhutan, Government is also encouraging farmers to grow high value crops under protected cultivation and certain benefits (subsidy on cost-sharing basis) are being given for adopting protected cultivation.

Before starting a protected cultivation, grower must plan in advance all the aspects such as funds/source of capital, crops to be grown, marketing, growing periods (seasonal or year round), medium for cultivation (soil or soilless) and production target. After deciding the above aspects, details of the protected cultivation such as design and cost of climate control mechanism, source of the plant material, source

Reprint 2022

or cost of raw material and complete detail about the company fabricating it should be considered. The type of designs and materials should be according to the local climate. Following points should be considered for different agro-climatic areas:

a) For hot climates

The height should be more than 5.5 m with top and side ventilations with rolling type curtains having insect net under it. Insect net should be of 40 mesh size.

- The percentage of ventilation should be at least 40 - 60% of the total area of the polyhouse where temperature go very high
- A separate evaporative cooling system (fan pad system) may be provided to reduce heat.
- Structural design should have strength to bear high wind load and crop load (>10 kg/m^2)
- Shade nets or thermal screens (50%) can be used to reduce the temperature, preferably on the outer side of the polyhouse
- Water supply must be ensured on regular basis along with rain water harvesting structures. Drainage system should be good.
- Black plastic mulches may be used to reduce evaporation and control weeds.

b) For wet and humid climate

- The height should be at least 5.5 m with top and side vents,
- The percentage of ventilation should be at least 30-40% of the total area of the poly-house where temperature go very high,
- Maintain good air circulation inside the poly-house when humidity is high,
- Water supply must be ensured on regular basis along with rain water harvesting structures. Drainage system should be good.
- Use black plastic mulches to reduce evaporation and control weeds.

c) For cool climate

- The height should be less than hot and humid areas (3-4.5m) and top ventilation should not be there.
- It should be closed completely during night to maintain higher temperature using day time solar radiation
- Structural design should have strength to bear high wind load, snow load

Reprint 2022

and crop load (>10 kg/m^2)

- If required, heating arrangement must be made
- Water supply must be ensured on regular basis along with rain water harvesting structures. Drainage system should be good.
- Use black plastic mulches to reduce evaporation and control weeds
- Insect net must be of 40 mesh size.
- In snow bound areas, gothic type (pointed top) design is more beneficial.

There are different types of protected cultivation and they are as follows:

1. *Quonset:* It is suitable for cool climate but without any snowfall.
2. *Gothic:* It is similar to Quonset but has a gothic shape i.e. distinctly pointed at top of the arch instead of being round and is suitable for cold areas with snowfall.
3. *Single span*: It is suitable for warm climate and is best for small area upto 250 m^2.
4. *Multi span:* It consists of series of single span connected at sidewall through gutter without having a partition wall and are used in larger areas.
5. *Tunnel type:* It is used for raising seedlings and off-season production. These do not have any ventilation.

d) *Planning of protected structures*

Site selection should be based on water availability, natural temperature conditions, frost free days, light, wind, access to market, road, etc. Locating the greenhouse in the right site can help minimize costs, maximize efficiency and maximize productivity.

i. *Orientation*

The lengthy direction of poly-house (gutter direction) should be North-South in multi-span poly-houses and East-West in single span poly-houses.

ii. *Accessibility*

For easy marketing and other uses, poly-house should be near to roads. It helps in taking the produce to markets well in time without any problem and with minimum expenditure.

Reprint 2022

iii. Access to utilities – water

Irrigation water is needed year-round in the poly-house. Trenching and installation of water lines can be done well in advance of construction once the site is identified.

iv. Light

Since poly-house involves the business of harvesting light, maximizing exposure to the sun is very important. To maximize light in poly-houses, an east-west orientation is preferred. With multi-span structures, the orientation should be north-south.

v. Wind

Some wind can help with ventilation and cooling. However, excessive wind can possibly damage the structure.

e) Climate regulation equipment and management

Temperature is the most important factor that influences the crop growth and production in the protected structures. Two basic type of temperature control mechanisms are temperature reducing (tropical and sub-tropical areas) and heating mechanism (temperate and alpine areas).

i. Reducing the temperature

Three types of mechanisms are being used to reduce the temperature of poly houses. They are as follows:

1. *Ventilation:* Ventilation serves two main functions: exchange air between interior and exterior and cooling by ventilating the hot air created inside poly houses. The rate of air removal from poly house must increase as the altitude of the poly house site increases.
2. *Shading:* Shading can be done by application of shading compounds such as common slaked lime or calcium carbonate on the outer side of the covering material of the poly house and application of shade nets above the poly house or shade net below the roof. Lime coating reduces the inside temperature by 3-4oC.
3. *Evaporative cooling:* These are the systems practiced to cool down the temperature of poly houses by conversion of heat to latent heat. With more than

Reprint 2022

80% humidity, the effect of such cooling system turns out to be less effective. In that case, air circulating fan will be more effective as compared to exhaust fan. Another method is misting or fogging. In misting, water is dispersed in the form of fine droplets measuring 50-100 microns. An intermittent misting for a very short duration, ideally, 5-15 seconds is generally recommended. In fogging, fog is generated artificially by ultra-fine water droplets (2-40 microns) to modify the micro environment. Fan-pad cooling system can be of positive or negative pressure system. In positive system, both fan and pad are in the same side of poly house. The fan sucks the air from outside and it blows through the wet pad into the poly house and is suitable for smaller poly houses. In negative system, fan is at one side and wet pad on the opposite side. Fan drives out the inside air and due to pressure difference the hot and dry outside air enter into the poly house through the wet pad which gets cooled down after passing through the pad and moves towards the fan reducing the temperature.

ii. Heating of poly houses

Boiler and heater are the two main heating equipment used in commercial poly houses throughout the world. Boiler system is also called 'control heating system'. The steam (102oC) or hot water (85oC) produced by the boiler is piped to the poly house. Heater system is called 'localized heating system' as individual heater heats a specific area of the poly house. Force heaters, convection heaters and radiant or infra-red heaters are used. Infra-red heaters of solar heating systems are best as they are low energy heaters and reduces fuel and electricity bill.

1. *Lighting:* Light conditions are also very important for plant growth. The problem of radiation deficit during the winter conditions is affecting the poly-house crops and there is the need to improve the growing facilities towards optimizing the light balance in favour of the plants. Growers should pay more attention to the quality of the film in relation to the mechanical or thermal properties but with the optical ones too. Lighting arrangements can also be made for increasing the lighting hours for long day plants during winters.

2. *Water and nutrients:* The use of fertigation (injection of fertilizers) techniques, by means of localized irrigation supplying the water and minerals properly mixed from a unit provided with injecting, mixing, and measuring devices and control elements as well as a distribution system, is generalized in poly-houses. In hi-tech poly-houses, automation of irrigation through equipment with computer and software facilities that can help in the watering decision by

Reprint 2022

means of climatic measurements, namely the amount of solar radiation that is related to the volume of water transpired, is used. Computer modeling is used to calculate water and fertilizer requirements, irrigation scheduling, diseases and insects prediction and planting dates.

3. *Pollination:* When vegetables are to be grown under poly-houses, certain vegetables require pollination which can be achieved by honey bees or bumble bees. Rearing and domestication can also be optional money making business for the grower.

iii. Instruments required

Instruments required for poly-house are a highly accurate thermometer to measure the temperature (0-110oC), dry and wet bulb thermometer to measure humidity and Electro chemical pH meter to measure the voltage to determine the pH of the tested sample solution.

iv. Covering materials

1. *UV stabilized transparent and water impermeable materials* such as
   - *Rigid transparent:* It mainly includes glass, polyvinyl chloride (PVC), polycarbonate and fiberglass reinforced plastic (FRP). The advantages of these types are long life and better thermal and optical properties (low heat loss) but being costly makes them uneconomical for individual grower.
   - *Flexible transparent:* It includes flexible plastic films like polyethylene film (PE), vinyl, etc. The advantages include low cost, good transparency, light weight, etc. but heat loss and low durability are the main disadvantages. PE films of about 200 micron thickness, UV stabilized, anti-drip, multilayer, light diffusing, anti-dust, etc. are recommended.
2. *Insect-proof nets:* These are fixed in the openings for ventilation in the poly-house. Plastic or polyethylene nets of generally 40 mesh size are recommended. As temperature and humidity are main concerns in a poly-house, care should be taken while selecting insect proof nets as decrease in mesh size increases the inside temperature and humidity and vice versa.

v. Low plastic tunnels

It is the low height structures covered with by any transparent material or net made up of plastic to envelop only a row or bed to enhance the plant growth under it. It is a simple structure where covering material may be supported by hoops, made up of

Reprint 2022

flexible GI rods (6-8 mm) or plastic pipes (12 mm), closely placed (1.5-2 m) with a height of 45-100 cm, for the period of the crop. This is primarily used for off-season production of vegetables by increasing the temperature around the plants using transparent polythene film (30-50 micron), shade net or insect protection net. It also advances the maturity of crop by 35-40 days. The rows or bed are to be laid at North-South direction to get maximum sunlight. GI or plastic threads or ropes are sometimes used to fix the film/net from outside along the position of the hoop to protect the tunnel from strong winds. In general, low plastic tunnels can be used to grow strawberry and cucurbitaceous vegetables apart from raising nurseries of different vegetables.

f) Planning, designing and construction of naturally ventilated poly-house

The type and design for construction of a poly-house will depend on the region and the climatic conditions where it ought to be built. For the poly-house framework, GI pipe is ideal as compared to wooden or MS pipe considering the longevity and cost of maintenance although wooden or MS angle/pipe frame works out cheaper but not durable besides necessitating painting regularly to avoid rusting. As regards the size/dimensions, a minimum area of 50m2 or 100m2 for a single span structure for mass production of planting materials or 300 m2 multi-span structures for cultivation of horticultural crops oriented North-South direction was found to be desirable and optimum for commercial production. Among the various cladding materials, use of UV stabilized LDPE film of 200 micron was found to be most ideal. Providing ventilation of 40-60% of floor area (top and sides) for cultivation and 20 to 30% ventilation of floor area on either side for production of planting materials is desirable to maintain the requisite environmental conditions.

i. Planning and designing

The structure should be planned in such a way that it should have provision for future expansion, adaptability to the local region/type of crop and locally available materials must be taken into account. The poly-house should be so designed that it not only withstands the load of prevailing wind velocity, intensity of rain, snow load, occurrence of frost, covering material and the cropping activity but also should admit adequate quantity and quality of sunlight for crop growth and production.

Reprint 2022

ii. Construction

Before taking up the construction, one has to decide whether it should be a single span unit or a multi-span unit. The details are as follow:

1. *Foundation pipes* provide a firm support to the supporting pipes and main structure. GI pipes of 90 cm length and 6.5 cm diameter are used to which 10cm2 3 mm MS flat is centrally welded at one end of the pipe. The flat welded end is put in the dug hole to a depth of 75 cm at every supporting pipe at same elevation grouted with concrete cement.
2. *Supporting pipes:* GI pipes of varying dimensions are made into pieces of required length and are used for grouting as well as on supporting pipe or they are bolted on to the foundation pipe depending on the type of poly-house. The other top end is provided with MS flat of 10 cm x 2.5 cm size for fixing the already fabricated arches with bolts and nut system to complete the structural framework.
3. *Arches* are the integral part of the poly-house frame which are semi-circular in shape and fabricated by bending the GI pipes and joining the ends of such fabricated pipes with MS angles and/or GI pipes of required specifications. Both the ends of the arch should be welded with 10 cm x 25 cm MS flat to enable the fixing of arches on to the supporting pipes.
4. *End frames* are fixed in between the supporting pipes on the sides and at both the ends to have better grip. These end frames are made up of MS angles of 11/4"x11/4"x11/4" or 11/2"x11/2"x11/2" size which are usually to be fixed at the point where the arches and the supporting pipes are to be joined together.
5. *Poly grip assembly:* The polythene covering is to be firmly secured to the end frames of foundation pipes on either side (single span) or between foundation pipe and central purlin, so that it can withstand wind and rain load without being blown off or damaged (sagging). Among the various systems, MS angle and/or MS flats with bolts and nuts system was found to be desirable than "U" channels or poly grippers.
6. *Gutter system* is to be provided where the poly-houses are of double or multi span to drain out the rain water. This gutter system should be made of GI sheet having at least 120 cm drain size and should be fixed to the arch pipes with the help of MS flats in between the two spans of poly-house.
7. *Cladding materials:* The transparent/translucent materials used for covering

the poly-house structure are called cladding materials. Among the various materials, use of Ultra Violet Rays stabilized; low density polyethylene film of 200 micron (800 gauge) was found to be best from its light transmission, durability and the cost point of view.

g) *Planning, designing and construction of shade net house*

Shade net house is a metal or wooden framed structure made of materials such as GI pipes, MS iron angle, wood or stone pillars and covered with plastic nets (net made of 100% polyethylene thread with specialized UV treatment) of different shade percentages. It provides a favourable micro-climate by partially controlling the atmosphere and environment by reducing both light intensity and effective heat during daytime to crops hence year round and off-season cultivation is possible. Shade nets are available in different shade percentages of 15, 25, 35, 50, 70 and 90.

Shade net transmits light evenly throughout the visible part of the light spectrum, thus acting as neutral density filters. Every plant has its own individual requirements for sunlight and shade under which it flourishes at its best. To create optimum climatic conditions, selection of the correct percentage of shade net plays an important role under which the plant's productivity and quality produce is maximized. Under these optimum conditions, photosynthesis is enhanced and extremes of soil temperatures and sometime air temperature are reduced and moderated. Even more importantly, plant leaf temperatures are lowered to the same level as surrounding air temperature and it is this mechanism which accounts for the improved productivity of the plant. The advantages of shade nets are as follows:

- *Light control:* Enhances photosynthesis by manipulating the quantum amount and quality of light by means of various densities of netting.
- *Temperature control:* Improves productivity by moderating extremes of temperatures. It prevents sun burn and frost damage.
- *Wind control:* Air movement is restricted, thus reducing wind damage to the crop and evaporation of soil moisture.
- *Physical barrier:* Shade net provides a physical barrier against hail and heavy rain and keeps many birds and insects off the crop.

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i. Planning for a shade house

The shade house structure should be planned taking into consideration the type of crop to be grown, locally available materials and local climatic conditions. There are no hard and fast rules when it comes to selection criteria of shade nets. It varies regionally, and according to prevailing climatic conditions in each region. In general, 30 and 40% shade net provide ideal conditions for germination of seeds and development of seedlings as this is the highly vulnerable stage of a plant's lifecycle. 50% and 55% shade net are for flowers cultivation and are recommended for general nursery stock. Shade selection depends on the type of crop, its light and photosynthesis needs (see Table 2.2).

Table 2.2 Crop that is suitable for different shading factors

Shading net (%)	Suitable crops	Comments
15%	Tomatoes, peppers, lettuce, spring onions, fruit producing plants, chrysanthemums, carnations, roses.	Prevention of sun burn on fruits, plants that need a good degree of sunlight
30%	Leafy vegetables, vegetable seedlings, cabbage, peppers, lettuce, spring onions, fruit producing plants, cauliflower, sprouts, flower seedlings, strawberry, tomatoes, cucumber, brinjal, capsicum	Prevention of sun burn on fruits, plants that need a fair degree of sunlight (6-8 hours)
40%	Vegetable seedlings, olive root stock, nursery stock, cabbage, peppers, lettuce, some orchid varieties, pot plants	Use as hail net, plants that need a fair degree of sunlight.
50%	Nursery stock, cabbage, peppers, lettuce, some orchid varieties, pot plants, geraniums, caladiums	Plants that require partial shade (3-4 hours)
70%	Ferns, violets, indoor plants, certain orchid varieties, shade loving ornamentals, lilies	Used on domestic shading plants that enjoy dense shade
80%	Some ferns, large olive trees, protection barriers on buildings	
90%	Some ferns, anthuriums, dieffenbachia, aglaonema, dracaeba, indoor plants	

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ii. Design consideration of shade houses

Site location and its selection depend mainly on availability of land but it should be away from natural shades, buildings, trees, industrial and vehicular pollutants. It should be easily accessible, free from drainage problems and windbreakers should be available at a distance of 30m from the structure. The orientation of a shade net house depends on the type and shape of the structure. The square or rectangular type shade net house with a flat roof may be oriented either in north-south or east-west direction. But, if the structure is with a gable or an arch shaped roof which is very common in Bhutan, the lengthy portion of the shade net house is recommended to be oriented preferable in the north-south direction to enable the uniformity of light intensity inside the structure. A shade net house structure comprises of two basic components – frame work viz., metal, wooden or stone and shade net of the required capacity depending on the purpose and the region where it is installed. The shade net house constructed of GI pipes will generally last for about 15 to 20 years. On the other hand, shade net houses constructed with mild steel (MS) pipes treated with anti-rust material will last for about 10 to 15 years.

The framework of the shade net houses can be of locally available wooden materials also like bamboo. When the bottom 3 to 4 feet of the wooden materials are treated with anti-termite / anti decay materials like coal tar, waste engine oil, grease and diesel paste, etc., the framework will last for around 3 to 5 years. If stone pillars of size 14'x 6"x 4" (Length x Breadth x Thickness) is used for erecting the framework of the shade net house of 8' side height and 12' central height will last for about 20 years. Shade net being the second major component of the shade net house, should be selected based on the purpose, season, region and type of the structures. If the structure is constructed mainly for propagation or multiplication of plants, green and black interwoven shade net of 50% capacity is ideal for any region or season. If the structure is constructed for production / cultivation of flowers or vegetables, selection of shade net with regard to colour and shading percentage depends on the crop and the region as in areas where bright sunshine occurs for more than 6 months in a year, then 75% shade nets are recommended, otherwise 25, 35 or 50% shade nets are ideal depending on the light intensity of the region.

Reprint 2022

2.5 Plant nutrients management

Organic manures include plant and animal by-products such as farmyard manure, compost, oil cakes, bone meal, etc. These manures are relatively slow acting, but they supply available N for a longer period. Organic manures supply plant nutrients including micronutrients. Organic manures improve physical properties of the soil, water holding capacity and infiltration capacity of the soil. Organic manures supply energy (food) for microbes and increase availability of 'nutrients and improve soil fertility. Farmyard manure is produced in the farm which is made up of excreta (dung and urine) of farm animals, bedding materials provided for them and house hold wastes. In general, FYM contains 0.8% N, 0.41% P_2O_5 and 0.74% K_2O. Compost is a manure derived from decomposed plant residues usually made by fermenting waste plant materials heaped or put in a pit usually in alternate layers with a view to bring the plant nutrients in a more readily available form. Green manuring is the act of growing short duration crops preferably legumes and ploughing in situ and incorporated into the soil. Green leaf manuring is incorporation of green matter into the soil transported from elsewhere. In our situation, Sesbania aculeate or dhaincha is a very effective green manure. Daincha contains 3.2% N and 34% Ca on dry weight basis which helps to replace plant nutrients.

Bio-fertilizers are living organisms capable of fixing atmospheric nitrogen or making native soil nutrients available to crops. Atmospheric nitrogen is fixed effectively by the microorganisms either in symbiotic association with plant system (Rhizobium, Azolla) or in associative symbiosis (Azospirillum) or in free living system (Azotobactor, blue green algae) or in micorhizal symbiosis (VAM fungi). Rhizobium bacteria can fix atmospheric nitrogen symbiotically. They live in the nodules of host plants belonging to the family Leguminoceae. The quantities of nitrogen fixed by Rhizobia differ with the rhizobial strain, the host plant and the environmental conditions under which the two develop. Azolla is a small water fern of worldwide distribution under natural conditions. It contains blue green algae Anabaena azolla as a symbiont in an enclosed chamber in the dorsal leaf lobes. Azolla derives its entire nitrogen requirement by symbiotic association with the algae. The Azolla–Anabaena system is agronomically most signification plant algal association and this is being employed as a nitrogen source for rice culture.

Inorganic or chemical fertilizers are synthetic (commercially manufactured) or naturally occurring chemical compounds either as dry solid or liquid that are added to the soil to supply one or more plant nutrients for crop growth. They are

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classified as single or compound fertilizers depending on the number of nutrient they contain. Single fertilizers contain only one primary nutrient. For example, urea contains 46% N, single super phosphate contains 16% P and muriate of potash contains 60% K. By using the correct amounts of all three in combination, the exact primary nutrient requirements of any crop can be applied. Compound fertilizers contain all the three nutrients. An example is Suphala which contains 15% each of N, P and K. Secondary nutrients are added to the soil through fertilizers like ammonium sulphate, calcium ammonium nitrate and phosphatic fertilizers. Commercial fertilizers containing these secondary nutrients are: Magnesium sulphate (Epsum) – 9.6% Mg and 13% S, and Calcium sulphate (Gypsum) – 9% Ca and 23% SO_4. Micronutrients are added to the soil through some commercial fertilizers usually in liquid formulation.

The results of numerous farmer extension fertilizer use trials conducted across Bhutan indicate that it is usually more economical to use combinations of single nutrient fertilizers than to use a compound fertilizer supplemented with single nitrogen fertilizers in any crop. The nutrient content of a bag of fertilizer differs between fertilizers. It is written as a figure (%), which indicates the kg of the nutrient in 100 kg of fertilizer as given below:

Table 2.3 nutrient content of 100 kg of fertilizer

Fertilizer	N	P_2O_5	K_2O
Urea	46	0	0
Single Super Phosphate	0	16	0
Triple Super Phosphate	0	46	0
Muriate of Potash	0	0	60
Suphala	15	15	15

Crop growth is influenced by a number of factors of which plant nutrient availability is one important factor. There are 16 nutrient elements considered essential for normal plant growth and reproduction. In the absence of essential elements, the completion of the life cycle of the plant cannot be achieved. If a plant does not get enough of a particular nutrient it needs, it causes a setback to plant growth, and the deficiency symptoms show in the general appearance of the plant. Essential elements are usually categorized into three groups' namely primary nutrients, secondary nutrients and micronutrients. Primary nutrients consist of carbon,

Reprint 2022

hydrogen, oxygen, nitrogen, phosphorus and potassium. Secondary nutrients consist of calcium, magnesium and sulphur. Micronutrients consist of iron, zinc, copper, boron, molybdenum, chlorine and manganese. Primary and secondary elements are also referred to as macronutrients. Primary nutrients are required in larger quantities by the crop, and large quantities have to be applied if the soil is deficient in one or more of them. Secondary nutrients are needed in lesser amounts than primary nutrients, and the micronutrients are required in small quantities. Carbon, hydrogen and oxygen are obtained from air and water while the other thirteen elements are referred to as fertilizer elements and have to be obtained from the soil. Nitrogen, phosphorus and potassium are most often applied in commercial fertilizers or in manures. Secondary elements are normally applied as soil amendments or are components of fertilizers that carry primary nutrients. Although micronutrients are required by plants in very small quantities, they are equally essential to plant growth. The amount of each element required by the plant varies; however, all essential elements are equally important in terms of plant physiological processes and plant growth.

Three main terms are used to indicate the time to apply fertilizer and they are as follows:

- Basal dressing: Application of fertilizer or manure at or before sowing or planting the crops. Slow nutrient release fertilizers such as SSP, MoP and Suphala and slow nutrient release manures such as farm yard manure and compost are best applied as basal dressing.
- Top-dressing: Application of fertilizer or manure when the crop is standing in the field. Fast dissolving fertilizers such as urea are best applied by top-dressing.
- Split application: Application of fertilizer or manure in split doses at different stages of crop growth to avoid nutrient losses through leaching or volatilization. Urea is best applied in splits especially in light textured soils and in areas with high rainfall, because it is very soluble and does not stay in the rooting zone.

a) Integrated Plant Nutrient Management

Judicious combination of inorganic, organic and bio-fertilizers which replenishes soil nutrients removed by crops is referred as Integrated Plant Nutrient Management (IPNM) system. The concept of IPNM is to integrate the nutrient sources and methods of organic and inorganic nutrient application to maintain soil fertility and productivity i.e., the complementary use of chemical fertilizers, organic manures

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and bio-fertilizers to solve the problems of nutrient supply, soil productivity and environment. Developing an INM system for a particular crop sequence to a specific location requires a thorough understanding of:

(i) the effects of previous crop,

(ii) contribution of legume in the cropping system,

(iii) residual effect of fertilizers, and

(iv) direct, residual and cumulative effect of organic manures for supplementing and complementing the use of chemical fertilizers.

The main components of the N supply system are organic manures, green manures, crop residues, crop rotation and inter cropping involving legumes and cereals, and bio-fertilizers. All these can serve as an important supplementary source of nutrients along with the chemical fertilizers. Thus, INM is environmentally non-degradable, technically appropriate, economically viable and socially acceptable.

Nutrients taken up and removed by crops in the harvested product and the by-products should be replaced with external inputs (fertilizers, manures, etc.) to avoid depleting soil nutrient reserves. Some of the important recommendations for effective fertilizer use are as follows:

- Use SSP and MoP as a basal dressing. However, in areas with light textured soils and high rainfall, apply MoP in two or more splits to avoid losses through leaching.
- If urea is the only source of nitrogen, apply half the recommended rate as a basal dressing and use the remaining half to top-dress at the appropriate growth stage of the crop. If using a compound fertilizer like suphala, use urea to top dress I two or more splits.
- Always use FYM or compost at the rate of 2-3 MT/acre to help maintain soil structure and fertility.
- Do not use fertilizer rates higher than the recommended rates as this wastes money.

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- To apply the exact recommendations, use single nutrient fertilizers together, or with a compound fertilizer. If using Suphala, apply it at the rate needed to supply the amount of which ever recommended nutrient rate is the lowest. Then use single nutrient fertilizers, either as basal dressing or top-dressing, to supply the additional amounts that the crop needs of other nutrients.
- All chemical fertilizers should be mixed with soil. Keep a distance of one-two feet away from the tree when fertilizer is being mixed with soil. Most of the feeder roots that take up the nutrients from the soil are in the region under the tree canopy and applying nutrients in this area ensures proper uptake by the roots.
- The soil should be moist or a light irrigation should be applied after the application of fertilizers. The fertilizers must be dissolved to release nutrients and these nutrients can only be reached to root zone by water.

b) Fertilizer recommendation for priority horticultural crops

A yield target will be reached only when the correct amount of nutrients is supplied at the right time to match the crop's nutrient requirement during the season. High input farmers are aiming for "yield maximization" i.e. best yield with no resource constraint. Low input farmers are aiming for "profit maximization" i.e. best return on limited resources. Recommendations are presented as kilogram per acre of the main nutrient e.g. 26:16:16 means 26 kg N + 16 kg P_2O_5 + 16 kg K_2O per acre.

Table 2.4 Fertilizer recommendations for potato

District	High Resource Farmers			Low Resource Farmers		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Bumthang	40	32	24	32	36	18
Chukha	32	20	12	24	16	8
Gaylegphu	32	24	16	24	20	8
Haa	32	24	12	24	16	8
Paro	40	32	32	28	28	12
Thimphu	40	28	12	28	20	8
Trashigang	40	32	32	36	32	12
Tsirang	40	32	12	32	24	8
Wangdue	40	32	32	28	24	12

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Apply the entire dose of SSP, MOP and Suphala as a basal dressing. If half the urea is applied as basal dressing, then top-dress the other half at earthing up when the leaves are about 10-15 cm long, or at tuber initiation. Phosphorus is immobile in soil; therefore, it should be either mixed into the seedbed before planting or banded at planting. Potassium is also relatively immobile in the soil; therefore, it should be applied pre-plant and mixed into the seedbed. Place fertilizers close to but not in contact with seed tubers for more efficient fertilizer use. The desirable soil pH range is of 6.0-7.0. Soil pH above 7.0 can damage skin quality.

Table 2.5 Fertilizer recommendation for chilli

Area	High Resource Farmers			Low Resource Farmers		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Rain fed	24	18	18	16	8	8
Irrigated	28	24	24	20	12	12

Apply the entire dose of SSP, MOP and Suphala as a basal dressing. If half the urea is applied as basal dressing, split the other half into 2 top-dressings at 30 and 60 days after planting. Use 2-3 tons per acres of FYM / compost at land preparation. Chilli needs deep, well-drained soils, rich in organic matter and pH of 6.5 -7.5.

Table 2.6 Fertilizer recommendation for other vegetables

Crop	Time	FYM (MT/ Ac)	Nutrient (Kg/Ac)			Comments
			N	P2O5	K2O	
Asparagus 1st Year 2nd Year	Basal Side		20 60	36 40	16 80	Apply FYP / compost at transplanting. From the 2nd year, side dress fertilizer.
Beans	Basal	5-8	10	30	0	Grows on wide range of soils, pH 5.5-6.8
Brinjal	Basal Topdress		16 16	28	12	Best temperature for growth 25-30oC. Top-dress 30 DATP.

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Cabbage, Cauliflower & Chinese Cabbage	Basal Topdress1 Topdress2	5-6	20 10 10	30	0	Well-drained soils, pH 6-6.8, 1st top dressing 30 DATP & 2nd top-dressing 60 DATP
Carrot	Basal		8	4	24	Needs K for proper development of roots.
Cucumber	Basal Topdress	8-10	18 12	14	10	Requires good moisture & FYM / OM. Loamy soils. pH 5.5-6.8. Top dress 4-6 weeks after planting
Garlic& Onion	Basal Topdress	8-10	20 20	30	30	Top-dress after 6-8 weeks. pH 6.0-6.8. Bulbs may be poor on heavy wet soils.
Lettuce	Basal	4-5	8	16	8	Needs continuous moisture
Pea	Basal	8-10	20	30	30	Grows on all soils except waterlogged / compacted soils
Radish	Basal	4-5	20	20	20	Grow best in light OM-rich soil. pH 6.6-6.8
Saag& Spinach	Basal	8-10	20	0	0	Grow well in all soils; prefers well drained soils & adequate FYM/OM. pH 6.0-6.8
Tomato	Basal Topdress	4-8	20 15	20	10	Grows best in rich, well-drained soils. pH 5.5-6.8. Top dress 30 DATP

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Table 2.7 Fertilizer recommendation for citrus

Plant Nutrient	Nonbearing trees (g/tree/yr)		Bearing trees (g/tree/yr)		Time of application
	Nutrient	Fertilizer	Nutrient	Fertilizer	
N	50-100	110-220 g urea	150-250	330-550 g urea	After harvest & prior to spring flush
P_2O_5	20-50	126-315 g SSP	50-100	315-630 g SSP	
K_2O	100-150	170-255 g MOP	250-350	425-595 g MOP	

Micronutrients should be applied when trees have the most fully expanded leaves but based on soil & plant analysis result.

Table 2.8 Fertilizer recommendation for apple

Plant Nutrient	Non-bearing trees (g/tree/yr)		Bearing trees (g/tree/yr)		Matured bearing trees (g/tree/yr)	
	Nutrient	Fertilizer	Nutrient	Fertilizer	Nutrient	Fertilizer
N	46-69	100-150 g urea	46-69	100-150 g urea	69-92	150-200 g urea
P_2O_5	16	100 g SSP	24-32	150-200 g SSP	32-48	200-300 g SSP
K_2O	60-90	100-150 g MOP	90-120	150-200 g MOP	120-150	200-250 g MOP

Micronutrients should be applied based on soil & plant analysis result. N application should be split, half in December-March with full P and K; other half in June. Irrigate / moisten the soils after fertilizer application.

Table 2.9 Fertilizer recommendation for areca-nut

Plant Nutrient	Year 1 (g/palm/yr)		Year 2 (g/palm/yr)		Year 3 onwards (g/ palm/yr)	
	Nutrient	Fertilizer	Nutrient	Fertilizer	Nutrient	Fertilizer
N	34	75 g urea	67	147 g urea	100	220 g urea
P_2O_5	13	81 g SSP	27	169 g SSP	40	250 g SSP
K_2O	47	80 g MOP	94	160 g MOP	140	238 g MOP

For areca-nut, apply FYM in planting pit and early, 1-3 baskets / palm / year, according to tree size. FYM and compost may be applied in single dose in September – October. The fertilizers may be applied in two split doses: one third may be applied in May-June and two-third along with the organics during September – October. The first dose of fertilizers may be applied in basins of about 1 m radius, made around the palm to a depth of 15-20 cm and the second dose of fertilizers can be applied to the base of each palm all around and mixed with the soil by a light forking. A yield target will be reached only when the correct amount of nutrients is supplied at the right time to match the crop's nutrient requirement during the season. High input farmers are aiming for "yield maximization" i.e. best yield with no resource constraint. Low input farmers are aiming for "profit maximization" i.e. best return on limited resources. Recommendations are presented as kilogram per acre of the main nutrient e.g. 26:16:16 means 26 kg N + 16 kg P_2O_5 + 16 kg K_2O per acre.

It is important for the farmers to be critical in the use of IPNM and constantly ask '*What is the essence of IPNM (Integrated Plan Nutrient Management)? How would that be useful to farmers? Is it sustainable? Are there no alternative ways of enriching and renewing plant nutrients?* The farmers must keep on exploring for better solutions to sustain their farm.

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2.6 Horticulture Development Strategy of the MoAF

In the 11th FYP, a lot of importance is given on the promotion of horticulture crops for commercialization as well as from crop diversification point of view. In line with the commodity development initiatives, the following commodities viz. vegetables, citrus, potato, mushrooms, fruits and nuts, medicinal, aromatic plants and spices and floriculture will be continued with a greater emphasis on increasing the production for meeting domestic requirement and enhancing income through export.

The commodity programs therefore focus on all necessary measures for the advancement of the productivity, competitiveness and output of the targeted crop value chains in support of enhanced national food and nutrition security. A holistic commodity-chain approach covering production, post-harvest management, processing and marketing will be pursued to ensure a sustainable yet a very profitable horticulture industry.

Identification of potential areas and potential crops/varieties will be key to increasing the national horticulture productivity. Selection of potential areas will include parameters such as agro-ecology, road access, availability of land (including use of degraded state reserved forest land) and irrigation facility where rainfall is uncertain.

Two-pronged horticulture development strategy will be pursued. Potential areas which have road connection and with good market potential, commercialization will be promoted; while in outlying areas and where land-holding is limited and expansion is not an option, backyard farming and primary processing such as drying and fermentation will be supported to enhance household food security and improve nutrition.

State reserved forest land (SRFL) with potential for horticulture production shall be identified. Farmer/farmer groups shall be formed to take up cultivation of horticultural crops. It is envisaged that such leased lands would be large in terms of land area, thus it is imperative to select crops that have good market potential. Access to good quality planting materials is vital. Both government and private nurseries will be promoted and supported adequately to produce premium quality planting materials.

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Irrigation of horticultural crops needs attention. Modern irrigation will be introduced to replace traditional systems which lead to wastage of water and are inefficient. Demonstration orchards and farms should invest in modern irrigation. Simultaneously, supply of drips, sprinklers and others shall be introduced in the private sector. Innovative water harvesting techniques will be tested and promoted where feasible.

Integrated pest and disease management will be the guiding principle for plant protection. This will entail use of pest and disease resistant varieties, orchard hygiene management, use of bio-pesticides and when absolutely necessary efficient use of chemical pesticides as the last resort.

The long-term success of horticulture will depend on how well the land is managed. To prevent soil erosion and depletion of nutrients, judicious use of chemical fertilizers, cover crop planting, wind breaks, control of soil erosion by rain water etc. will be put in place where necessary.

Proper plant nutrient management is also critical to enhance the yield and quality of horticultural crops. Different types of plant nutrient will be tested, following which site and crop specific plant nutrient program will be introduced. Organic produce has a niche market and wherever feasible organic farming will be stepped up.

Appropriate post-harvest loss reduction technologies will be disseminated to growers and traders. Government investments are required to put post-harvest infrastructure such as cold stores, ambient stores and pack-houses in place. At the same time private investment will be encouraged for establishment of infrastructures through soft-loans and subsidies; so that in the long run, such facilities are fully owned and operated by the private entrepreneurs.

Bhutan has potential in the value addition of horticultural crops, considering abundant water supply, relatively cheap power, good communication system and the availability of diverse range of raw materials. This is an area where there is good scope for public private partnership. Potential value addition enterprises will be identified and promoted among the private sector. On a smaller scale, small scale food-processing ventures that have domestic market potential will be promoted on individual or community level, on cost sharing basis. Market infrastructure, market information and market research and development are imperative for a

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vibrant horticulture industry. Market structures and auction yards will be set up wherever feasible. To avoid seasonal market gluts, match demand and supply and ensure a consistently high price, it is fundamental to have a well-designed market information system (MIS). Alternative markets will be explored for export crops such as apple, mandarins, potatoes and a host of important fruits, vegetables and medicinal and aromatic plants.

To enhance the economy of scale of production or reduce marketing costs, horticulture producers or marketing groups will be pursued where feasible. Training on group management, resolving of conflicts etc. and assistance in the formulation of laws and by-laws will be provided. In collaboration with relevant agencies, crop insurance scheme will be introduced. Such schemes have to be attractive to both the insurer and the insurance companies.

There is a need to privatize and promote some of the regular services such as pruning/ training, plant protection, plant nutrient management, etc. provided by the government to farmers/ growers. Initial government support in the form of training to the service provided and some basic equipment, etc. would be warranted to kick start such business opportunities.

Significant budget allocations are required to efficiently increase domestic production and reduce import. Funding is required for all interventions such as infrastructures, inputs, services, storage, processing/value adding, marketing, capacity development, organization development, subsidies, and credit facilities. Similarly, private sector involvement is also to be encouraged in this process, in the context of the government's Public-Private Partnership (PPP) and Foreign Direct Investment (FDI) policies.

To conclude, in the present time of modern life and living, food has emerged with important components like adequacy, nutrition and health requirements which are often referred to as food security, nutrition security and health security. Horticulture undoubtedly has a serious stake in nutrition and health security. In order to ensure that horticulture continues to contribute effectively towards achieving food, nutrition and health security, adequate budget allocation, sound policies, enabling environment for economic growth and human well-being, innovations, etc., are very critical. Horticulture farming should be taken up as a business and innovations should be there in all aspects in order to increase the crop productivity per unit area, improve the produce quality, engage unemployed

Reprint 2022

youths, pursue sustainable development and ultimately achieve the livelihood security of Bhutanese people.

Protected cultivation enables some control of temperature, moisture, wind velocity, mineral nutrients, light intensity and atmospheric composition that are conducive for plant growth. It contributes to better understanding of growth factor requirements and inputs for improving crop productivity. Protected cultivation is a unique and specialized form of agriculture. Devices or technologies for protection such as green houses are used with or without heat. The purpose is to grow crops where otherwise they could not survive by modifying the natural environment to prolong the harvest period, often with earlier maturity, increase yields, improve quality, enhance the stability of production and make commodities available when there is no outdoor production. The primary emphasis is on producing high value horticultural crops such as vegetables and ornamentals. Green house technology as an important component of protected cultivation is gaining popularity in our country. It is mostly used for vegetable production in colder areas or during the winter season.

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Student Activity

1. Discuss, with the class, to study the local climatic condition and horticulture that can be grown in protected cultivation, poly-house cultivation, green house cultivation and shade net house and
   - a) Plan, design and propose constructing poly-house/green house or shade net house in the school campus to the school management,
   - b) Construct green house or shade net house with locally available materials or materials available in the market,
   - c) Plan growing of pattern of horticulture plants in the green house /shade net house for sustainability of protected cultivation farming,
   - d) Prepare soil, water and plant nutrients appropriate for the horticulture crop,
   - e) Identify Horticulture (vegetables, medicinal herbs, fruits or flowering plants) to be grown in the green house /shade net house,
   - f) Install climatic condition control equipment appropriate to the crops, net for control of insects, regulation of fresh air, etc.
   - g) Sow seeds or plant horticulture in the house or net shade and maintain growing conditions such as humidity, temperature, light and fresh-air.
   - h) Monitor and manage horticulture plants growing in the green-house or shade net house.
   - i) Market horticulture produce, or use of the produce, records expenses and economic returns from the protected cultivation.

   Or

2. Plan a field trip to a govern farm or private farm where protected cultivation is practiced to:
   - study the work involved in protected cultivation, expenses, advantages and dis-advantages, economic return and challenges.
   - seek professional and technical support on starting protected cultivation of horticulture.

Reprint 2022

3

CHAPTER

Introduction to Organic Agriculture

Bhutan had traditionally subsistence mixed farming systems that integrate cropping, livestock rearing, and use of forest products being organic by nature and it is so in most parts of rural Bhutan even today. It is, however, different in places of growing urbanization such as the capital city and in the more progressive dzongkhags. While some Bhutanese farmers are learning to produce more from their farms using some chemical fertilizers, pesticides, etc. and make more money, there are also consumers who are increasingly becoming more health conscious and demand healthy and safe food as in other parts of the world. Organic Agriculture is gaining popularity in Bhutan and it has good scope for development.

This chapter starts with basic concepts on organic agriculture (OA) and its importance, types and principles of organic farming, agro-biodiversity and ecological balance of an organic farm, procedures of composting and manure management. Government's strategies and policies on supporting organic produce, regulation and certification to go for international marketing of organic produce of Bhutan are also discussed. It is hoped that Bhutanese literate farmers will take organic farming and serve this GNH nation, but first there is the need to understand what organic agriculture is, why organic agriculture and how organic agriculture is different from other forms of agriculture?

3.1 Organic Agriculture

Organic agriculture is essentially a production system that sustains the health of soils, ecosystems and people. It relies on ecological processes, biodiversity and cycles adapted to local conditions, rather than the use of inputs with adverse effects. Organic agriculture combines tradition, innovation and science to benefit the shared environment and promote fair relationships and a good quality of life for all involved. In simple words, organic farming is a way of farming that improves the health of the soil, plants, animals, insects, and the entire agro-ecosystem.

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It promotes the use of on farm resources over off-farm external inputs such as chemical fertilizers, herbicides and pesticides.

Organic agriculture was close to what was practised in Bhutan before the use of fossil fuel and petroleum based agrochemicals such as fertilizers, fungicides, pesticides and herbicides were introduced as farming aids as part of the green revolution technology to increase food production. Some farmers have learned to depend on these synthetic chemical based farm inputs so much that many have forgotten the natural way of farming with the use of indigenous and traditional knowledge. We have started losing the link with the natural ecosystems and the inter-connectivity of the environment we live in with all other living things such as plants and animals. People are least aware of the existence of microorganisms in the soil. Though invisible to the human eye, it is said that a gram of soil contains more organisms than there are human beings on this earth.

With the increasing use of fertilizers used in conventional agriculture, the residues pass through the soils and water systems and eventually end up in the oceans. This results in the contamination of waterways or rivers and oceans resulting in toxic water which poses serious threat to the aquatic life. In countries where very high levels of agrochemicals are used, the soils do not respond to increased application of fertilizers anymore. Pests, diseases and weeds have become resistant to the pesticides, plant-protection chemicals and herbicides used to control them. The food products in some countries have excess chemical residues leading to chronic health issues. This in turn escalates the expenditure on public health care. We need to ask ourselves '*Should we learn from other's mistakes or do we knowingly repeat what others are experiencing? Can we decide not to repeat history if we can avoid it?*'

a) Benefits of Organic Agriculture

Adopting organic agriculture in our food production has several benefits in the long run for the health, environment and economy of the country.

i. Benefits for people

It leads to overall improvement in quality of life because organic agriculture produces healthy chemical free food, promotes health and provides food security and sovereignty.

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ii. Benefits for environment

Improves soil fertility, reduces water and air pollution, protects natural and agricultural biodiversity, assures safe and healthy environment for the future generations.

iii. Economic benefits

Organic agriculture provides fair returns for farmers, creates rural employment, and reduces cost of farming due to reduced need for purchasing external farm inputs. Better income for safe healthy foods through potential premium or better sales and reduced risk of farm income due to diversity of crops on farm.

iv. Suitable for rural communities

Organic agriculture is particularly well suited for rural communities in developing countries that are currently most exposed to food shortages with poor or marginal farm lands. Since organic agriculture contributes to food security by a combination of many features that are good for the smaller farms such as family farms as those found in Bhutan.

b) Features of Organic Agriculture

Some of the features that contribute to organic farming are series of practices that are traditional, sustainable and good for the long term productivity, are as follows:

1. Increasing yields in low-potential areas (e.g. dry lands) and market-marginalized areas
2. Conserving bio-diversity and nature resources on the farm and in the surrounding environment
3. Increasing income and/or reducing production costs
4. Producing safe and diversified food suited to the local soil and agro climatic conditions
5. Creating sustainable food supply chains for local farmers and communities
6. Reducing dependence of imported farm inputs such as synthetic fertilizers and pesticides,
7. Reducing dependence on imported food
8. Reducing exposure of farmers to harmful toxic agrochemicals.
9. Increasing food diversity and nutritional security

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10. Increasing local food trade within the country
11. Reducing pollution caused due to conventional production systems

c) Principles of Organic farming

Organic farming is known by various names, definitions and description in different countries. However, a group of common concepts has been developed based on widely used definitions common to these farming systems to describe what can encompass organic farming and related activities by the International Federation of Organic Agriculture Movement (IFOAM). In the process of production, processing, trading, and consumption all actions should adhere to or promote the following principles among people, animals, and natural resources. The four principles of organic agriculture are as follows:

1. *Principle of health* - Organic agriculture should sustain and enhance the health of soil, plant, animal and human as one and indivisible.
2. *Principle of ecology*- Organic agriculture should be based on living ecological systems and cycles, work with them, emulate them and help sustain them and must not lead to imbalances.
3. *Principle of fairness*- Organic agriculture should build on relationships that ensure fairness with regard to the common environment and life opportunities. Responsibilities and benefits must be shared equally among the stakeholders: animals, farmers, workers, processors, distributers, traders and consumers.
4. *Principle of care* - Organic agriculture should be managed in a precautionary and responsible manner to protect the health and wellbeing of current and future generations and the environment.

The above four principles are translated into practice of organic farms in various ways by farmers or operators of organic establishments trying to ensure that in the process of their farming or business that these principles are kept in mind. Some examples of such efforts are through the following:

d) Agro-biodiversity and Ecological balance in the farm

In an organic farm, all efforts are put in to establish a balance of a holistic cyclic system whereby, all natural resources are reused or recycled and the farm is designed to encourage the growth and development of a bio-diverse condition by planting a wide variety of crops for all purposes for a livelihood on farm such as food, medicine, fodder, textiles, dyes, biomass, feed and shelter for animals. On such a farm, the natural habitat of animals and native plants and water sources are protected so that the ecological system established on the farm can support a balanced existence of humans, wild and domestic animals with native plants and cultivated crops. When a farm has good ecological balance, the soils are healthy, the crops are healthy, and the prey and predator numbers enable a natural control of pests and diseases.

i. Natural habitat in the farm

To encourage a good balanced ecosystem on farm the natural habitat in the form of water ponds, or streams and springs are taken care of. Maintenance of border plants such as live fences, trees and hedges, buffer zones, nearby forests and along streams are taken care of so that a host of birds and bees, worms and insects will be part of the helpers who make the farmers work easier. Selection of plants besides the main crops such as pollen, nectar, seeds and berries for birds are important to attract animals and animal predators to our garden to pick on the pests. Building or protecting the refuge of such beneficial animals should be incorporated in the farm plan.

ii. Friends and Foes important to recognize

There are many different types of insects in a garden which might be seen as pests. However, not all insects and animals are pests; some are friends of farmers who work in controlling the population of harmful pests. While managing a farm it is important to recognize which are friends and which are foes as this will help the farmers or gardener in maintaining a healthy environment and well balanced ecosystem of prey and predator so that the damage done to crops is minimal and the need to use pesticide is prevented.

iii. Plant or animal selection

In an organic farming system it is important to start a crop or animal farm with suitable varieties, species and companions so that management of the crop or animals is easy. Resistant varieties of crops and animal species are selected to ensure that they do not easily fall sick or suffer damage. Locally adapted varieties of seeds and species of animals will survive and do much better than hybrid seeds and pure breeds of livestock animals as they can manage with much lesser soil fertility or poorer diet of feeds. They will not be dependent on high fertilizer

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inputs and irrigation in crops and medications and feed formulations in livestock.

iv. Livestock production

Having livestock on an organic farm is an integral part of a complete integrated organic farm as the soil fertility and plant health management has to depend on animal manure and by-products such as droppings, urine, milk, and dairy products, which are used very widely since thousands of years in our traditional farming. The farm management will be much easier with cattle /livestock on farm than without any animals. The animals on farm function as producer, processor, recycler, provider and protector of crops from pest and diseases.

Organic livestock production needs to be considered in two ways. First where farm animals are maintained as part of the organic farm mainly as producers of manure, users of waste and to recycle resources to support crop production, second is when livestock production is the primary enterprise and crop production is to support livestock production such as poultry, dairy, meat or fisheries.

v. Animal feed and health management

Ideally on an organic farm, most of the animal feed, fodder and medicines need to be organically produced that are allowed by law for use in organic production. Use of synthetic fertilizers, pesticides, herbicides, antibiotics and vaccines are not permitted to be used as part of regular management. Animals on organic farms have to be treated well and their welfare and health ensured so they have a comfortable living conditions. Sick animals are provided with extra medical care with approved medicines and they need to be isolated from the rest of the herd till the animals are well.

vi. Soil nutrient management

The status of soil health and fertility are the most important factors in an organic farm as all the nutrient requirements for the crop have to be met from the natural sources that are added to the soil and chemical addictives such as NPK cannot be added. However, NKP requirements need to be ensured though composts, manures, green manure incorporation and other organic matter to the root zone. To develop ideal soil conditions, drainage, aeration, organic matter content, irrigation and soil pH, nutrients levels are maintained so that the soil supports micro flora and fauna that helps decompose organic matter and convert into humus that can support healthy plants.

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vii. Crop rotation

Crop rotation is a system of growing of different crops in different plots each year in such a sequence that any similar type of crops is not grown in the same plot for another three to four years. Usually, a highly exhaustive crop grown is followed by a legume to fix nitrogen. The benefits of such a crop rotation in a field have better yield and reduced diseases. A typical example of crop rotation in practice is the cole crop-potato rotation. A plot grown with cole crops previously needs to be replaced with other non-Brassica crops.

viii. Mulching

Mulching has many benefits in crop production. Having mulch on the soil or bed can help to conserve soil moisture, retain heat or keep the soil cool, suppress weeds, add organic matter to soil and also reduce soil erosion.

ix. Plant nutrition

Plant nutrition can be provided through chemical fertilizers in the form of NPK or through natural mean by way of farm yard manure (FYM), composts, minerals, liquid manures, compost teas etc. Some claim that the plant cannot differentiate the NPK coming from chemical fertilizers or that coming from compost. However, the difference is seen in the quality of soil structure as chemical fertilizer in the long run damages the soil structure and productivity. Use of composts and natural inputs provides a multitude of required elements. The aim of soil fertility management is to build a strong healthy soil that supports strong and healthy plants.

x. Green Manures

Green manures are leguminous or other crops grown before a main crop mainly to be ploughed in just before flowering stage to get the highest level of nutrient into the soil. Leguminous crops are preferable as they not only add nitrogen with the rhizobium found in the nodules of the roots but also add the green biomass as organic matter in the soil.

xi. Liquid manures

They can be made either from soaking compost in water as compost tea or prepared with weeds and plant materials with cow dung and cow urine. Liquid manures are fast and convenient to make and use as to supplement nutrition for crops when there is not enough compost at hand.

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3.2 Composting

Composting is a technique of converting the wastes into humus-rich manure to improve the fertility and productivity of soil. It's very simple and suitable for small holder farmers. During the process of composting biodegradable wastes like crop residues, weeds, leaf litter, animal wastes etc. are transformed into manure which is called as compost. The compost is rich in beneficial soil microorganisms, provides the nutrition to the crops and improves the structure and texture of the soil. Compost provides many benefits as a soil amendment and as a source of organic matter by improving soil biological, chemical, and physical characteristics viz.,

- Increases microbial activity, compost rich with all kinds of microorganisms and soil fauna that help convert soil nutrients into a form that can be readily absorbed by your plants.
- Enhances plant disease suppression with increased plant health and rich microbial population, the microorganisms, enzymes, vitamins and natural antibiotics that are present in compost actually help prevent many soil pathogens from harming your plants
- Increases soil fertility with the most complete range of balanced nutrients over many months unlike chemical fertilizer that provides fast but short term effect.
- Improves soil structure in clayey soils to be fluffy and friable
- Improves water retention in sandy soils with increased organic matter and humus
- Adding compost moderates pH and fertility problems

There are different methods of composting which are practiced across the world, some simple and common methods are heap composting and worm composting. Various ingredients can be used in the compost depending on the availability in the local area or the farm. Important points to consider before composting are as follows:

- Sources of raw materials used for composting
- Containers or locations
- Water and shelter
- Labour and maintenance

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a) How Composting Happens

Organic matter is transformed into compost through the work of microorganisms, soil fauna, enzymes and fungi. When making compost, the best possible environment for these beneficial organisms to do their work has to be provided. With the right balance of environment, the decomposition process works very rapidly but if you don't provide the optimum environment, decomposition will still happen, but it may take from several months to several years.

The trick to making an abundance of good compost in a short time is to balance the following four things:

i. Carbon

Carbon-rich materials are the energy food for microorganisms. You can identify high-carbon plant materials because they are dry, tough, or fibrous, and brown in color. Examples are dry leaves, straw, rotted hay, sawdust, shredded paper, and cornstalks.

ii. Nitrogen

High-nitrogen materials provide the protein-rich components that microorganisms require to grow and multiply. Freshly pulled weeds, fresh grass clippings, waste fruits and vegetables, kitchen scraps and other moist green matter are the sorts of nitrogen-rich materials you'll probably have on hand. Other high-protein organic matter includes kelp meal, seaweed, manure and animal by-products like blood or bone meal.

iii. Water

Moisture is very important for the composting process. But too much moisture will drown the microorganisms and too little dehydrate them. A general rule of thumb is to keep the material in the compost pile as moist as a well-wrung sponge. If you need to add water, sprinkle the pile with water whenever dry. Using an enclosed container or covering your pile with a tarpaulin or roof will make it easier to maintain the right moisture level.

iv. Oxygen

To do their work most efficiently, microorganisms require a lot of oxygen. When

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your pile is first assembled, there will probably be plenty of air between the layers of materials. But as the microorganisms begin to work, they will start consuming oxygen. Unless you turn or in some way aerate your compost pile, they will run out of oxygen and become sluggish.

v. Microorganisms and other soil fauna

They work most efficiently when the ratio of carbon-rich to nitrogen-rich materials in your compost pile is approximately 25:1 (brown to green) but most people find three parts brown and one-part green works quite well. In practical terms, if you want to have an active compost pile, you should include lots of high-carbon "brown" materials (such as straw, wood chips, or dry leaves) and a lesser amount of high-nitrogen "green" materials (such as grass clippings, freshly pulled weeds, or kitchen scraps).

If you have an excess of carbon-rich materials and not enough nitrogen-rich materials, your pile may take longer to decompose (there is not enough protein for those microbes!) and produce compost with low Nitrogen content. If your pile has too much nitrogen and not enough carbon, your pile will also decompose very slowly (not enough for the microbes to eat!), have less volume and not be bulky and it will probably be soggy and smelly along the way.

vi. Catalysts

Some activating materials such as forest soil, manure, compost, bone meal, rock phosphate, rock dust, dolomite, wood ash, etc. can be sprinkled onto your compost pile as you build each layer. They will add important nutrients and will help speed up the composting process and produce balanced compost with good NPK ratio.

Heat is generated by the intense microbial activity in the heap. It indicates that the microorganisms are eating the organic matter and converting it into finished compost. The temperature of the compost pile determines what types of microbes are active. There are primarily three types of microbes that work to digest the materials in a compost pile. They each work best in a particular temperature range:

The psychrophiles work in cool temperatures from even as low as - 2^0C. As they begin to digest some of the carbon-rich materials, they give off heat, which causes the temperature in the pile to rise. When the pile warms to 15 to 20^0C, mesophilic bacteria take over. They are responsible for most of the decomposition work. If the

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mesophiles have enough carbon, nitrogen, air, and water, their work can raise the temperature in the pile to above 37^0C. At this point, thermophilic bacteria come in. It is these bacteria that can raise the temperature high enough to sterilize the compost and kill disease-causing organisms and weed seeds. Three to five days of 70^0C. is enough for the thermophiles to do their best work.

b) To Turn or Not to Turn

The purpose of turning is to increase oxygen flow for the microorganisms, and to mix un-decomposed materials into the center of the pile. If you are managing a hot pile, you'll probably want to turn your compost when the interior temperature dips below about 43^0C. Monitor the temperature to check if the heat is on in the centre of the pile. After turning, the pile should heat up again, as long as there is still un-decomposed material to be broken down. When the temperature stays pretty constant no matter how much you turn the pile, your compost is probably ready. Though turning can speed the composting process, it also releases heat into the air, so you should turn your pile less frequently in cold weather. There are several ways to help keep your pile well-aerated, without the hassle of turning:

i. Choice of structure

Generally, there are two types through which wastes can be decomposed at the farm level. Mainly composting is done in a heap or tank like structure with provisions for aeration. Any one of these can be used. Heap method is economical and easy to manage. Wooden boxes, old bathtubs, washing machines, containers of all kinds can be used for composting.

ii. Construction of the heap

The dimensions of the heap or tank are; width 2m, height 1m and the length depends on the quantity of the material. At the base of the heap a layer of old branches or wooden logs or big stones should be laid as this would provide aeration and prevent water logging. The heap is constructed using alternate layers of green biomass and dry materials from plants and animals like cow dung slurry, poultry, weeds, etc. Composts can be enriched using minerals such as rock phosphate, dolomite, gypsum etc. Soft green plant materials like stinging nettle that are partially decomposed are said to act as catalyst in speeding decomposition.

Turning also improves aeration of the heap. The first turning should be done

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after 2-3 weeks of heaping, when temperature has started to drop after reaching a peak. The heap can be turned again after three weeks of first turning. If the heap is prepared properly, not compacted, holes are made and proper ratios of residues having different C: N ratio, is maintained; only one turning of the heap is enough.

c) *Maturing of compost:*

The time required for the heap to mature and become good compost, depends on the local climatic conditions and the materials used. If the weather is warm, the heap is moist, well aerated and good combination of materials is used for building the heap, the compost is ready in three months' time. In colder or dry conditions and dominance of materials with high C: N ratio, heap usually takes 4-5 months to ripe. When the compost is ripe the material is converted from dark brown to grey colour, gives an earthy smell and is coarse. The volume of the mature heap is reduced to half of the original.

The following pictures (taken from the Training Manual) below shows the procedural steps of compost making.

Step 1- Basal layer for aeration

Step 2- First layer of waste material

Step 2- Preparation of cow dung slurry

Step 4- Heap building with dry/fresh material

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Step 5- Finishing up of the compost heap

Step 6- Thatched roofing

Figure 3.1 Steps of making compost

d) Worm Composting

Farming earthworms by feeding them to multiply the worms is called vermi-culture. Vermi-composting is the method of converting wastes into compost by use of earthworms. Manure worms, red worms, and branding worms (the small ones usually sold by commercial breeders) are active when it comes to decomposing organic matter—especially kitchen scraps. The problem is that these worms cannot tolerate high temperatures. If worms are added to active compost pile, they'll be dead in an hour. Field worms and night crawlers (common garden worms with one big band) are killed at even lower temperatures.

To maintain a separate worm bin for composting food scraps, you need a watertight container that can be kept somewhere that the temperature will remain between 10^0C and 27^0C all year-round. Good quality compost is produced in a short period depending upon on the number of earthworms. In other words, about 4-5 kg of wastes can be composted by 1000 worms (approximately 1 kg) in a day. The commonly used earthworms like *Eudrillus sp. Perionyx sp., Eisenia sp.* or any locally available surface feeding (epigeic) earthworms can be collected from the nearby soil and then used in vermi-composting.

Vermi-composting can be made in a tank or in any old container on the soil surface. The tank can be constructed with bricks or stones depending on the availability of materials. The height of the tank should be 0.75 metres, width 1 metre and length can be 3 - 4 metres or even more depending on the availability of raw materials. Smaller sections are easier to handle during preparation and harvesting. The base of the tank should have a slight slope directing towards two drainage holes. Basal Sand Layer - The first layer (5-10 cm) at the base is of sand as

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it helps in the drainage of excess water and also prevents the movement of worms into deeper layers of soil or out of the tank.

- *Dung Layer* - On the top of the sand, a layer of one-month old dung is laid. This layer is approximately 3-5 cm. thick.
- *Waste Layer* - On the top of this dung layer all the biodegradable wastes are put and the tank is filled up to the brim (65 cm) with the waste.
- *Soil Layer* - The wastes are covered with a thin layer (1-2 cm) of soil.
- *Dung Layer* - Above the soil layer mature dung is uniformly spread (3-5 cm) which forms the top layer in the tank.

In other words, the wastes are sandwiched by two layers of mature dung. The contents are moistened with water (40-50% moisture level) for 7 days to pre-decompose the contents. After pre-decomposition, worms are introduced (1000 worms approximately 1 kg for 100-150 kg of wastes) and watered regularly to maintain 30-40 % moisture level for better activity of worms. Watering is done in such a way the contents in the tank are not too soggy or too moist as it results in earthworms dying. The tank is covered by a gunny sack in summer months to avoid evaporation of moisture. In places where the predators like rats, lizards, pigs are a major problem; the tanks can be covered with wire mesh to prevent them from feeding on the earth worms.

Step 1- Preparation of vermi-compost tank

Step 2- Waste layer on the dung and sand layer

Step 3- Layer of fresh material

Step 4- Locally collected earthworms

Step 5- Final dung layer

Step 6- Gunny sack to maintain moisture

Figure 3.2 Pictures showing stepwise demonstration of vermin-composting

i. Collection of vermi-compost

Vermi-compost appears on the top of the tank in the form of pellets. When this layer of vermin-compost becomes a few centimetres thick watering should be avoided for 3-4 days. The reduced moisture at the top layer will force the worms to move down towards the lower layers. The compost formed is heaped in the corners of the tank by gently scrapping with a shovel or a wooden raft and left for a day or two. This enables the worms to move towards the fresher food and away from compost so that compost can be used. Or compost taken from the top of the heap can be sieved and the worms are put back in the compost heap. This method

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ensures that the worms are not damaged and the compost can be collected every 7-10 days till 80% of the material is collected i.e 10-15 cm layer is left at the base. The tank/heap should be refilled with pre-decomposed wastes after the compost has been removed for use.

ii. Refilling the Tank or Heap

The compost tank is refilled with Pre-decomposed material to about 75% of its height. The standard procedure of vermin-composting as mentioned above is continued i.e over the pre-decomposed waste, a thin layer of soil is spread and the dung spread above it. The worms come on to the top and start feeding on the waste.

e) Bio-digester

The bio-digester is a structure where the wastes from cattle sheds are collected and put in a tank at the lower end of the shed so that all the dung and urine are collected and utilized. In this tank, any weeds, chips, mulches, biomass wood chips can be added and let to soak with water and ferment. The mixture is stirred up regularly to give aeration and mix the contents. Another small tank is built nearby connected through a pipe so the liquid from the mixture can be collected in the second tank. This liquid is rich with strong nutrient. This extract is diluted at the ratio of one (extract) to ten (water) and sprayed to soil, vegetable crops or tree crops for nutrient supplement as well as for pest and disease control. This is a popular technology preferred by farmers for its easy management.

(a) Biomass and cattle collection unit

(b) Digested liquid collection unit

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(c) Bio-digester with plant biomass

(d) Collection of nutrient rich liquid

Figure 3.3 Bio-digester

3.3 Effective Micro-organisms (EM)Technology

The Effective Micro-organism is cultured with beneficial microbes that exists in local environment, popularly used as inoculants for Organic farming. EM is a bio and eco-friendly brown solution. EM consists of three types of bacteria, namely *lactic acid bacteria, photosynthetic bacteria* and *yeast bacteria.*

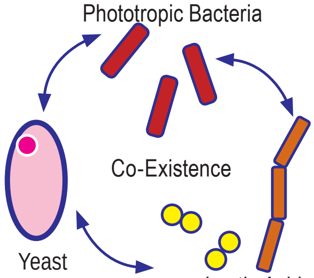

Figure 3.4 EM Technology

EM was first developed by a Scientist named Professor (Dr.) Teruo Higa in University of Ryukyus in Okinawa Japan in early 1980 and registered with EM Research Organization (EMRO) as trade Mark EM^{TM}.

a) How EM Technology works?

As mentioned in first paragraph, three types of microbes present in EM, with its specific function for crop and livestock health. Lactic Acid Bacteria (LAB) has the capacity to decompose the organic matters by fermentation process and it produces lactic acid that protects and keeps away the harmful

Lactic Acid has a barrier that keeps harmful microbes away

Figure 3.5 LAB

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microbes from the plant body maintaining a healthy crop. Usage of Activated EM in field can keep away most of the harmful microbes due to the presence of lactic acid. The organic matter undergoes faster decomposition providing nutrients to plants and improving the soil structures. Feeding EM in drinking water and feeds induces Lactic acid bacteria in the rumen of cattle that enhances digestion and keeps animals' health.

Photosynthetic bacteria have the capacity of decomposing harmful gases, such as ammonia and hydrogen sulfide and change them into odorless gases. Therefore it helps to reduce the bad smell from the decaying organic matters. Therefore using EM in cleaning toilets, pigsty and in composting reduces bad smell.

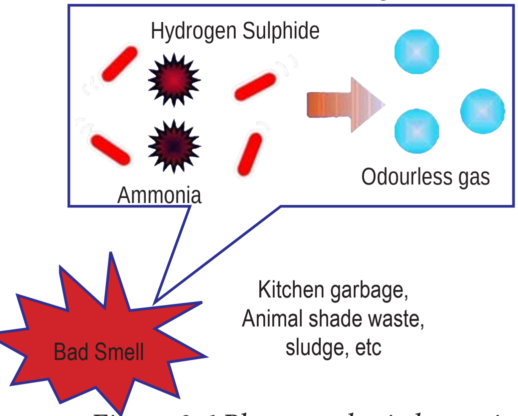

Figure 3.6 Photosynthetic bacteria

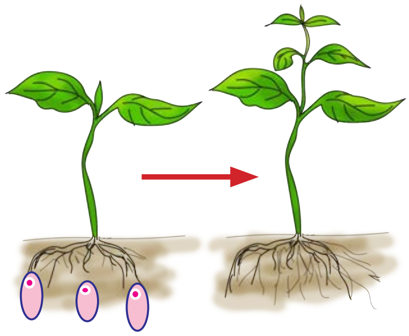
Figure 3.7 Yeast bacteria

Yeast bacteria present in EM solution have the perfect capacity to decompose the organic matter through the fermentation process that results in faster compost formation and improves the soil fertility. During the fermentation process yeast also produces bioactive substances like hormone and enzymes that promote the plant growth. Therefore, the crops grow healthier and faster with EM compost. In livestock, the presence of yeast bacteria helps in acceleration of fermentation process of dung in the rumen resulting in better digestion.

i. Concept of EM in Nature

Mechanism of EM working in nature is very simple. As in nature there are both harmful and useful microbes both in water, soil and air. However, with little efforts from external source, the population of effective microbes can be added and the harmful microbes suppressed

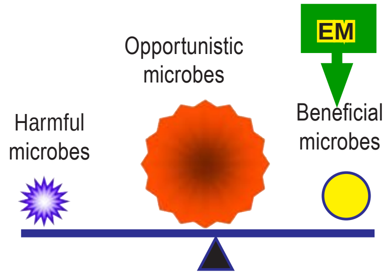

Figure 3.8 EM in nature

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as shown by the diagram where EM as beneficial microbes has suppressed the harmful microbes.

ii. Fetching EM Solution

The use of EM Technology begins with Fetching of EM Solution from the nearest EM Production Centre. Service and information from the nearest RNR Centre should be obtained for its availability.

EM1 or Mother Solution, in Bhutan can be currently collected either from the EM Centre, NSSC (National Soil Service Centre), Simtokha, Thimphu or RNR RDC, Bhur Gelephu. Once fetched, EM1 solution can be kept for maximum of six months under cool and dark storage condition. It should be kept air tight in Jerricans. The quality of EM1 will be deteriorated if kept for more than 6 months.

iii. Process of EM Activation

EM mother solution is dormant and it has to be activated before using.

- Activating EM is done by adding water and sugar in standard ratio of 1:1:50 (1litre EM1:1 Kg Sugar/Guar: 50 litres of water).
- Mix and store in dark place with airtight container for a week.
- Activated EM can be stored only for 1 month under cool and dark condition.
- Use activated EM (EMAS) within 1 month.
- Make another stock of activated EM before the completion of existing activated EM solution.

The diagram below depicts the process of EM activation and dilution after a week period of fermentation.

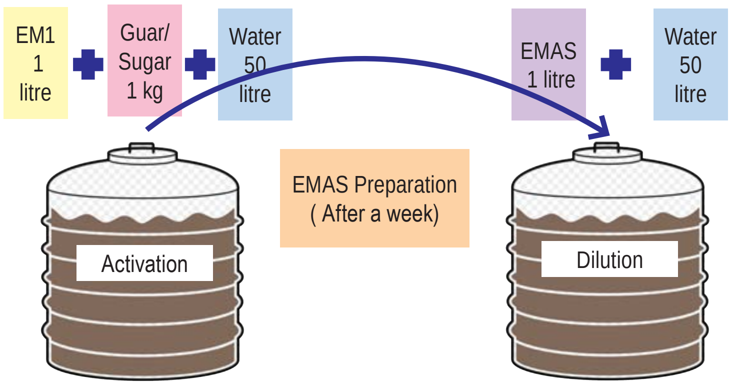

Figure 3.9 steps of EM activation and dilution

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Please note: Use clean water, do not use chlorinated water in EM as it can also kill the useful the EM microbes. Do not use EM in hot water that is above 40^0C. Do not store activated EM (EMAS) more than 1 month as the food for microbes get exhausted and the microbe population gets lesser resulting in poor performance. A fresh stock of EMAS should be prepared one week before the last stock gets exhausted.

iv. Dilution for usages

Activated EM (EMAS) is recommended for dilution to be more economical and also to avoid osmotic distortion in plant physiology. Activated EM (EMAS) can be diluted at different ratios based on the need and purpose. However, general dilution recommended for schools in Bhutan is 1: 50 (1 liter of activated EM in 50 liters of water). It can be used in composting and drinking water for livestock, especially for piggery and poultry. The EMAS can be daily prepared based on the need. Do not keep diluted EM more than 24 hours as it can be contaminated and feeding to livestock may result in complications. Therefore, dilute the required quantity just before usage.

b) Application of EM

EM solution can be applied in multiple ways of daily life as follows:

i. Agriculture

Activated EM (EMAS) is used in compost making to enhance the decomposition process and add the beneficial microbes resulting in faster soil fertility. Carefully prepared EM fermented plant extracts can also be used as insects' pest repellent in vegetable farming. Fermented compost is called "Bokashi" and can be prepared by mixing EMAS with kitchen waste or plants materials that can be used as manures in gardening. Fermented plant extracts with EM called (EMFPE) can be sprayed in plants to add nutrients and as pest repellents in vegetables.

How to make EMFPE (EM Fermented Plant Extract)

EMFPE is made from fermentation of fresh aromatic weeds and plants with EM. Therefore, EMFPE contains organic acids, bioactive substances, minerals and other useful organic compounds that are produced or extracted from plants through fermentation process.

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EM FPE is mainly used as a plant activator and insect's pest repellents. Plants and plant products from neem, stinging nettles, Artemisia, mint, Xanthoxylum, ginger, garlic, chilli and any plants with strong and pungent smells are good combinations with EMAS for extraction of EMFPE that can be used as organic pesticides.

To make 20 litres of EMFPE, you require following materials;

- ✓ Fresh aromatic/pungent smell weeds (chopped) : 3-4 kg
- ✓ Crushed Xanthoxylum/Ginger/Garlic/Chilli powder: 300 g (Optional)
- ✓ Clean water (Not chlorinated): 14 litres
- ✓ Molasses/Sugar based glucose: 420 g (3% of water volume)
- ✓ EM1 Solution: 420 g (3% of water volume)
- ✓ Plastic drum or bucket 20 L (Air tight lid): 1 No

Process of preparation

Following process of preparation may be considered to make 20 litres of EMFPE as home-made Organic pesticide in Organic farming.

1. Chop freshly harvested weeds into small (2-5cm) pieces and place in container.
2. Mix EM and molasses in water and add to weeds in container.
3. Cover container with black polythene or vinyl for airtight container (i.e. container must be full).
4. Store the container in a warm and dark place. (Ideally 20^0C to 35^0C), away from direct sunlight.
5. Fermentation is initiated and gas is generated within 4-8 days. This depends on the ambient temperatures.
6. Stir the liquid in container at the interval of 3 days to release gases and avoid explosion.
7. EM FPE is ready to use, 10-16 days from the preparation. Usually a good EMFPE has sweet and sour taste with pH value of 3-4.5.
8. Sieve the liquid and bottle the EMFPE in plastic bottle and regulate the air release every 3 days until you finish using it. Never use glass bottle to store the EMFPE as it can be explosive if not regulated properly.

Note: EMFPE best used within a month from the date of bottling. The bottling should be airtight.

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Application of EMFPE in the crops

EMFPE works mostly as avoidance and repellent for most of the insect's pest, besides adding certain micronutrients to the crops.

ii. General application

Mix 1 liter EMFPE in 2 liters of water (Ratio 1:2) and spray regularly at the interval of 3 days from the transplantation till harvest to avoid pest such as cut worms, flea beetle, white butterfly and green aphids. Sprays are also determined based on the prediction of pest incidences according to weather

iii. Upon insects pest incidence

If you see the crops already infested by certain insects pest and you could not control by other IPM methods, then a concentrated spray of EMFPE at the ratio of 1:1 (EMFPE:H20) may be sprayed at alternate days until they are eradicated. Normally three sprays should either repel the insects or even kill due to direct contact effect of concentrated EMFPE to the soft skin of pest.

Normally in Chemical sprays, harvest of crops for immediate consumption before a week is lethal, however immediate harvest with the organic sprays is not a problem, although a thorough wash with clean water before consumption is always a good habit of Water Sanitation and Hygiene (WASH).

iv. Animal husbandry

EMAS can be diluted @ 1:50 in drinking water and fed daily to the poultry and dairy cows, to keep them healthy and productive. Bokashi feed can be prepared by mixing EMAS with animal feed and fermented that can be mixed as additives in the regular animal feed to improve palatability and improve digestion, resulting good health and production.

EMAS can be used in fish pond and shrimp farms to rejuvenate the quality of water and improve the health of aquatic life.

v. Environment and Sewerage treatment

EMAS is used in treatment of sewerage pond to improve the Biological Oxygen Demand (BoD) and suppress the foul smell. Use of EM in Organic farming can reduce the usage of Chemicals and save the environment. EM mud ball are used

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to treat the foul smell in sewerage pond. EM can be sprayed daily in City garbage landfill sites to induce faster decomposition and reduce foul smell. Public toilets can use EM to reduce the bad smell reducing the cost for buying phenyle.

vi. Household use

EMAS solution can be sprayed daily in toilets and wash basins to keep it clean and avoid foul smell. Kitchen garbage can be sprayed daily in the plastic containers and converted into good EM compost. Diluted EMAS can be used in cleaning household furniture (tables, chairs and electronic gadgets) that keeps glazing and avoids insects attack. Diluted EMAS can also be sprayed in indoor plants to protect them from insects/ pest and keep them look beautiful.

****** **Caution**: *EM should not be used in combination with Chemicals such as Phenols, Dettols and other synthetic chemicals as there are chances of the useful EM being killed.*

c) Compost Making using EM

i. Heap site and size

The ideal site for compost heap should not be in water logged areas. It should be either under a semi shed or under a canopy of well branched trees. Compost do not like too much of rain or too much of sunshine. So building a shed over a compost heap to maintain optimum moisture and avoid too much sun light. The size of heap should not be too big or too small. If the heap is too big, it is difficult to handle and there will be some portion without moisture and

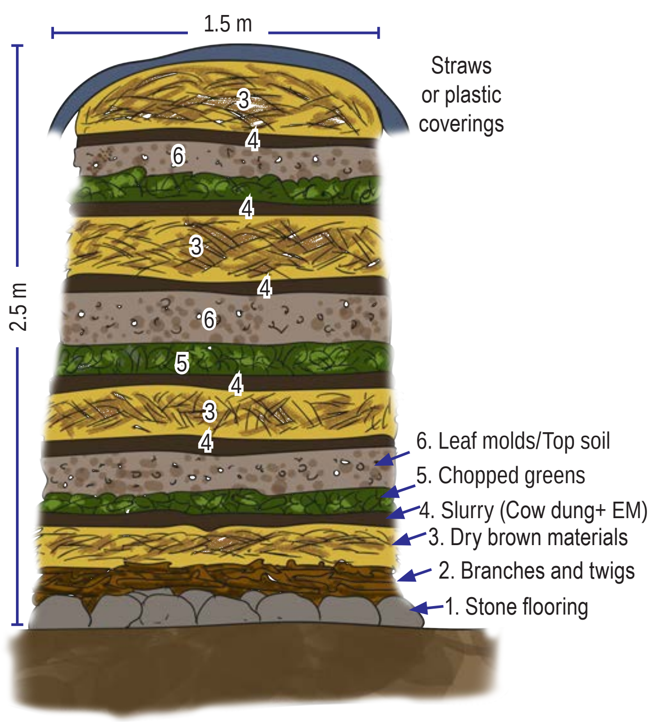

Figure 3.10 Vertical section of Heap Compost by different layers

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heat do not build up. Similarly, if the heap is too small, it will easily dry up and raising temperature for decomposition will be difficult. Ideal size of Heap compost should be minimum of 2 m length X 1.5 m breadth X 2.5 m height, with tapering top narrower than the base. Too big size is difficult to manage and too small size also cannot retain the heat and moisture required for composting.

ii. Preparation of cow-dung slurry

One litre of EMAS is diluted in 50 litres of water. One Kg fresh cow dung can be mixed with 10 litres diluted EMAS, i.e 1:10 (Cow dung: Diluted EM) that is sprinkled or spread sufficiently to wet all the materials thoroughly at every layer as inoculants.

iii. Formation of compost heap

It is like making the foundation of a building and mixing of different materials of green and brown materials to provide sufficient food for microbes. The foundation of heap is made with thinly laid stones/bricks and on top of stones tree twigs and branches are kept for good aeration and strong basement. The first layer of heap on top of the twigs are brown materials viz (chopped straws) followed by green materials and leaf litters/top soil. In every layer slurry is sprayed to make the materials well drenched followed by adding another layer of composting materials until a desired height of 1.5 m is obtained. Each layer of well chopped brown and green materials should be staged layers after layers at the ratio of Carbon to Nitrogen (C:N) ratio of 25:1. Carbons (C) from dry and brown materials such as dry leaves, top soils and straws are required by microbes as food for energy and multiplication. Nitrogen (N) from green materials such as green leaves and grasses are required for protein and body building. Too much of C slows down the decomposition and too much of N produce decaying compost with bad smell. Addition of some wooden ashes adds traces of phosphorous in the compost.

Note: Compost can be made even absence of EM solution by using cow dung slurry. However, use of EM enhances the acceleration of decomposition process.

iv. Aftercare and management

The faster the heat formation, more the microbial activity takes place resulting in faster decomposition rate of compost. The population of microbes is influenced by the available or balance of C: N ratio, which should be preferably 25-30:1. The cover

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of the compost heap with gunny bags or plastic helps in formation of heat and retention of moisture. If you feel the heap inside is too dry, water manually from time to time either from a running water pipe or from a bucket as less moisture slows down the decomposition process. Do not drench it as it can develop unfriendly environment for microbes and slows down the composting process due to less aeration. The heap should be turned over after every four weeks making a total of two turnings and mixing up. Sufficient moisture in the heap compost is mandatory for proper composting. Properly managed compost should be ready by the end of two months. Pack the compost in an airtight gunny bags and keep it in shade until used. The good compost smells like mud and should not smell foul.

Figure 3.11 Well decomposed Compost by 2 months of preparation

Discussion questions

1. *From where you can fetch EM Mother Solution?*
2. *Which microbes are present in EM solution and what are their functions in Agriculture?*
3. *Describe the steps of activation of EM1 mother solution to EMAS.*
4. *Prepare a practical project on preparation of EM compost for Organic farming.*

3.4 Organic approaches of managing pest, disease and weeds

Management of pests, disease and weeds are major issues in an organic farming system as any other farming system. These problems are approached with a long-term strategy like a planned planting, adopting certain cultural practices and being prepared for the worst situation. The following are some of the important ones to adopt.

i. Prevention of problems

A basic understanding of plant physiology as to when and under what conditions pest and disease problems break out is a good starting point. Maintaining a

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healthy plant condition can reduce the incidences of pest and diseases. Stress under heat, water, cold are sources of problems. Ensuring that the crops or animals are managed under optimum conditions will reduce pest and disease problems. However well prepared, unexpected problems will crop up and the best way to manage is to have a good monitoring schedule in the daily farm operations. Regular inspection of the crops or animals to identify pest and disease problems by the farmer or operator is important. Identifying the problems early – before the problem becomes widespread on the farm, solves half the problem. Problems can often be addressed easily.

ii. Cultural and mechanical Practices

Understanding of local climatic conditions, crop suitability, seasonal weather situations and pest conditions are important as a starting point. Crops planted at a time when it is not prone to pest and disease attacks or coincide with heavy rains or dry spells is essential. Hand picking insects or removing them manually before population builds up is a good way to keep pest numbers under control so that the damage done to crops is minimum.

iii. Trap crops

Besides physical separation of crop from pests by using net houses to protect the crops, other forms of traps are also used. Trap crops are used to distract pest insects from main crop in the field so that damage is reduced. Usually brightly coloured flowering plants such as marigold or mustard are good for planting on the borders or at intervals within the fields.

iv. Intercropping

It is referred to as the planting of different crops or plant species of varying heights in alternate lines or alternate beds. This helps to utilize the nutrients in the soil at different soil depths as well as providing a break in similar crops in the field inviting fewer attacks by pests on crops.

a) Botanical Pesticides preparations on farm

Preparation of pesticides solution from plants that can be used as pesticides must be a regular activity on an organic farm like EM solution and keep solution ready for improving soil nutrients or against pest as and when needed.

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Bio-pesticides are best prepared with available local plant materials known for their medicinal values, and used as bio-pesticide in our tradition and culture. Traditionally, plants such as artemisia (Khempa), stinging nettle, lantana, eupatorium, walnut leaves and cover, etc., are all known to have good properties to control pests and diseases in crops. These plants can be used as mulch or chopped and extracted as liquid or even fermented and the liquid extracts used as spray for pest control in a diltution of 1:10 with water. Other materials that can be used to make bio-pesticides are onion, garlic, chillies, ginger, Szechwan pepper (*Zanthoxylum peperitum/ Thingey*), baking soda, vinegar, cooking oil.

Figure 3.12 Garlic cloves crushed into fine pieces mixed with cow's urine

i. Biological control

It is control of pests including weeds and diseases that cause destruction by disrupting their ecological status. This can be done with the use of one organism to control another that is causing damage to crops such as predators, natural enemies or parasites. They are used in the form of introduction of bio controls such as lady bugs, lacewings, or bacteria, fungi and virus. Some that are commonly used outdoor in gardens are Trichoderma, *Bacillus thuringiensis* (Bt). Trichoderma is a fungus that repels other fungi. Bacillus *thuringiensis* is a Bacterium used to control caterpillar. It is used like a spray on crops.

ii. Management of weeds

It is one of the most challenging problems in organic farms, especially in a place like Bhutan where labour shortage is acute. Chemical weed control using herbicide is not acceptable in organic systems so either mechanical and cultural weed management or bio control have to be used. Weeds are most commonly controlled

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by hand weeding using small tools or by mulching the ground with dried plants, sheets or cloth or plastic sheets to prevent weed growth. Steam and flame is also used to control weeds by burning the weeds with heat. Some bio-herbicides used are natural vinegars (citric acids, lime/ lemon juice, apple cider vinegar) found effective in controlling weeds, or introduction of some insects eating the weed species. Vinegars control weeds by changing the pH and disrupting the growth of the undesired plant. Use of animals like chicken, ducks and geese in controlled areas and fish in rice field are few methods of managing weeds.

b) Seeds

In organic agriculture open pollinated seeds play a very important role than hybrid seeds. The hybrid seeds although yield high and of expected better quality is expensive and can be used for only one season. Their seeds cannot be conserved and used again. Farmers have to be fully dependent on the seed companies every season which increases the risk especially for small land holders. Open pollinated varieties breed "true to type" and adapt well to low-cost agriculture using organic principles. The open pollinated seeds have advantages over hybrid seeds and ensure seeds for the small scale farmers for their next season without having to depend on a seed supplier and farmers can exchange seeds amongst the community. Bhutan has always had a very strong tradition conserving the traditional varieties. Traditional varieties are not adapted to industrial chemical farming but to small scale farming which rely on crop rotation, crop diversification and systematic varietal mix up of crops from different genetic makeup.

i. Source of seeds

Good crops are best assured with the use of good seeds and disease tolerant or resistant varieties. Sourcing the right variety seeds of good quality is of prime importance in an organic farming system. It is important that the seeds you get have sources either from an organic seed producer or that the seeds are not treated with chemicals for packaging and storage.

ii. Seed selection

Select good seeds – suitable varieties with resistance and tolerance organically produced using appropriate seed techniques and management. Quality of the seed is very important to obtain good germination and optimum plant density, characterized by resistance to pest and diseases, being genetically diverse (multi gene resistance) ensures the farmer against pest outbreak, crop losses, biotic and

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abiotic stresses. They contain more micro nutrients which combat malnutrition and micro nutrient deficiency in the diet of rural/poor people.

iii. Seed Treatment

It must be done using different methods with the local available materials. In organic seed system no chemicals should be used in the process of production, processing and storage of the seeds. Before storage, seeds can be treated with cow urine and dung paste to protect it and provide good viability during germination and prevent spoilage from pest and disease.

1. *Cow Urine:* Facilitates germination and prevents seed borne diseases. Prepare cow urine solution by diluting one-part cow urine in 5 parts of water, soak the seeds in the cow urine solution for 15 minutes, dry in the shade and sow them immediately when dried.
2. *Cow's milk:* Prevents yellowing of leaves and leaf spot diseases. Prepare a solution by mixing one part of cow's milk with 5 parts of water, soak the seeds in the above solution for 30 minutes and dry seeds in the shade and sow them immediately.
3. *Wood ash:* Prevents seedling rot. Prepare a solution by mixing 10 grams of ash (approximately 2 table spoons) in one litre of water, dip the vegetable seeds in the solution for 15-30 minutes, dry in the shade and sow the seeds immediately when dried.
4. *Hot water treatment:* Controls seed borne pathogens in seeds which are stored for a long period. Boil the water till it reaches 55oC. Check the temperature with a thermometer; dip the seeds for 7-10 minutes; dry the treated seeds in the shade and then dry them in the sun, store treated seeds in an insect proof containers and used when required.
5. *Seed treatment using bio-fertilizers:* Prepare Sugar or Jaggery solution 5% (boil 50 g of jaggery in 1 litre of water) and cool the solution. The solution after cooling is sprinkled over the seeds and mixed properly.

iv. Seed storage

Seeds should be produced, prepared as required for seed quality in organic conditions, stored in cool place in a well-sealed insect tight container with a clear label on the container. In case there are no seeds produced organically in the market, naturally grown seeds should be used. If such seeds are not available, then conventional seeds packed with chemicals should be washed before sowing.

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3.5 Converting Farm to Organic

Converting a farm from conventional to organic farming is part of making changes in the way crop, animal or forest management is done so that the cultural and management practices are sustainable, environment and worker friendly and if trading is involved that requirements to the market specifications and standards are met. The main components involved in converting a conventional farm to an organic farm are

- increasing the production output and efficiency in term of work and economy
- finding alternative farm inputs for organic production or by sourcing from organic origins.
- making changes to the farm set up or its operations tools, equipment and infrastructures to adjust to new needs.

The time and process required for this change in farming inputs is to change and stabilize soil fertility, pest and disease issues. The time taken for all toxins and pollutions to be cleaned out for the farming system is called transition period. It might take from two to three years if the farms have been managed conventionally for some time. Transition could be shorter of the farm that had been managed naturally, traditionally or without any synthetic agrochemicals in the past. It is expected that during this phase the farm becomes ecologically, environmentally and economically stable and sustainable.

The key elements in conversion are how to prepare growing the same or new crops or products without using unsustainable methods and farm inputs; avoid use of synthetically manufactured fertilizers, pesticides and herbicides; use natural materials on farm that can be reused, recycled or decomposed without hazardous impact on human, animal or environmental health.

A detailed plan of action specific to the farm situation and farm need is necessary. Such a plan comprises key elements such as:

- Soil Improvement Measures
- Manure production and handling methods
- Development of a crop rotation strategy
- Manure application
- Tillage alteration
- Livestock stocking rate

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» Weed, Insect and disease management
» Mechanization possibilities
» Housing and storage requirement
» Marketing opportunities.
» Labour requirement estimates
» Yield estimate rates
» Financial estimates and implications
» Timetable for conversion.

a) Strategy for Conversion

The main strategy of a farm conversion is to do an assessment of the farm or area of operation. This is to study the existing practices that are not suitable or not agreeable with organic principles. Prepare an action plan to replace or substitute the harmful practices or materials that are used in order to clean out the farming system of hazardous materials, repair the damages done to soil and ecosystem and return to the natural farm ecosystem. It may involve strategies requiring education of farmers and farm workers before anything else. Changing old habits needs time and energy but plays significant role in Bhutan. Therefore, strategy involves

✓ Changing the mindset of farmers to opt for organic farming approaches in line with the Buddhist philosophy.
✓ Creating interest to learn more about simple techniques.
✓ Providing exposure to organic farms and farming system and
✓ Training in organic agriculture, participatory planning and implementation within the time frame of financial year.
✓ Developing skills to manage stress and drudgery.
✓ Providing orientation to family and sharing the task with the family members and related workforce.
✓ Breaking down the plan into various simple tasks for implementation.

The extension support of the Department of Agriculture (DoA) will be essential tool for facilitating the conversion process. Equipping in low cost sustainable farming technologies and appropriate solutions on utilizing the local resources efficiently would be an important factor for conversion. Preparing a list of issues that might crop up during the life of the crop from seed to harvest and then after harvest in storage to market is required.

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After creating awareness and working out the basic strategy, it is important to design a plan of action considering the ground realities. It helps the farmer to plan in advance for meeting the requirements on time. In Bhutan more than 70% of the farmers are small landholders, under such circumstances, it is better if the farmers take up organic agriculture in a collective way. It is very economical for such a group to enter into the certification processes as the costs and resources are shared. The plan of action comprises of working out the requirement of the standard if the farm is aimed for certification.

b) Maintenance of an organic farm

In an ideal organic farm everything used on the farm would be from nature and it is done sustainably. Unfortunately, this is not always possible as ideal conditions don't exist. Adjustments have to be made to get to the best situation depending on the location or regions of the farm, climatic conditions, natural settings and availability of resources. As the guiding principles of an organic farm, use the DOs and DON'Ts provided hereunder.

#	DO'S	DON'TS
1	Use organic methods and manage the whole farm organically.	Use chemicals in the farm and its surrounding plants.
2	Keep close look on your garden or farm and have interactive relations with it to notice problems early.	Ignore problems once notices as it is easier to solve problems when small
3	Know the useful insects and worms on the farm that do a lot of work for you	Assume all creatures are pests, many are harmless or even beneficial
4	Practice crop rotation for vegetables and annual crops. This utilizes the soil's fertility better and helps to prevent pests and diseases.	Grow the same crop in the same area of garden as this cannot capture all the soil's nutrients and it breeds pest and disease specific to the crops grown.
5	Grow indicator plants, flowers and trap crops around to attract insects	Use sprays that kills beneficial and predators

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6	Create habitats, bird boxes or shelters to house helpful animals.	Clean up all areas on the farm that may lead helpful animals to disappear
7	Grow a mixture of crops to create diversity on farm. This helps with pest and disease control and maintain good household food diversity for nutrition.	Grow monocultures of one crop as this can create soil fertility imbalance and build pest and disease problems.
8	Recycle all kitchen wastes and degradable wastes in the garden to make compost to develop soil fertility.	Throw away kitchen and garden wastes; it will create garbage in the surrounding.
9	Collect all possible plant wastes and leaves, weeds and make compost or leave them on the soil to feed soil organisms	Burn garden wastes and debris especially on the soil if it is biodegradable as it adds to pollution and kills soil organism that turn the wastes to wealth
10	Add as much organic matter to soil as possible to improve soil structure	Damage the soil structure by using necessary heavy machinery to dig and breaking it up too often
11	Use organic matter that can feed the soil organisms that make the soil fertile for crops	Use synthetic chemical fertilizers that inhibit the activity of natural organisms in the soil
12	Keep the soil covered with cover crops or mulch. This will improve soil structure and control weeds	Keep soils exposed for long durations as this encourages soil erosion and damage by rain
13	Hand weed and use simples tools in crops areas and leave weeds in non-crops areas to provide habitat and materials for compost	Use herbicides as they contain harmful chemicals and they kill all weeds and beneficial insects too

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14	Collect and store your own seeds as much as possible to conserve seeds varieties and avoid chemically treated seeds	Use genetically modified and hybrid seeds if you can get local seeds as they are not sustainable

c) *Marketing scope for organic produce*

The farmer groups and cooperatives in Bhutan are encouraged to develop their farm produce into marketable products or to work together to build volume of products to enable them to market. Some organic groups have been linked to hotels and consumers through special shops or outlets to distinguish organic produce from general local produce but most sell their produce in local markets. Organic products are sold by producers or producer groups with their assurance of being organic based on trust and backed by organic farmer registration.

There are opportunities to improve marketing to promote organic products using labels, brands and certification to verify that the products are grown and processed and packed using organic ingredients and methods. Bhutan is known for its conservation policies to protect the environment and the clean conditions under which most crops are grown. This is a good marketing edge in a growing market where people are increasingly aware of health and environmental issues connected to food grown with heavy agrochemical use. Regulation, standards and certification system are in place for quality control of organic produce in the market as well.

d) *Challenges and Opportunities*

The marketing of organic produce in Bhutan faces a challenge of making the Bhutanese market feel the presence of organic produce. Most of the organic produce of Bhutan is for home consumption and little marketing is done beyond the local markets. Lemon grass essential oil is the only organic certified product that has been exported from Bhutan in the last decade. While it is good that the local markets are now filled with Bhutanese products there is little or no distinction between those products intentionally grown by organic farmers and the others. Since there is no market premium in Bhutan there is not much incentive to market organic products differently. Bhutanese enjoys organic food at the same price as conventional food at this stage of market maturity. However, there is a growing preference for organic and local food products by all consumers due to growing

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knowledge that the imported foods, especially the vegetables and fruit contain high levels of chemicals and hormones sprayed on them. There is also the awareness of health risks associated with consumption of contaminated food amongst consumers. Bhutanese have a strong preference and attachment to traditional and ethnic foods, hence opportunities for organic food over imported food are a good area to develop for local market.

Organic regulations consist of the policies, law and rules that apply in a country's organic sector. The rules and standards are the guidelines or conditions required to be followed in the process of producing a crop, animal, fibre, textile, medicines, food or feed and trade it under the definition of organic.

i. Standards

They are set by a government authority or a private group which may also include consumers. Standards specify what the need for such conditions is and the objective of such conditions to either maintain certain requirements or to prevent contamination of the food or product by non-organic materials or synthetic contaminants. The standards are used as a framework within which the process of production, processing, manufacturing or marketing/ trading happens to define if a product can be qualified as organic.

This is a process of checking the requirement of organic products as per the standards set by persons technically trained to carry out inspections after which certification is awarded by an organization responsible for inspection and certification. There are various standards in the global trading that are meant to ensure quality, purity, ethical methods of production or to ensure sustainability of the environment, the resources and social justice or welfare of people and animals involved in the process. It includes the site visit to verify that the performance of an operation is in accordance with the standards.

ii. Types of certifications

There are many types of certifications in the global market which are specific for different standards. Good Agricultural Practices (GAP), Global GAP, EURO GAP, now Bhutan GAP, Good Manufacturing Practices (GMP), Good Agricultural and Collection Practices (GACP) are some other standards which are not organic but are ways of ensuring a product being is produced, collected from the wild, manufactured, processed and packaged and traded as per requirements in the

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standards at national or international standards for food safety using limited or very low levels of external farm inputs or so they are sustainable.

Organic certification is a process of providing guarantee of organic integrity based on recognized organic standards, national or international that has been accredited by a recognized authority, national or international. A written assurance is given by the Inspection and Certification Agency that identifies production or processing system systematically assesses and conforms to the specified requirements. With growing global organic trade, need for certification has grown as the distance between the producer and consumers increase and the trust of local grower cannot be depended upon anymore.

Organic products have evolved from being sold with self-claim of being organic directly by the grower to consumers to a stage where a neutral certification body is used for verifying the organic products. It is to maintain the standard of organic produce and gain consumer's trust. This is called third party certification.

iii. Accreditation

The certification bodies that inspect and certify the process of production and processing food are further verified and validated for their competence by a higher authority called an accreditation body. Organic market accepts certificates of the organic producers issued by the certified bodies accredited by the accreditation body.

A certification programme is a system operated by an Inspection and Certification Body in accordance with the criteria for carrying out certification of conformity as laid down in the country's National Organic Standards. In Bhutan there are three levels of assurances namely:

1. Local assurance system by registration with NOP and meeting the required standards for local trading within Bhutan and meeting required criteria.
2. National Organic certification by registering for BAFRA's national organic certification which is a third party certification for trade within Bhutan.
3. International third party certification through BAFRA for exporting organic produce or products using a foreign certification agency.

A certification mark or label is a sign, symbol or logo that identifies the products as being certified according to approved or recognized Organic Standards. In

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Bhutan, the organic certification mark is issued by Bhutan Agriculture and Food Regulatory Authority (BAFRA) to operators registered with National Organic Programme (NOP) and BAFRA and those that have been inspected and certified for marketing within Bhutan or for export as per the approval.

To obtain organic certification by individual certification or by group certification documentation of farm records is very important. It is more critical to maintain the documents of the group's members and their farm records if the group is part of an internal control system or a participatory guarantee system programme. Documentation of records ensures traceability of products from the farm to the consumers. Problems or doubts of contamination can be traced to its source, investigate as to how and where it occurred and resolve problems. To safe guard the standard of organic produce, it is mandatory to have internal control system within the production management unit or the cooperative group.

iv. Internal Control System (ICS)

It is a management plan within group or Cooperative of organic producers to document and check that organic integrity is maintained with an assurance system that allows the external certification body to inspect or delegate inspection to an authorized agency. The system must provide transparency of the system from production, inputs to sales of total produce through the whole value chain. ICS is commonly used for group certification to facilitate traceability in the system. The ICS is mandatory in a third part certification and optional in other systems but having an ICS is advantages as it makes graduation to third party certification easier in case export opportunities come up.

v. Participatory Guarantee System (PGS)

It is a method of providing documented and assured guarantee to consumers that the produce coming from this system is grown and processed under a set of organic standards or rules agreed within a group or entities and marked with a PGS label. The system provides close monitoring and traceability based on trust of peer inspections. The PGS is a self-governed and peer-reviewed system by the members of the PGS group consisting of the farmers, consumers and processers. This system includes education and training of farmers and supporting new members though exchange of technical knowledge and skills and experiences in farming and managing problems. PGS usually starts with local village based groups, escalate to regional level and National level.

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e) Support for Organic Agriculture

To enable the growth of an environment friendly agriculture and to enable a phase wise transition towards organic farming, the Ministry of Agriculture has dedicated a national programme known as the National Organic Programme (NOP). It is to coordinate and facilitate the growth of the organic sector in collaboration with the various agencies within and outside the Ministry of Agriculture and Forests. The NOP is responsible for creating and developing policy recommendations, initiate research, make development plans, field production plans and linking with other stakeholders for marketing. Bhutan has an aspiration to be organic in the future. Its Economic Development Policy emphasizes on green energy, clean safe products and supports tax free incentive to the organic producers and processors.

The need for more food, as you are aware, has led to the discovery of chemical fertilizers and genetically modified crops (GMC) which are often not very good for healthy living. Organic agriculture is an alternative to mass production commercial farms – going back to traditional farming system but with scientific technology of farming system. Organic farm produce are gaining popularity throughout the world and it is so in Bhutanese market. Organic farm produce are expensive as mass production is difficult but the produce do fetch good price in the market. As more people become health conscious, organic farm produce is bound to do well. Start organic farm now.

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Theoretical Discussion Questions

1. *In what ways are the weed, pest and disease management of an organic farm different from a conventional farm?*
2. *Why is there a need to have certification procedures for marketing organic produce unlike the conventional farm produce?*
3. *Should organic produce be more expensive? Justify.*
4. *What is your view on Bhutan Going Fully Organic in the future?*
5. *What would be the pros and cons of the organic movement?*

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Student Activity

1. Discuss with the class to plan and grow vegetables, medicinal herbs or fruits as in the past years, and assign work:
   - a. in small groups,
   - b. growing different crops,
   - c. prepare (following the procedures from the text) and use manure from:
     - i. green manure,
     - ii. compost,
     - iii. vermi-compost,
     - iv. bio-digester, and
     - v. compost using EMT.
   - d. use organic approaches to managing diseases, pests and weeds.
   - e. Observe students' participation in their group work, monitor and support work to be carried out systematically, record development, and harvest.
   - f. Discuss challenges and issues in the class so that all will understand and resolve issues

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4

Chapter

Plant and Animal Breeding

Plant breeding is the art and science of changing the traits of plants in order to produce desired characteristics. It is the process by which humans change the characteristics of plants over time to make them better crops and more nourishing food. In its most simple form, breeding consists of selecting the best plants in a given field, growing them to full seed and then using that seed to grow further generations. Such selective breeding changes the genetic composition of the plants over time. The most important factor for plant breeding is genetic variation (differences at the gene level) in the desired characteristic. For example, a farmer who wants to select a plant with resistance to an insect pest will look for the plants that survive an insect attack. Another farmer wanting larger fruits will save seeds from plants yielding the biggest fruits in the field. The most important factor for basic selective breeding is to start with plenty of genetic variation and to select and multiply the characteristic of interest. As a result of breeding, most of the plant species we rely on for food are very different from their wild relatives.

This chapter attempts to provide a basic concepts of genetics and breeding, DNA and mutation, principles of genetics transmission and variations, Mendelian Inheritance and laws of inheritance; principles of plants and animal breeding; Methods of breeding and types of breeding; distribution and introduction of new species, bio-technology in Agriculture, genetic engineering and genetically modified crops – revolutionizing Agriculture throughout the world. However, concerns also arise alongside development. This chapter raises concerns as food for thoughts for young Bhutanese entrepreneurs of Agriculture. The chapters on 'seed production and marketing' and 'dairy farming' are specific examples of application of this chapter. It is hoped that this chapter opens the learner's window into the study of genetics and the wonderful explorations and scope of biotechnology in sustaining agriculture in Bhutan. Let us begin learning more about 'genes' which you have learned in Biology.

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4.1 Genetic basis of inheritance

As you have learned in science, our universe consists of non-living objects (called in-animates) and living organisms (animates). The in-animates are static, lifeless and non-reproducing whereas animates have life and have the capacity to reproduce. The structural and functional unit of all living organisms is the cell. The 'cell theory' was propounded by Schleiden and Schwann in 1838, and Virchow in 1855 which stated that 'all organisms are composed of one or more cells and these cells arise only from pre-existing cells', remember?

Let us refresh our knowledge. An organism may be as small as unicellular or as big as an elephant consisting of billions of trillion cells. The cell is a microscopic unit surrounded by a cell membrane in animals or a true cell wall in plants. The inner material (protoplasm) consists of a dense mass in the centre called 'nucleus' and a jelly like thick matrix surrounding the nucleus called 'cytoplasm'. The cytoplasm contains many submicroscopic organelles like mitochondria, golgi bodies, centrosome, lysosomes, endoplasmic reticulum etc., which perform specialized functions in the cell. The nucleus contains thread like bodies termed as chromosomes. The chromosomes are the structural unit of inheritance and carry many genes on them which are the functional unit of a trait or character.

The location on the chromosome where a gene rests is termed as locus. Each species has a specific number of chromosomes ranging from 4 in drosophila fly to 254 in shrimps (*Eupagurus ochotensis*). The humans have 46 (23 pairs) of chromosomes.

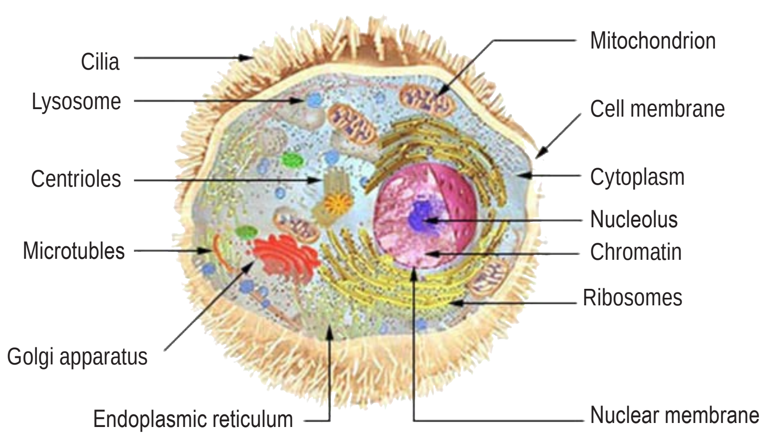

Figure 4.1 Cell Structure

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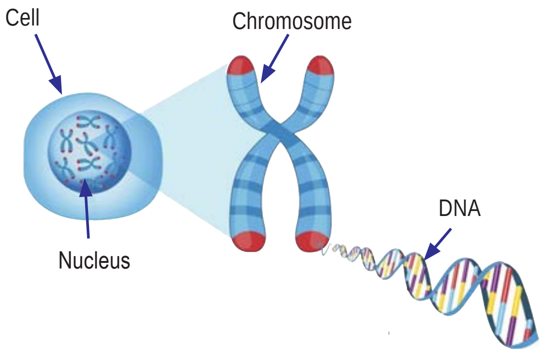

Figure 4.2 Chromosome

Chromosomes always occur in pairs. All cells of the body bearing germ cells are called somatic cells and are characterized by the presence of the number of chromosomes specific for the species. The gamete cells (ova, produced by ovary in female and sperm, produced by testes in male) contain half the number of chromosomes present in a somatic cell deriving one member from each pair of chromosomes. If n is equated as the number of pairs of chromosomes, then a somatic cell will have 2n chromosomes, known as diploid number. A gamete cell has only n chromosomes and it is termed as haploid number. Occasionally, more than two chromosomes are present in a pair and depending on its number, i.e., 3 to 4 or more and the condition is known as tri-ploid or tetra-ploid or in a general term poly-ploid.

There are two chief processes of cell division called mitosis and meiosis. In the process of Mitosis, the sister chromosomes of each pair arrange themselves in a single plane about the centre of the cell. Each chromosome is then replicated, one of the replicated chromosome passes to each pole of the cell. The cell wall constricts and the cytoplasm is divided into two equal halves giving rise to two daughter cells which are exactly similar to that of the mother cell and each daughter cell carries diploid number of chromosomes. Thus, mitosis is the process of increasing the cell number without disturbing the genetic constitution of the cell. In Meiosis, the genetic composition is changed through sexual recombination. The main feature of this process of cell division is that one partner of each pair of chromosomes passes into daughter cells with the result that each daughter cell has half the number of chromosomes (n) of the parent cell. This process is observed in gametogenic cells and the gametes (ova, sperm) so formed have only half the number of chromosomes (haploid number).

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4.2 Genes and proteins

a) Proteins

Proteins are large biological molecules (macro-molecules) made up of basic building blocks called amino acids. Amino acids are made up of hydrogen, carbon, nitrogen, oxygen and sulphur. There are more than 100 amino acids in nature, however there are about 20 essential amino acids that animals require. A linear chain of amino acid residues is called a polypeptide. A protein contains at least one long polypeptide. The individual amino acids are bonded together by peptide bonds. Proteins play an enormous variety of roles such as transport, storage, the structural framework of cells, antibodies, the enzymatic machinery that catalyzes biochemical reactions essential for metabolic activities, many hormones, and contractile proteins for muscle contraction and cell motility. Examples of proteins include hemoglobin, collagen, thyroid hormone, insulin, and myosin. Proteins are produced by genes coded in the DNA.

For example, the base sequence ATG in a DNA strand specifies the amino acid methionine (Met), TTT specifies phenylalanine (Phe), GGA specifies glycine (Gly), and GTG specifies valine (Val). How the genetic information is transferred from the base sequence of a DNA strand into the amino acid sequence of the corresponding protein is known as the central dogma of molecular genetics. The main concept in the central dogma is that DNA does not code for protein directly but acts through an intermediary molecule called ribonucleic acid (RNA). The structure of RNA is similar, but not identical, to that of DNA. The sugar is ribose rather than deoxyribose. RNA is usually single-stranded (not a duplex), and RNA contains a base, uracil (U), that takes the place of thymine (T) in DNA. Protein production consists of two major steps: transcription and translation. Together, transcription and translation are known as gene expression.

b) Transcription

Transcription is the process whereby DNA is used as the template for the production of molecules of RNA. RNA has different forms, including messenger RNA (mRNA), transfer RNA (tRNA), and ribosomal RNA (rRNA). Each type of RNA is involved in the process of constructing a protein based on the DNA sequence of a gene. The process of constructing RNA from DNA is carried out by an enzyme, RNA polymerase II, and is controlled through sequences in the genome termed promoters. This process requires many different proteins and is tightly regulated to ensure proper gene expression. Mutations in the proteins that are involved in replication, or mutations in the DNA promoter sequences themselves, can lead to improper expression and function of a gene.

Genetic Significance of Chromosomes

The chromosomes are considered as the organs of heredity because of following reasons:

1. They form the only link between two generations.
2. A diploid chromosome set consists of two morphologically similar (except the X and Y sex chromosomes) sets; one is derived from the mother and another from the father at fertilization.
3. The genetic material, DNA or RNA is localized in the chromosome and its contents are relatively constant from one generation to the next.
4. The chromosomes maintain and replicate the genetic information contained in their DNA molecule and this information is transcribed at the right time in proper sequence into the specific types of RNA molecules which directs the synthesis of different types of proteins.

Each organism has a defining set of chromosomes that contain all of its genetic information. An organism's total DNA content is known as its genome. The human genome, for example, is the set of genetic information encoded in 46 chromosomes found in the nucleus of each cell. The chromosomes are organized into 23 pairs– one chromosome of each pair is inherited from the mother and one from the father.

One pair of chromosomes - X and Y - determines sex; the other 22 pairs are called autosomes. So, the human genome is made up of a set of very long DNA molecules, one corresponding to each chromosome. Arrayed along these molecules are an estimated 35,000 genes.

4.3 Mendelian inheritance

It is a matter of common experience that the individuals of different species differ widely both in structure and function. Not only that, even the individual within a species is highly variable. The offspring inherit characters from their parents but still neither the parents and their offspring, nor the real brothers and sisters

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are identical in all respects. The variation between individuals is attributed to genetic composition, environmental factors and their interaction. A number of theories were propounded from time to time to explain the possible mechanism of inheritance based on experience and speculations, but none stood the test of time. Later, the theory of quantitative or biometrical genetics came into existence on the basis of experiments conducted on garden pea in 1866 by Gregor J. Mendel who is honoured as the 'Father of Genetics'. Mendel proposed three laws of inheritance which were not recognized until the same were rediscovered and reaffirmed by Derries in Holland, Correns in Germany and Tschermark in Austria in 1900. Mendel died in 1884 and never lived to see that he had opened the Watergates to a new science called genetics.

Mendel discovered that when he crossed purebred white flower and purple flower pea plants (the parental or P generation), the result was not a blend or mixture. Rather than being a mix of the two, the offspring (known as the F1 generation) was purple-flowered. When Mendel self-fertilized the F1 generation pea plants, he obtained a purple flower to white flower in the ratio of 3:1 in the F2 generation. The results of this cross are tabulated in the Punnett square (Figure 4.3).

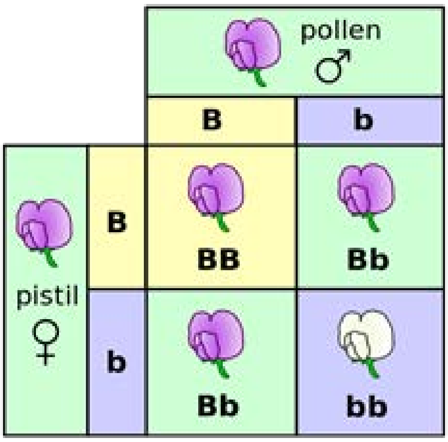

Figure 4.3 Punnett Square

He then conceived the idea of heredity units, which he called "factors". Mendel found that there are alternative forms of factors – now called genes that account for variations in inherited characteristics. For example, the gene for flower color in pea plants exists in two forms, one for purple and the other for white. The alternative versions of a gene are now called alleles. For each biological trait, an organism inherits two alleles, one from each parent. These alleles may be the same or different. An organism that has two identical alleles for a gene is said to be homozygous (e.g. BB) for that gene (and is called a homozygote). An organism that has two different alleles for a gene is said to be heterozygous (Bb) for that gene (and is called a heterozygote). Mendel also hypothesized that allele pairs segregate or separate randomly from each other during the production of gametes. Because allele pairs separate during gamete production, a sperm or egg carries only one allele for each inherited trait. When sperm and egg unite at fertilization, each contributes its allele, restoring the paired condition in the offspring. This is called

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the Law of Segregation. Mendel also found that each pair of alleles segregates independently of the other pairs of alleles during gamete formation. This is known as the Law of Independent Assortment (detailed description below).

Table 4.1 Mendel's Law of Inheritance

Mendel's Laws of Inheritance	
Law	Definition
Law of Segregation	During gamete formation, the alleles for each gene segregate from each other so that each gamete carries only one allele for each gene.
Law of Independent Assortment	Genes for different traits can segregate independently during the formation of gametes
Law of Dominance	Some alleles are dominant while others are recessive; an organism with at least one dominant allele will display the effect of the dominant allele

a) Law of Dominance

The genotype of an individual is made up of the many alleles it possesses. An individual's physical appearance (or phenotype) is determined by its alleles as well as by its environment. The presence of an allele does not mean that the trait will be expressed in the individual that possesses it. If the two alleles of an inherited pair differ (the heterozygous condition), then one determines the organism's appearance and is called the dominant allele; the other has no noticeable effect on the organism's appearance and is called the recessive allele. Thus, in the example above dominant purple flower allele will hide the phenotypic effects of the recessive white flower allele. This is known as the *Law of Dominance*. We use uppercase (capital) letters to represent dominant alleles and lowercase (small) letters to represent recessive alleles.

In the pea plant example above, the capital "B" represents the dominant allele for purple flowers and lowercase "b" represents the recessive allele for white flowers. Both parental plants were true-breeding, and one parental variety had two alleles for purple flowers (BB) while the other had two alleles for white flowers (bb). As a result of fertilization, the F1 hybrids each inherited one allele for purple flowers and one for white. All the F1 hybrids (Bb) had purple flowers, because the dominant B allele has its full effect in the heterozygote, while the recessive b allele has no effect

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on flower color. For the F2 plants, the ratio of plants with purple flowers to those with white flowers (3:1) is called the phenotypic ratio. The genotypic ratio is 1 BB: 2 Bb: 1 bb in a monohybrid (in which parents differ in one trait or character only, e.g. pea colour) cross. In a dihybrid (parents differing in two traits) cross, the phenotypic ratio will be 9 : 3 : 3 : 1 in the F2 generation.

In the example (Figure 4.4), coat color is indicated by B (brown, dominant) or b (white, recessive), while tail length is indicated by S (short, dominant) or s (long, recessive). When parents are homozygous for each trait (SSbb and ssBB), their children in the F1 generation are heterozygous at both loci and only show the dominant phenotypes (SsbB). If the children mate with each other, in the F2 generation all combinations of coat color and tail length occur: 9 are brown/short (purple boxes), 3 are white/short (pink boxes), 3 are brown/long (blue boxes) and 1 is white/long (green box).

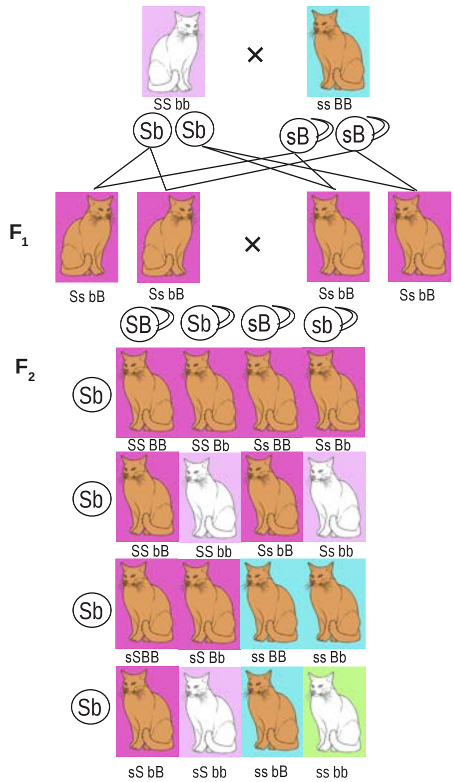

Figure 4.4 Law of dominance

b) Law of Segregation

The *Law of Segregation* states that every individual contains a pair of alleles for each particular trait which segregate or separate during cell division for any particular trait and that each parent passes a randomly selected copy (allele) to its offspring. The offspring then receives its own pair of alleles of the gene for that trait by inheriting sets of homologous chromosomes (chromosome pairs, one from each parent) from the parent organisms. More precisely, the law states that when any individual produces gametes, the copies of a gene separate so that each gamete receives only one copy (allele). A gamete will receive one allele or the other. Paternal and maternal chromosomes get separated in meiosis and the alleles with the traits of a character are segregated into two different gametes. Each parent contributes a single gamete, and thus a single, randomly successful allele copy to their offspring and fertilization.

c) Law of Independent Assortment

The *Law of Independent Assortment*, also known as "Inheritance Law", states that separate genes for separate traits are passed independently of one another from parents to offspring. That is, the biological selection of a particular gene in the gene pair for one trait to be passed to the offspring has nothing to do with the selection of the gene for any other trait. More precisely, the law states that alleles of different genes assort independently of one another during gamete formation. While Mendel's experiments with mixing one trait always resulted in a 3:1 ratio between dominant and recessive phenotypes, his experiments with mixing two traits (dihydric cross) showed 9:3:3:1 ratio. Independent assortment occurs in eukaryotic organisms during meiotic metaphase I, and produces a gamete with a mixture of the organism's chromosomes. Along with crossing over or recombination, independent assortment increases genetic diversity by producing novel genetic combinations.

Of the 46 chromosomes in a normal diploid human cell, half are maternally derived (from the mother's egg) and half are paternally derived (from the father's sperm). This occurs as sexual reproduction involves the fusion of two haploid gametes (the egg and sperm) to produce a new organism having the full complement of chromosomes. During gametogenesis (the production of new gametes by an adult) the normal complement of 46 chromosomes needs to be halved to 23 to ensure that the resulting haploid gamete can join with another gamete to produce a diploid organism. An error in the number of chromosomes is termed aneuploidy. By definition, aneuploid cells have an abnormal number (more than or less than 46) of chromosomes. The addition or loss of even a single chromosome disrupts the existing equilibrium in cells, and in most cases, is not compatible with life. In humans, the most common aneuploidies are trisomies, which are characterized by the presence of one additional chromosome, bringing the total chromosome number to 47. With few exceptions, trisomies do not appear to be compatible with life. In fact, trisomies represent about 35% of spontaneous abortions. The most common human trisomy involves chromosome 21 and is known as Down syndrome. Common physical signs of Down syndrome include decreased or poor muscle tone; short neck, with excess skin at the back of the neck; flattened facial profile and nose; small head, ears, and mouth; upward slanting eyes; wide, short hands with short fingers and retarded mental ability.

Mendel's *Law of Dominance* states that recessive alleles will always be masked

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by dominant alleles. Therefore, a cross between a homozygous dominant and a homozygous recessive will always express the dominant phenotype, while still having a heterozygous genotype. Law of Dominance can be explained easily with the help of a mono hybrid cross experiment. In a cross between two organisms pure for any pair (or pairs) of contrasting traits (characters), the character that appears in the F1 generation is called "dominant" and the one which is suppressed (not expressed) is called "recessive." Each character is controlled by a pair of dissimilar factors. Only one of the characters expresses. The one which expresses in the F1 generation is called Dominant. For example, one allele of a particular gene, say R, may impart red colour to a flower while its allele, r, may be responsible for white colour to the flower. When either is present in a homozygous condition, the colour of the flower is either red (RR) or white (rr). On the other hand, if they are present in a heterozygous condition (Rr), the expression of the white colour is masked by the dominant red colour and the flower emerges as red. In this case, red colour allele (R) is said to be dominant and white colour gene (r) is said to be recessive.

From the above, it is evident that an organism inherits genes from its parents which are responsible for the expression of characters. However, these genes are not expressed in vacuum but need proper environment to manifest their maximal capacity. If the required environment is not available, the expression of the character may be inhibited fully or partially. For example, a plant may have the gene to grow tall but if the soil is deficient in nitrogen, minerals and water, the plant's growth may remain stunted belying the presence of gene for tallness. Thus, an individual can be deemed as genotype depending on the genetic material inherited from its parents and what it appears to be is phenotype. Ideally, the genotype can be defined as the inherited genetic constitution or the sum total of heredity that an individual receives from its parents. Thus the total genic composition (genome) carries the blue print of structure and function for an individual. On the other hand, a phenotype is the appearance or performance of an organism as a result of the interaction of a genotype with that of a given environment. In nut shell, a genotype determines, what an individual should be while phenotype reveals what it is. Further, a genotype is constant from birth till death whereas phenotype changes with time, place, age, food, environment etc.

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4.4 Principles of plant and animal breeding

Plant breeding is the art and science of changing the traits of plants in order to produce desired characteristics. It is the process by which humans change the characteristics of plants over time to make them better crops and more nourishing food. In its most simple form, breeding consists of selecting the best plants in a given field, growing them to full seed and then using that seed to grow further generations. Such selective breeding changes the genetic composition of the plants over time. The most important factor for plant breeding is genetic variation (differences at the gene level) in the desired characteristic. For example, a farmer who wants to select a plant with resistance to an insect pest will look for the plants that survive an insect attack. Another farmer wanting larger fruits will save seeds from plants yielding the biggest fruits in the field. The most important factor for basic selective breeding is to start with plenty of genetic variation and to select and multiply the characteristic of interest. As a result of breeding, most of the plant species we rely on for food are very different from their wild relatives.

Genetic diversity within a population refers to the number of different alleles (the alternate forms of genes) of all genes and the frequency with which they appear. Variation is high when there are many different alleles of all genes and many different combinations of those alleles.

A *gene pool* is the collective set of alleles found in a population. Plant breeders can also make use of the gene pool of closely related species that can cross and produce fertile hybrids, called inter-specific hybrids. The level of genetic variation in a population is constantly changing: different alleles of a single gene can appear and disappear from time to time within a population. This means that the gene pool of a population is always dynamic. For some characteristics, such as maize grain colour, there is a great level of genetic variation in nature.

The aim of plant breeding is to develop superior cultivars, which are adapted to specific environmental conditions and suitable for economic production in a commercial cropping system. The basic concept of varietal development is very simple and involves three distinct operations:

- ✓ produce or identify genetically variable germplasm (term to denote seeds, seedlings of other parts of a plant that can reproduce);
- ✓ carry out selection procedures on genotypes (genetic composition of plants

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or animals) from within this germplasm to identify superior genotypes with specified or desired characteristics;

✓ stabilize and multiply these superior genotypes and release cultivars for commercial production.

The general philosophy underlying any breeding scheme is to maximize the probability of creating, and identifying, superior genotypes which will make successful new cultivars or varieties. In other words, they will contain all the desirable characteristics/traits necessary for use in a production system.

Classical or conventional plant breeding uses deliberate interbreeding (crossing) of closely or distantly related individuals to produce new crop varieties or lines with desirable properties. Plants are crossbred to introduce traits/genes from one variety or breeding line into a new genetic background. For example, a blight disease resistant rice variety may be crossed with a high yielding but susceptible (that is easily affected by disease) variety, the goal of the cross being to introduce blast resistance without losing the high-yield characteristics. Progeny (literally meaning children, here plants developed after the crossing) from the cross would then be crossed with the high-yielding parent to ensure that the progeny were mostly like the high-yielding parent, (backcrossing). The progeny from that cross would then be tested for yield and blast resistance and high-yielding resistant plants would be further developed. Plants may also be crossed with themselves to produce inbred varieties for breeding. Modern plant breeding may use techniques of molecular biology to select, or in the case of genetic modification, to insert, desirable traits into plants. Application of biotechnology or molecular biology is also known as molecular breeding. More details on this subject will follow in the next section. However, specific examples of 'seed production and management' will be discussed in Chapter 5.

a) Animal breeding

Animal breeding may be defined as the application of the principles of Genetics and other related sciences to improve the efficiency of production in farm animals. These principles were applied to change animal populations thousands of years before the science of genetics was formally established. Animal breeding with specific examples are discussed in Chapter 4 – Dairy farming.

i. *Need for breeding*

Breeding is needed to address our food, feed and nutritional requirements. Food is the most basic of human needs. Plants are the primary producers in the ecosystem. Without them, life on earth for higher organisms would be impossible. Most of the crops that feed the world are cereals.

- Plant breeding is needed to *enhance the value of food crops*, by improving their yield and the nutritional quality of their products, for healthy living of humans. Certain plant foods are deficient in certain essential nutrients to the extent that where these foods constitute the bulk of a staple diet, diseases associated with nutritional deficiency are often common. Cereals tend to be low in lysine and threonine, while legumes tend to be low in cysteine and methionine, both sulfur-containing amino acids needed for protein synthesis.
- Breeding is needed to *augment the nutritional quality of food crops*. Rice, a major world food, lacks pro-vitamin A (the precursor of vitamin A). The "Golden Rice" project, currently underway at the International Rice Research Institute (IRRI) in the Philippines and other parts of the world, is geared towards developing, for the first time ever, a rice variety with the capacity to produce pro-vitamin A.
- Breeding is also needed to make s*ome plant products more digestible and safer to eat* by reducing their toxic components and improving their texture and other qualities. A high lignin content of the plant material reduces its value for animal feed. Toxic substances occur in major food crops, such as alkaloids in yam, cynogenic glucosides in cassava, trypsin inhibitors in pulses, and steroidal alkaloids in potatoes. Forage breeders are interested, among other things, in improving feed quality (high digestibility, high nutritional profile) for livestock.
- Similarly, animal breeding is important to *increase the production of human food* such as milk, meat, egg etc. Improvement in quality is another vital consideration.

ii. *Genetic resources for breeding*

Genetic resources can be defined as all materials that are available for improvement of a cultivated plant or animal species. In classical plant breeding, genetic resources may also be considered as those materials that, without selection for adaptation to the target environment, do not have any immediate use for the breeders. According to the extended gene pool concept, genetic resources may be divided into primary gene pool, secondary gene pool, tertiary gene pool and isolated genes.

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The *primary gene pool* consists of the crop species itself and other species that can be easily crossed with it. The *secondary gene pool* is composed of related species that are more difficult to cross with the target crop, i.e. where crossing is less successful (low percentage of viable kernels) and where crossing progenies are partially sterile. The *tertiary gene pool* consists of species which can only be used by employing special techniques like embryo rescue or protoplast fusion. The fourth class of *genetic resources, isolated genes*, may derive from related or unrelated plant species, from animals or microorganisms. The importance of the different classes of genetic resources for crop improvement depends on the target crop species. In maize, for example, genetic variation in the primary gene pool is so large that the secondary or tertiary gene pools are rarely used. In rape seed, on the other hand, genetic variation in the primary gene pool is small and breeders have to transfer important traits from *Brassica* species of the secondary and tertiary gene pool into the cultivated species. The main aims of using the genetic resources are to develop cultivars that are specifically adapted to marginal or stress environments; assure sustainable production in high-yielding environments through better input-output relations, i.e. through reduced application of agro-chemicals and increased nutrient and water efficiency; and to open production alternatives for farmers through development of industrial or pharmaceutical crops.

Genetic resources are sometimes called the “first resource” of the natural resources on this planet, the others being land, air, and water. Genes are the link from generation to generation of all living matter. Therefore, attention to genetic resources means attention to the vast diversity among and between species of animals, plants, and micro-organisms. Within this diversity there is a hierarchy of organization and the term genetic resource has meaning at each level. At one level, genetic resources include all the individuals of a species, particularly if it is threatened with extinction. Genetic resources also include populations, gene pools, or races of a species which possess important attributes not found uniformly throughout the species. Breeding lines and research materials, such as mutant, genetic, or chromosomal stocks, are also genetic resources and are important in animal and plant breeding and in all phases of biological research. Finally, genetic resources can refer to genes themselves, maintained in selected individuals or cloned and maintained in plasmids. Genetic improvement in animals has profoundly increased productivity of livestock, dairy, and poultry operations. Genetic resource for improvement includes agriculturally important plants and animals – both native and exotic or introduced. Beyond the easily recognized

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plants and animals used directly for human sustenance are lesser known useful genetic resources, such as yeast, microorganisms used in fermentation for bread, beer, and winemaking. Plants and animals in their natural habitats are valuable for their aesthetic values, their potential uses by humans, and for maintaining functioning ecosystems. There exist two main approaches to genetic resources conservation: offsite (*ex situ*) conservation, by which is meant the maintenance of the resources in a site or facility which is not their natural or native habitat, and onsite (*in situ*) conservation, by which is meant the preservation of the resources in their native habitats.

iii. Methods of Breeding

Different approaches and techniques that are used for genetic improvement of crop plants are referred to as plant breeding methods or plant breeding procedures. The choice of breeding methods mainly depends on the mode of pollination, mode of reproduction, gene action and breeding objective of crop species. Such common breeding methods include plant introduction, selection (pure line selection, mass selection) hybridization (pedigree), hybrid breeding and synthetic breeding. On the other hand, those breeding procedures that are rarely used for improvement of crop plants are referred to as special breeding methods. Such methods include mutation breeding, polyploidy breeding and wide hybridization. However, we begin with plant introduction to a new locality, which may later on give rise to new species or varieties of related species that can be useful or harmful to the environment. Methods of breeding are discussed briefly following the plant introduction

b) Plant introduction

Plant introduction consists of taking a genotype or a group of genotypes of plants into new environments where they were not being grown before. Introduction may involve new varieties of a crop already grown in the area, wild relatives of the crop species or a totally new crop species. Mostly, materials are introduced from other countries or continents. The movement of crop varieties from one environment into another within a country is also introduction. Introduction may be primary or secondary. When the introduced variety is well suited to the new environment, and if released for commercial cultivation without any alteration in the original genotype, it constitutes primary introduction. Examples of primary introduction in Bhutan include rice variety IR 64, wheat variety Sonalika etc. In secondary introduction, the introduced variety may be subjected to selection to isolate a

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Figure 4.5 Plant introduction

superior variety. Alternatively, it may be hybridized with local varieties to transfer one or few characters from this variety to the local ones. Introduction consists of the following steps: procurement, quarantine, evaluation, multiplication and distribution. Research centres in Bhutan are primarily involved in procurement of new crops and varieties. Quarantine means to keep materials in isolation to prevent the spread of diseases etc. All the introduced plant materials are inspected for contamination with weeds, diseases and insect pests. Evaluation is to assess the potential of new introductions; their performance is evaluated at different research stations. Promising introductions or selections from the introductions are increased and released as varieties after the field trials.

The advantages of plant introduction are many. It may provide entirely new crop plants to a region or country. It provides superior varieties either directly or after selection and hybridization. It is a very quick and economical method of crop improvement, particularly when the introductions are released as varieties either directly or after a simple selection. Plants may be introduced in new disease free areas to protect them from damage, e.g., coffee and rubber. The disadvantage of plant introduction is associated with the introduction of weeds, diseases and crop breeding methods depend upon the type of crop and its reproductive or mating system. Plant mating systems depend on the type of pollination or the transfer of pollen from flower to flower. A flower is self-pollinated if pollen is transferred to it from any flower of the same plant and cross-pollinated if the pollen comes from a flower on a different plant. About half of the more important cultivated plants are naturally cross-pollinated, and their reproductive systems include various devices that encourage cross pollination; e.g. protandry (pollen shed before the ovules are mature, as in the carrot and walnut), dioecy (stamens and pistils borne

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on different plants, as in the date palm and asparagus), and genetically determined self-incompatibility (inability of pollen to grow on the stigma of the same plant, as in white clover, cabbage, and many other species).

Other plant species, including a high proportion of the most important cultivated plants such as wheat, barley, rice, peas, beans, and tomatoes are predominantly self-pollinating. There are relatively few reproductive mechanisms that promote self-pollination; the most positive of which is failure of the flowers to open (cleistogamy), as in groundnut. In barley, wheat, and lettuce the pollen is shed before or just as the flowers open; and in the tomato pollination follows opening of the flower, but the stamens form a cone around the stigma.

In controlled breeding procedures it is imperative that pollen from the desired male parent, and no other pollen, reaches the stigma of the female parent. When stamens and pistils occur in the same flower, the anthers must be removed from flowers selected as females before pollen is shed. This is usually done with forceps or scissors. Protection must also be provided from "foreign" pollen. The most common method is to cover the flower with a plastic or paper bag. When the stigma of the female parent becomes receptive, pollen from the desired male parent is transferred to it, often by breaking an anther over the stigma, and the protective bag is replaced.

The production of certain hybrids is, therefore, tedious and expensive because it often requires a series of delicate, correct, and properly timed hand operations. When male and female parts occur in separate flowers, as in maize, controlled breeding is easier. A cross-pollinated plant, which has two parents, each of which is likely to differ in many genes, produces a diverse population of hybrid plants for many traits. A self-pollinated plant, which has only one parent, produces a more uniform population of pure breeding plants. The question that you need to ask is '*Why is 'plant introduction' considered as a breeding method? What scope of 'control breeding' do you think a literate farmer has? Would you as a literate farmer take breeding and marketing as an enterprise?*'

i. Breeding self-pollinated species

The breeding methods that are commonly used for self-pollinated species are (1) mass selection; (2) pure-line selection; (3) hybridization, with the segregating generations handled by the pedigree method, the bulk method, or by the backcross method; and (4) development of hybrid varieties.

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1. Mass Selection

In mass selection, seeds are collected from desirable individual plants in a population, and the next generation is sown from the stock of mixed seed. This procedure, sometimes referred to as phenotypic selection, is based on how each individual looks. Mass selection has been used widely to improve old "land" varieties, varieties that have been passed down from one generation of farmers to the next over long periods. An alternative approach that has been practiced for thousands of years is simply to eliminate undesirable types by destroying them in the field. The results are similar whether superior plants are saved or inferior plants are eliminated: seeds of the better plants become the planting stock for the next season.

A modern refinement of mass selection is to harvest the best plants separately and to grow and compare their progenies. The poorer progenies are destroyed and the seeds of the remainder are harvested. It should be noted that selection is now based not solely on the appearance of the parent plants but also on the appearance and performance of their progeny. Progeny selection is usually more effective than phenotypic selection when dealing with quantitative characters of low heritability. Mass selection is perhaps the simplest and least expensive of plant-breeding procedures.

2. Pure-Line Selection

Pure-line selection generally involves more or less three distinct steps: (1) numerous superior appearing plants are selected from a genetically variable population; (2) progenies of the individual plant selections are grown and evaluated by simple observation, frequently over a period of several years; and (3) when selection can no longer be made on the basis of observation alone, extensive trials are undertaken, involving careful measurements to determine whether the remaining selections are superior in yielding ability and other aspects of performance. Any progeny superior to an existing variety is then released as a new "pure-line" variety. Much of the success of this method during the early 1900s depended on the existence of genetically variable land varieties that were waiting to be exploited. They provided a rich source of superior pure-line varieties, some of which are still represented among commercial varieties. In recent years the pure-line method as outlined above has decreased in importance in the breeding of major cultivated species; however, the method is still widely used with the less important species that have not yet been heavily selected.

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3. Hybridization

During the 20th century planned hybridization (controlled crossing of plants as described above) between carefully selected parents became dominant in the breeding of self-pollinated species. The object of hybridization is to combine desirable genes found in two or more different varieties and to produce pure-breeding progeny superior in many respects to the parental types. Genes, however, are always in the company of other genes in a collection called a genotype. The plant breeder's problem is largely one of efficiently managing the enormous numbers of genotypes that occur in the generations following hybridization.

As an example of the power of hybridization in creating variability, a cross between hypothetical wheat varieties differing by only 21 genes is capable of producing more than 10,000,000,000 different genotypes in the second generation. So it is important to have efficient techniques in managing hybrid populations, for which purpose the pedigree procedure is most widely used.

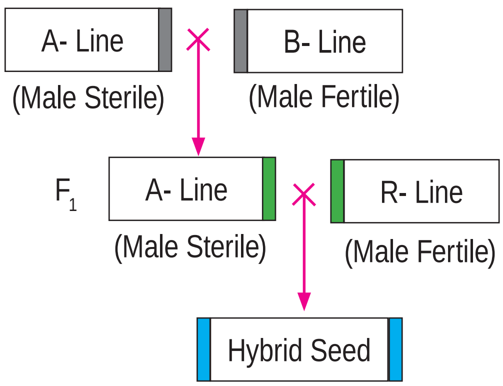

Figure 4.6 Hybridization

Pedigree breeding starts with the crossing of two genotypes, each of which has one or more desirable characters lacked by the other. If the two original parents do not provide all of the desired characters, a third parent can be included by crossing it to one of the hybrid progeny of the first generation (F1). In the pedigree method superior types are selected in successive generations, and a record is maintained of parent-progeny relationships. The F2 generation (progeny of the crossing of two F1 individuals) provides the first opportunity for selection in pedigree programs. Usually one or two superior plants are selected within each superior family in these generations. The family of plants is grown for several years, usually F7-F8 generations, and selections are made depending on the aims of the breeding program. The final evaluation of promising lines involves field observation, yield and quality testing before they are formally released as varieties.

4. Hybrid Varieties

The development of hybrid varieties differs from hybridization in that no attempt

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is made to produce a pure-breeding population; only the F1 hybrid plants are sought and used.

The F1 hybrid of crosses between different genotypes is often much more vigorous than its parents. This hybrid vigour (or heterosis) can be manifested in many ways, including increased rate of growth, greater uniformity, earlier flowering, increased yield etc.

By far the greatest development of hybrid varieties has been in maize, primarily because its male flowers (tassels) and female flowers (ears) are separate and easy to handle, thus proving economical for the production of hybrid seed. The production of hand-produced F1 hybrid seed of self-pollinated crops is tedious and time consuming. However, a built-in cellular system of pollination control has made hybrid varieties possible in a wide range of plants, including many that are self-pollinating. This system, called cytoplasmic male sterility, or cytosterility, prevents normal maturation or function of the male sex organs (stamens) and results in defective pollen or none at all. It avoids the need for removing the stamens either by hand or by machine. Cytosterility depends on the interaction between male sterile genes (R + r) and factors found in the cytoplasm of the female sex cell. The genes are derived from each parent in the normal Mendelian fashion, but the cytoplasm is provided by the egg only; therefore, the inheritance of cytosterility is determined by the female parent. All plants with fertile cytoplasm produce viable pollen, as do plants with sterile cytoplasm. The production of F1 hybrid seed between two strains is accomplished by inter planting a sterile version of one strain (say A) in an isolated field with a fertile version of another strain (B). Since strain A produces no viable pollen, it will be pollinated by strain B, and all seeds produced on strain A plants must therefore be F1 hybrids between the strains. The F1 hybrid seeds are then planted to produce the commercial crop. Much of the breeder’s work in this process is in developing the pure-breeding sterile and fertile strains to begin the hybrid seed production.

ii. Breeding cross-pollinated species

The most important methods of breeding cross-pollinated species are (1) mass selection; (2) development of hybrid varieties; and (3) development of synthetic varieties. Since cross-pollinated species are naturally hybrid (hetero-zygous) for many traits and lose vigour as they become purebred (homozygous), a goal of each of these breeding methods is to preserve or restore heterozygosity.

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Mass selection in cross-pollinated species takes the same form as in self-pollinated species; i.e., a large number of superior appearing plants are selected and harvested in bulk and the seed used to produce the next generation. Mass selection has proved to be very effective in improving qualitative characters, and if applied over many generations, it is also capable of improving quantitative characters, including yield, despite the low heritability of such characters. Mass selection has long been a major method of breeding cross-pollinated species, especially in the economically less important species.

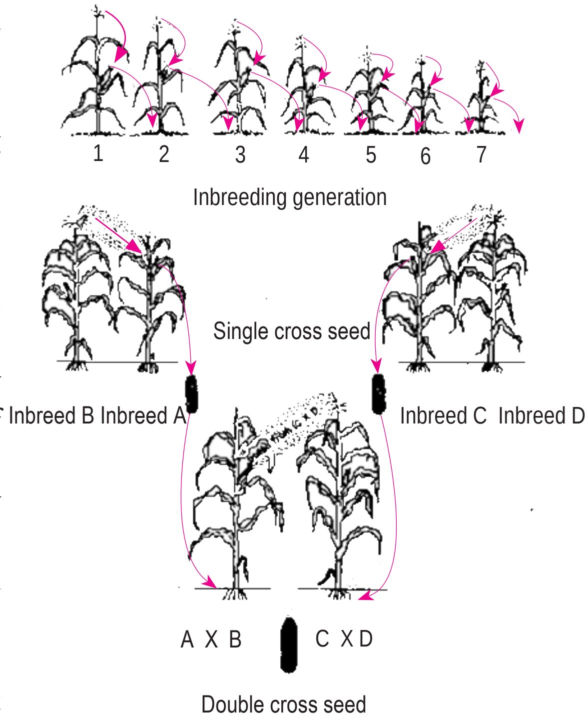

Figure 4.7 Cross pollination

1. Hybrid Varieties

The outstanding example of the exploitation of hybrid vigour through the use of F1 hybrid varieties has been with maize. The production of a hybrid maize variety involves three steps: (1) the selection of superior plants; (2) selfing for several generations to produce a series of inbred (self-fed) lines, which although different from each other are each pure-breeding and highly uniform; and (3) crossing selected inbred lines. During the inbreeding process the vigour of the lines decreases drastically, usually to less than half that of field-pollinated varieties.

Vigour is restored, however, when any two unrelated inbred lines are crossed, and in some cases the F1 hybrids between inbred lines are much superior to open-pollinated varieties. Once the inbred which gives the best hybrids have been identified, any desired amount of hybrid seed can be produced. Pollination in maize is by wind, which blows pollen from the tassels to the styles (silks) that protrude from the tops of the ears. Thus controlled cross-pollination on a field scale can be accomplished economically by inter planting two or three rows of the seed parent inbred with one row of the pollinator inbred and de-tasselling the former before it sheds pollen. In practice most hybrid corn is produced from

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"double crosses," in which four inbred lines are first crossed in pairs (A × B and C × D) and then the two F1 hybrids are crossed again (A × B) × (C × D). The double-cross procedure has the advantage that the commercial F1 seed is produced on the highly productive single cross A × B rather than on a poor-yielding inbred, thus reducing seed costs. In recent years, cytoplasmic male sterility, described earlier, has been used to eliminate de-tasselling of the seed parent, thus providing further economies in producing hybrid seed. Much of the hybrid vigour exhibited by F1 hybrid varieties is lost in the next generation. Consequently, seed from hybrid varieties is not used for planting stock but the farmer purchases new seed each year from seed companies.

2. Synthetic Varieties

A synthetic variety is developed by inter-crossing a number of genotypes of known superior combining ability i.e., genotypes that are known to give superior hybrid performance when crossed in all combinations. By contrast, a variety developed by mass selection is made up of genotypes bulked together without having undergone preliminary testing to determine their performance in hybrid combination. Synthetic varieties are known for their hybrid vigour and for their ability to produce usable seed for succeeding seasons. Because of these advantages, synthetic varieties have become increasingly favoured in the growing of many species, such as the forage crops, in which expense prohibits the development or use of hybrid varieties.

4.5 Crop breeding in Bhutan

Crop breeding has been recognized as one of the proven means to achieve accelerated food production. Improved varieties, through their higher yield potential and ability to resist pest and disease have played a fundamental role in increasing productivity in developing countries in the past and it still remains a potential means to raise production. In Bhutan introduction and selection of crop varieties have received a very high priority ever since the systematic and organized agricultural research started in 1982. At present there are five RNR Research and Development Centers (RNR RDC) at Bajo, Wengkhar, Bhur, Jakar and Yusipang which carry out research on food crops and horticulture. Almost over 80% of the time and resources of RNR RDCS is allocated to germplasm adaptation, improvement and management. RNR RDCS are the main institutions responsible for development, adaptation and maintenance of crop genetic resources. The CGIAR centres like IRRI, CIMMYT, CIP (International Potato Centre), AVRDC (Asian Vegetable Research and Development Centre, now called World Vegetable

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Centre) etc and the National Agriculture Research Centers in the region have been the main sources of crop germplasm. The RNR RDCs are engaged also in improving local crops and their varieties through seed selection, cross breeding and selection, crop competitions and seed fairs. The focus is on important food crops such as rice and maize. Many crop varieties have been developed and released by RDCs. Example: 34 varieties of cereals including 23 rice varieties, 4 oilseeds varieties, 5 grain legumes, 27 fruit varieties and about 30 vegetable varieties.

Breeding for climate resilient crop varieties is another priority for research. Hybridization of traditional Bhutanese rice cultivars with improved varieties or lines was started in the mid-1980s as a longer-term strategy for the improvement of Bhutanese indigenous rice varieties. The Bhutanese rice varieties are low yielding as response to added inputs is limited by lodging and disease manifestation. However, they are valued for their yield stability and grain quality. The principal objective of the cross breeding program is to assimilate desirable genes for high yield, adaptability, grain quality, cold tolerance and disease resistance from various sources. To date, over 150 crosses have been made involving traditional varieties of Bhutan. More than 60 popularly grown rice varieties were used as local parents. From this effort, 8 new rice varieties have been developed.

Table 4.2 Climate resilient rice varieties developed by RDCs

Variety name	Parents	Year released	Developed by	Altitudes (m)
Bajo Maap 1	Local Maap/IR 64	1999	RDC Bajo	600-1500
Bajo Maap 2	Local Maap/IR 64	1999	RDC Bajo	600-1500
Bajo Kaap 1	Paro Maap/IR41996	1999	RDC Bajo	600-1500
Bajo Kaap 2	Bja Naab/IR41996	1999	RDC Bajo	600-1500
Yusi Ray Maap1	Suweon 359//IR41996-118-2-13/Thimphu Maap	2002	RDC Yusipang	Above 1800
Yusi Ray Kaap1	YR3825-11-3-2-1/ YR3825-11-3-2-1/Barkat	2002	RDC Yusipang	Above 1800
Yusi Raykaap 2	Akiyutaka/Naam	2010	RDC Yusipang	>1800 m
Yusi Raymaap 2	Akiyutaka/Rey Maap	2010	RDC Yusipang	>1800 m
Wengkhar Raykaap 10	-	2010	RC Wengkhar	300- 700
Bhur Raykaap 1	-	2010	RC Bhur	< 600
Bhur Raykaap 2	-	2010	RCBhur	< 600
Bhur Kambja 1	-	2010	RC Bhur	< 600

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Bhur Kambja 2	-	2010	RC Bhur	< 600
Sokha Rey 1	-	2018	RC Bhur	<600
YusireyKaap 3	-	2018	RC Yusipang	>1800
YusireyKathra-Mathra Rey	-	2018	RC Yusipang	>1800

a) Release of new crop varieties

Variety release encompasses a broadly inter-related series of activities. Firstly, new varieties are introduced into the country or new lines developed from a cross breeding program. Examples of introductions are rice varieties from IRRI (International Rice Research Institute), wheat and maize varieties from CIMMYT (International Maize and Wheat Improvement Centre) and so on. Such introduced varieties are tested in the research centres for a number of years following standard research protocols. The promising materials are then tested in farmers' fields in different locations to get their feedback and acceptability. Once promising varieties are identified and adequate research data generated, then a proposal for official release of the variety is made to the Variety Release Committee (VRC) of the Ministry of Agriculture and Forests. This is according to the requirement of the Seeds Act of Bhutan, 2000. After the VRC approves the release, then small amount of pure seed (breeder seed) of that variety is provided to the National Seeds Centre for further multiplication and distribution to the farmers. New varieties have to pass the DUS (Distinctness, Uniformity, and Stability) test before release. Variety release procedure is thus a collective term that refers to the protocols and administrative procedures used in releasing a new variety for seed production and distribution.

b) Distribution and maintenance of new varieties

The benefits of superior new varieties obviously cannot be realized until sufficient seed has been produced to permit commercial production. Although the primary function of the plant breeder is to develop new varieties, he or she usually also carries out an initial small-scale seed increase. Seed thus produced is called breeders seed. The next stage is the multiplication of breeder seed to produce foundation seed. Production of foundation seed is usually carried out by seed companies or institutes, whose work is regulated by government agencies (e.g. BAFRA in Bhutan). The third step is the production of certified seed, produced on a large scale by specialized seed growers (e.g. National Seed Centre) for general sale to farmers. Certified seed must be produced and handled in such a way as to

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meet the standards set by the certifying agency (BAFRA). Research centres that develop new varieties are responsible for maintaining the purity of new varieties once they have been released for commercial production.

We need to question ourselves as to '*What role does the 'breeding in Plants and animals' play in agriculture? Which methods do you suggest that the Bhutanese farmers/farm workers use to sustain agriculture in Bhutan? What scope do you foresee in privatizing the 'production and distribution of seed' in Bhutan? What is your view if you would like to join the farming community?*'

c) *Molecular Breeding and Marker-Assisted Selection*

The process of developing new crop varieties requires many steps and can take many years. Now, however, applications of agricultural biotechnology have considerably shortened the time it takes to develop varieties. One of the tools, which make it easier and faster for scientists to select plant traits is called marker-assisted selection (MAS). The different traits and physical features of plants are encoded in the plant's genetic material, the DNA which occurs in pairs of chromosomes coming from each parent. Traits like flower color, may be controlled by only one gene. Other more complex characteristics, however, like crop yield or starch content, maybe influenced by many genes. Traditionally, plant breeders have selected plants based on their visible or measurable traits, called the phenotype. But, this process can be difficult, slow, influenced by the environment. As a shortcut, plant breeders now use molecular marker-assisted selection. To help identify specific genes, scientists use what are called molecular markers which are short strings or sequence of nucleic acid which makes up a segment of DNA. The markers are located near the DNA sequence of the desired gene. Since the markers and the genes are close together on the same chromosome, they tend to stay together as each generation of plants is produced. This is called genetic linkage.

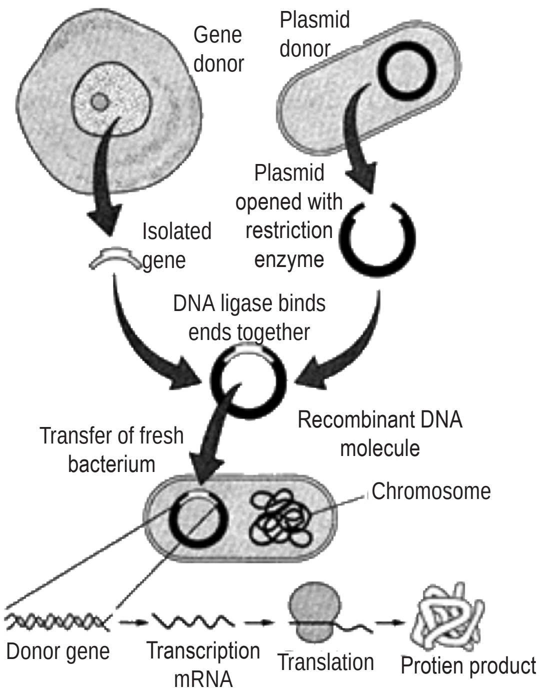

Figure 4.8 Molecular Breeding

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This linkage helps scientists to predict whether a plant will have the desired gene. If researchers can find the marker for the gene, it means the gene itself is present. As scientists learn where each of the markers occurs on a chromosome, and how close it is to a specific gene, they can create a map of the markers and genes on specific chromosomes. This genetic linkage map shows the location of markers and genes, and their distance from other known genes. Scientists can produce detailed maps in only one generation of plant breeding. Currently, molecular marker-assisted breeding, an agricultural biotechnology tool is already a routine step in breeding of most crops where the gene and the markers for a specific trait are known. This technique is being used in the efficient introgression of important genes into rice such as bacterial blight resistance, increased beta carotene content, and submergence tolerance to name a few.

4.6 Genetic Engineering and GM Crops

Genetic engineering is one of the modern agricultural biotechnology tools that is based on recombinant DNA technology. The term genetic engineering, often interchanged with terms such as gene technology, genetic modification, or gene manipulation, is used to describe the process by which the genetic makeup of an organism can be altered using "recombinant DNA technology." This involves using laboratory tools and specific enzymes to cut out, insert, and alter pieces of DNA that contain one or more genes of interest. The ability to manipulate individual genes and to transfer genes between species that would not readily interbreed is what distinguishes genetic engineering from traditional plant breeding. With conventional plant breeding, there is little or no guarantee of obtaining any particular gene combination from the millions of crosses generated. Undesirable genes can be transferred along with desirable genes or while one desirable gene is gained, another is lost because the genes of both parents are mixed together and re-assorted more or less randomly in the offspring. These problems limit the improvements that plant breeders can achieve. The process of genetic engineering requires the successful completion of a series of steps.

Step 1. Nucleic acid (DNA) extraction, either DNA or *ribonucleic acid (RNA)* is the first step in the genetic engineering process. It is therefore important that reliable methods are available for isolating these components from the cell. In any isolation procedure, the initial step is the disruption of the cell of the desired organism, which may be viral, bacterial or plant cells, in order to extract the nucleic acid. After a series of chemical and biochemical steps, the extracted nucleic acid can

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be precipitated to form thread-like pellets of DNA/RNA.

Step 2. The second step is *gene cloning*. There are basically four stages in any cloning experiment: generation of DNA fragments, joining to a vector, propagation in a host cell, and selection of the required sequence. In DNA extraction, all DNA from the desired organism is extracted. This genomic DNA is treated with specific enzymes called restriction enzymes cutting it into smaller fragments with defined ends to allow it to be cloned into bacterial vectors. Copies of the vector will then harbor many different inserts of the genome. These vectors are transformed into bacterial cells and thousands of copies are produced. Using information relating to specific molecular marker sequences and the desired phenotype, the vector harboring the desired sequence is detected, selected, isolated and clones are produced. Restriction enzymes are again utilized to determine if the desired gene insert was cloned completely and correctly.

Step 3. Once the gene of interest has been cloned, it has to be linked to pieces of DNA that will control its expression inside the plant cell. These pieces of DNA will switch on (promoter) and off (terminator) the expression of the gene inserted. *Gene designing and packaging* can be done by replacing an existing promoter with a new one, incorporating a selectable marker gene and reporter gene, adding gene enhancer fragments, introns, and organelle-localizing sequences, among others. Promoters allow differential expression of genes.

Step 4. The most common methods used to introduce the gene package into the plant cells in a process called *transformation or gene insertion*, include biolistic transformation using the gene gun and Agrobacterium-mediated transformation.

Step 5. Molecular detection methods have been developed to determine the *integrity of the transgene* (introduced gene) into the plant cell. Polymerase chain reaction or PCR is a quick test to determine if the regenerated transgenic cells or plants contain the gene. It uses a set of primers (DNA fragments) whose nucleotide sequences are based on the sequence of the inserted gene.

Step 6. Backcross Breeding (if needed): Genetic transformation is usually conducted in elite or commercial varieties which already possess the desired agronomic traits but lacks the important trait of the transgene. Thus, once successfully conducted, the genetically modified plant will be easily recommended for commercialization if it shows stability in several generations and upon successfully passing and fulfilling varietal registration requirements.

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Student Activity

1. Discuss with the class to:
    a. Grow vegetables, medicinal herbs or flowers or fruits tress in the campus:
        i. Smaller groups with different vegetable, medicinal herbs and flowers, etc.
        ii. Allocate different plots and prepare soil with same conditions,
        iii. Saw different seeds – local pure breed and hybrid seeds,
    b. Care the plants, observe and record development and health, harvest/yield.
    c. Compare, analyze data, write which plants did better and justify the differences if any.
2. Discuss and plan for a field trips to nearby RDC or government farm to study researches being done on plants and animals breeding, challenges and benefits.

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5

Chapter

Dairy Farming II

Dairy farming is one of the most prominent features of farming system in Bhutan. To boost the dairy farming and make it more efficient, Royal Government is providing support for breed improvement, housing, feed/fodder development and control of economically important livestock diseases. Besides, farmers are assisted to form self-help groups, support capacity building, provide access to vital infrastructure for products processing and marketing.

Improved dairy farming is emerging around the periphery of major cities. Availability of markets for fresh milk and milk products is the driving force for its emergence. This is helping to meet substantial portion of dairy products demand of the urban areas. This endeavor needs to be further strengthened through awareness creation among farmers to organize themselves into groups and cooperatives, adoption of modern farming technologies to make dairy farming economical and viable enterprise.

This chapter on 'Dairy Farming' aims at providing basic concept of dairy farming; apply the genetic theory and biotechnology learned from chapter 3 in cattle breeding and breeding system – local pure bred cattle and exotic dairy breeds of cattle; breeding methods in dairy cattle – inbreeding and out breeding, species hybridization; basic requirement for establishment of a dairy farm; fundamental of improved dairy farm management – proper housing and other facilities, good breeding practice, clean milk production, basic condition for clean milk, farm animal herd improvement, disposal of unproductive animals, disposal of farm waste – good practices of dairy farming for sustenance. Tips to modernize farming methods are also provided in this chapter and it is important to begin with a basic question 'what is dairy farming?'

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5.1 Dairy farming

Dairy farming is rearing of animals for production of milk which is either consumed as it is or processed into dairy products for home consumption and sale.

Although any mammal can produce milk, most commercial farms rear cattle as the main dairy animal. Other species used in dairy farming include buffalo, goat, sheep, yak, camel and so on. It is also important to know from the beginning what kinds of tasks are involved in a dairy farm – a commercial dairy farm, a larger scale farm than rearing just a few cattle in our village farm.

a) Tasks involved in dairy farming

Task involved in dairy farming are many-fold and they can be grouped under different categories such as (1) management of establishment (infrastructure), (2) management of dairy animals: rearing of dairy animals, feeding with quality feed and fodder, good breeding practices to improve the herd and animal health care that includes timely vaccination, deworming and treatment of sick animals; (3) management of production of milk and its products; and finally the (4) workers and their welfare. However, the second task is the most important one with which a dairy farm cannot compromise. The success of the dairy farm will depend heavily on understanding the animals and care for them. Selected cattle, more economical for farm to rear are being discussed. Let us start with understanding the cattle in the farm first – common and productive ones.

b) Cattle breeds

i. Local purebred cattle

It means a local cattle population that is recognized to receive a very little or no genetic influence by the recent crossbreeding, with modern breeds of cattle, introduced from Europe and other countries. Most of the country's 300,000 cattle are local purebred cattle. They are known locally as *Thrabam* (female), *Nublang* (male).

Figure 5.1 Nublang

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These local cattle *Nublang* or *Thrabam* have typical cervical hump of *Bos indicus* type. Other distinguishing features are: long head and face, wide and flat forehead. Humps are well developed in bulls and prominent for cows. Legs and feet are long and strong. Neck is broad and long with a well-developed dewlap in the male and prominent in female. These cattle type is mainly for draft power though they also provide some milk and manure.

ii. Mithun cattle

The Mithun (*Bos frontalis*) is a domesticated form of wild Gaur *(Bos gaurus*). Mithun is a rare bovine species indigenous to parts of the North-East Hills Region of India. Distinguishing features of pure Mithun are the prominent dorsal ridge on the crest of the shoulder, flat forehead and big horns with large base. The animals are mostly brownish black. Most animals have white stockings. Government farms in Bhutan also periodically import and maintain small numbers (<500) for pure line breeding and supply of Mithun bulls to farmers.

Figure 5.2 Mithun (Bos frontalis)

Bhutanese farmers have a long tradition of inter-species crossing of *Thrabam* with Mithun bulls to improve the productivity of cross-bred progenies for traits such as milk yield, fat percent, size and power.

iii. Exotic Dairy Breeds of Cattle

1. Jersey

Jersey breeds originated from British isle of Jersey. They are most often brown or tawny with a light-colored underbelly and dark hooves. Their milk contains higher milk fat than other exotic dairy breeds making it the ideal milk for the production of butter and cheese. The distnguishing features of this breed is dish shaped face and compact body.

Figure 5.3 Jersey cross cow

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2. Holstein-Friesian

Figure 5.4 Holstein-Friesian Cross cow

Originally bred in Northern Germany and the North Holland/Friesland regions of the Netherlands, it is the most popular of all the dairy cow breeds and produces more milk than all the other breeds. Holstein Frisian are mostly black and white.

3. Brown Swiss

Figure 5.5 Brown Swiss Cow

This breed is native to Switzerland. Their color varies from light-to-dark brown and sometimes gray, but they are easily recognized by their large furry ears. Brown Swiss have a very kind nature. Brown Swiss is a dual purpose breed used for milk and meat purpose.

5.2 Breeding System in Dairy Cattle

In animal breeding, a population is a group of interbreeding individuals i.e., a breed that is different in some aspects from other animals. Typically, certain animals within a breed are designated as purebred. The essential difference between purebred and non-purebred animals is that the genealogy (history or record) of purebred animals has been carefully recorded, usually in a hard-covered book. Selective breeding utilizes the natural variations in traits that exist among members of any population. Breeding progress requires understanding the two sources of variation – genetics and environment. For some traits there is an interaction of genetics and the environment. Differences in the animals' environment, such as amount of feed, care, and even the weather, may have an impact on their growth, reproduction, and productivity. Such variations in performance because of the environment are not transmitted to the next generation. For most traits measured in domestic animals, the environment has a larger impact on variation than do genetic differences. For example, only about 30 percent of the variation in milk production in dairy cattle can be attributed to genetic effects; the remainder of the variation is due to environmental effects. Thus, environmental factors must

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be considered and controlled in selecting breeding stock. Genetic variation is necessary in order to make progress in breeding successive generations. Genetic variations can be used for improving stock. Animal researchers study and analyze the genetic variation and use the information to calculate gains in improvement of the target traits or characteristics such as milk yield, meat production etc. Genetic gains made are permanent and cumulate from one generation to the next. Traits that can be observed directly, such as size, colour, shape, and so forth, make up an organism's phenotype.

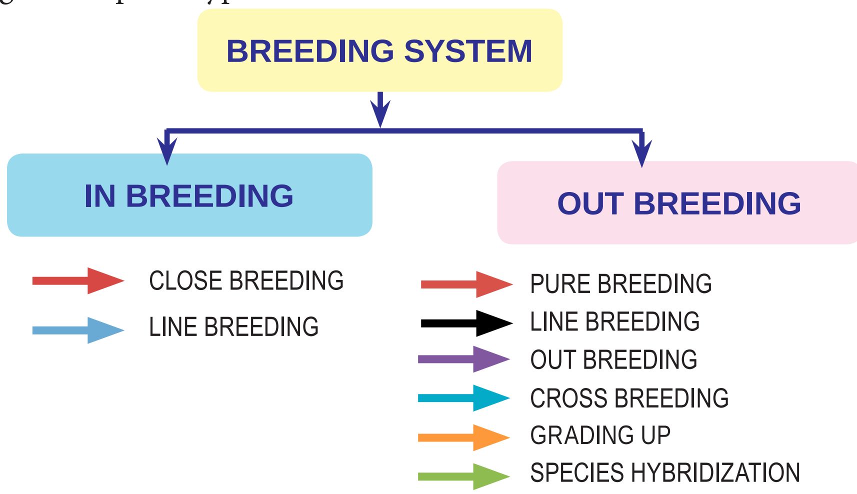

Figure 5.6 Breeding system

Breeding is defined as the crossing of the male and the female parents to get the offspring for the characters desired. The main breeding methods are:

a) In breeding

Inbreeding is the mating of closely related individuals. The example is the individual having one or more common ancestors or relatives. Inbreeding may be close inbreeding or line breeding.

i. Close inbreeding

In this type of inbreeding, mating is made between very closely related individuals, such as full brothers are crossed with full sisters, or off springs are crossed with parents.

ii. Line breeding

It is repeated back crossing to one outstanding ancestor, so that its contribution to the progeny is more. In this type of breeding, mating is made to concentrate

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the inheritance of desired characters of some favored individuals.

Advantages of Inbreeding

1. It increases homozygosity (similarity) and decreases genetic variance (variations).
2. Breaking down of population into different inbreed lines.

Disadvantages of Inbreeding

1. The progeny becomes more susceptible to diseases
2. Breeding problems and reproductive failure usually increases
3. Inbreeding has little value in dairy cattle breeding programs, because of its numerous detrimental effects.

b) Out breeding

It is the opposite of inbreeding. Mating unrelated animals is known as out breeding. It is divided into six classes as detailed below:

i. Pure breeding

Pure breeding is mating of unrelated male and female belonging to the same breed. Pure breeding is a sort of out breeding. The examples of pure breeding are:

1. Local purebred cows x local purebred bull
2. Jersey Cow x Jersey Bull

The advantage of pure breeding is for improving quality of animals within the breed. It avoids mating of closely related individuals.

ii. Line crossing (Crossing of inbreed lines)

This method of breeding is crossing of inbred lines. Inbred lines are developed through intensive inbreeding of more than five generations from unrelated line for the male and for the female. The unrelated inbred line male is mated to the inbred lines of female and the offspring born out of such mating becomes a hybrid which exhibits heterosis or hybrid vigour. Heterosis is the phenomenon where in the crosses between inbreed lines populations are better than two parental populations.

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iii. Out crossing

It is mating of unrelated pure bred animals in the same breed. The animals do not have common ancestors on either side of their pedigree (parental generations) up to four to six generations. It is an effective system for genetic improvement if carefully combined with selection. It is also pure breeding.

iv. Cross breeding

It is mating of animals of different breeds. Cross breeding is followed for breeding animals for milk production and meat production. In Bhutan local breeds of cows are crossed with exotic breeds such as Brown Swiss and Jersey bulls or use their semen for artificial breeding, to enhance the milk production potential of the progeny. The progeny inherits the desirable characters of the parent: high milk yield, early maturity, higher birth weight of calves, better growth rates, better reproductive efficiency and local (indigenous) parents' characters: disease resistance and ability to thrive on scanty feeding and coarse fodder.

Advantages of cross breeding

1. The desirable characters of the exotic parent are transmitted to the progeny which the indigenous parent does not have.
2. Results are seen more quickly in characters like milk yield in the cross bred progeny.

Disadvantages of cross breeding

1. The breeding merit of cross breed animals may be slightly reduced to that of parents.
2. Cross breeding requires maintenance of two or more pure breeds in order to produce the cross breeds.

v. Grading up

It is the practice of breeding in which the sires (male parent) of the exotic breed are mated with the local females and their off-spring from generation to generation. After five or six generations of grading up -a population resembling the exotic breed results. This is the breeding policy that is being pursued in Bhutan. Females of less developed breeds are continuously bred by exotic Jersey or Brown Swiss bulls.

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Advantages of grading up

1. After five to six generations progeny resembles pure bred animals both for physical appearance and production
2. Grading up avoids expenditure of purchasing the exotic females herd of improved animals as grading up is carried on with a few exotic bulls and the local female animals.
3. Farmers can get better price for upgraded animals

Disadvantages of grading up

1. The graded males are less useful for breeding and draught purpose
2. The adaptability to climate and the environment is reduced for upgraded animals

vi. Species hybridization

It is mating of male and female belonging to the different species to produce hybrid progeny. Species hybridization is extreme form of out crossing. The examples of species hybridization are: Local purebred cows (*Bos indicus* species) x Mithun bull (*Bos frontalis* species) to produce hybrids *Jatsham* and *Jatsha*, Mare (Female horse) x Donkey stallion to produce mules.

Figure 5.7 Jersey cross cows reared by farmer

Advantages

1. Hybrid progeny has higher production, greater strength for draught work and environmental adaptability because of new combinations of useful genes.
2. Farmers can get better price for hybrid animals.

Disadvantages

The graded males are sterile and useless for breeding purpose e.g Mithun-Local cattle Species hybridization results in sterility of first cross male *Jatsha* which is a major problem. Therefore, farmers have to back cross *Jatsham* with Nublang bull continuously for the next four to five generations are to regain the fertility of males.

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5.3 Basic Requirement for Establishment of a Dairy Farm

a) Land

It is the most essential requirement for establishment of a dairy farm. As a thumb rule in a good soil, one acre of green fodder cultivation is required for every five animals. However, in poor soil the acreage has to be increased based on grass growth rate and fresh/dry matter yield from pasture. In rugged terrain of Bhutan, where soil fertility is low roughly about one acre of land is required per head of adult livestock unit. Some portion of land should be devoted for building a dairy farm infrastructure.

b) Breeds of cows

Breeds of cows such as Holstein Friesen, Jersey and Brown Swiss or buffalo breeds such as Murrah, Surti, Nilli Ravi which are high milk producers are to be procured from commercial dairy farms within and outside the country. Cattle and buffalo yielding on an average 10 liters of milk a day, over a lactation period of 305 days, is recommended. Milking animals in second or third lactation are preferred, as the probability of increase in milk production is higher.

Frozen semen from progeny tested bull needs to be availed for Artificial Inseminations (AI) of cows in heat. The AI services can be availed from nearest Artificial Insemination outreach centre of Department of Livestock or from Community AI Technician trained and licensed by the Government. The farm should select offsprings of high producing cows; good quality female progeny born in the farm should replace the herd.

c) Skilled manpower, labor and labor saving device

For a dairy enterprise, manpower is required for performing different husbandry practices at the farm such as feeding, watering, milking and care of animals. The strength of labourers in the farm can vary with number of animals. Usually the thumb rule is one labour for every 10 animals on milk or 20 dry animals or 20 young stocks. One farm workers can handle 10 milking animals. With additional animals born in the farm the labour force should be proportionately increased. Labour saving devices/farm machineries such as mower machine, chaff cutter, milking machine, chilling and improved milk processing equipment, scythes, rack and fork saves labour.

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d) Farm development

During the first year, there is a need to construct boundary fencing to protect the pasture from encroachment by wild and stray animal and also for bio-security. The water channel can be constructed or water can be piped for use in farm. The land suitable for pasture development should be fully utilized in phased manner to develop pasture. Pasture, once developed, should be divided into paddock system for rotational grazing and each paddock size will depend on herd size. Some land should be devoted for planting of bunch forming species such as Gautemala, Napier, Paspalam and Sugarcane, which can be used for stall feeding (cut and carry system) and for winter fodder conservation. Some areas should be devoted for cultivation of lean season fodder such as oats and maize. Existing trees in the farm land (if any) should be kept to maintain soil moisture and provide shed to the animals. Fodder trees can be planted in and around the farm area for supplementing feed and to provide shed for the livestock.

5.4 Dairy farm management

Commercial/Semi-commercial dairy farmers depend on land, labor and dairy animals as the major resources. The thrust in modern dairy farming is on the increased use of capital and management. Successful dairy farming harnesses all available resources into productive and profitable unit.

Dairy farming is highly complex as it includes breeding, management, feeding, housing, disease control and hygienic production of milk. The judicious use of means and resources to achieve clearly defined goals is the key success factor in modern dairy farming.

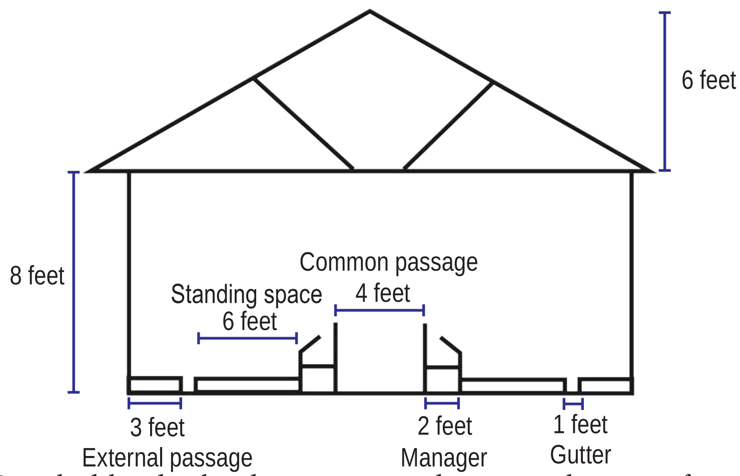
Basic requirements of a dairy farm re

a) Proper housing and other facilities

Sheds of the animals should:

1. be airy with protection of the animals from extreme temperatures and strong winds.
2. be 70 sq.feet for smaller breed like Jersey and about 84 Sq. feet for bigger breeds like Holstein Friesian space required per animal,

3. have floor dimension (as in diagram) are required for head to head arrangement,
4. have water trough has to be constructed along the Manger,
5. have proper drainage system to keep hygiene at the farm.



Note: Cow shed-head to head arrangement, dimension shown are for one side Other Side of common central passage will have similar dimension

Figure 5.8 Animal shed dimensions

b) Good feeding practices

Fresh green grass about 10% of body weight should be fed to each animal. Rice straw can be used as dry roughage along with green fodder during winter. Straw can be enriched with urea and molasses to improve nutrient content. When green grass is available in plenty it can maintain milk production (up to 5litres per day). However, for every litre of milk produced over and above 5 liters in a day, 0.5 kg of concentrate is required (thumb rule is 1 kg concentrate for the production of 2-2.5 liters of milk). The wet distillers' grain by-product of grain distillery if available nearby can be mixed with other feed ingredients and mineral mixture according to feed animals. This can provide adequate energy and protein required by animal in production.

On an average feed required by adult livestock unit is 10 kg DM/day. Therefore, optimum stocking rate is required to maintain the good pasture throughout the season and to feed the farm animal year round. Over grazing pasture will decrease the yield and after few year the species will disappear so it should be avoided. If

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the pasture grazing is not controlled, the maintenance cost will be high. Therefore, the over grazing should be controlled. Ways to control overgrazing are: paddock system (rotational grazing), tethering and stall feeding through cut and carry.

c) Clean milk production

Milk is the whole, clean lacteal secretion obtained by the complete milking of healthy milking animals, properly fed and managed, excluding that obtained within 15 days before and 5 days after calving. Milk may become a harmful food if it is not produced and handled under sanitary conditions. Milk produced at villages have high bacterial load. Basic steps to produce and consume clean milk will safeguard health of the consumers.

Figure 5.9 Clean and healthy cows

Milk marketed must be clean so that it will have good flavor and be free from harmful bacteria and other disease organisms. Milk produced under sanitary conditions will have longer keeping quality. It is more important to produce good quality milk for fluid use than when milk is converted into dairy products. Most dairy plants are now offering cash premiums for quality milk. Production of quality milk increases the profitability of the dairy farmer.

Purpose of clean milk production to:

1. produce clean milk free from dirt.
2. secure milk of low bacterial count.
3. keep milk free of disease organism.
4. prevent bad odour.
5. prevent spread of milk borne diseases like Tuberculosis (TB), Typhoid
6. increase the shelf like /keeping quality of milk.
7. make good quality dairy products.
8. initiate quality production of milk.

For human consumption clean and safe milk is desirable to minimize risk of zoonosis (disease transmitted from animals to human and vice versa). Proper sanitation during production and supply of milk to consumers is essential.

Sanitation can be maintained through: proper production and handling of raw milk, healthy cows: timely treatment and control diseases, proper housing and feeding, safeguarding health of producers/farmers, protection of water supply from contamination and protection from flies and insects. It is essential to provide adequate housing space allowance, flooring should be easy to clean and should not slippery to cause fall and injury, supply of bedding in cold weather and should have proper ventilation, provision for rapid diagnosis and treatment of injuries. Antibiotics to control disease should be allowed provided products entering the food supply don't contain antibiotic above recommended level.

d) Basic conditions for clean milk

The animals should be regularly checked for mastitis (infectious disease resulting in inflammation (swelling) of udder and teats), discard foremilk to remove dirt and contamination. Before milking udder should be wiped and dried, hairs around the udder and flanks should be clipped if required. Milking utensils should be cleaned, sanitized and dried before use. Practice of clean milking habits such as dry milking, cleaning of hands before milking is essential.

Once milking is complete, it should be strained using clean cloth/sieve to filter dirt and debris. The milk should then be immediately cooled after milking because micro-organisms grow at 20-400centigrade. At this temperature milk quality deteriorates quickly. Cooling of milk can be done through emersion of milk can/bottle in cold water, use of chilling machines/refrigerators to cool milk.

Figure 5.10 Aluminum milk can

Milk containers should be non-toxic, non-tainting, insoluble, resistant to corrosion, easy to clean. Containers recommended are stainless steel and aluminum. Containers not recommended are copper and alloys because milk forms green corrosion products which is highly toxic. Similarly iron and alloys

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rust easily and is slightly toxic.

Milk should be processed adopting good manufacturing practices; packing materials should be paper, aluminum foils and food grade plastics. Use proper packaging machinery for filling, sealing, handling and storage (where possible) is recommended. Use of deep fridge for storage and use of cool pack for transportation of milk and products to market will improve keeping quality of milk.

e) Farm animal herd improvement is necessary for improved milk production.

It involves keeping records at equal intervals, selection of bull from high producing mothers or use of progeny tested bulls for Artificial Insemination (AI) program. Timely heat detection and mating with selected bull or availing AI service is crucial.

Figure 5.11 Holstein Friesian and Jersey Calf born through Artificial Insemination

f) Preventive animal health care

It is essential like timely vaccination against Black Quarter, Foot and Mouth Disease, Hemorrhagic septicemia and other important endemic disease along with maintenance of udder hygiene to prevent mastitis and reduction of parasite load through deworming at least once in every six months should be practiced to improve overall performance of dairy herd.

g) Disposal of unproductive animals

The low performing animal female should be culled. Good males born in the farm can be sold to needy farmers or are purchased by Government (if breeding criteria are met) for supply to other needy farmers. Rest of the males should be sold for draft purpose or salvaged for meat.

Reprint 2022

h) Disposal of farm waste

Waste such as urine and dung should be collected in the dung pit constructed in the vicinity. It can be decomposed and used as farm yard manure/organic fertilizer in the established pasture field. This will supplement and reduce the use of chemical fertilizer. Farm Yard Manure application should be done right after harvesting/grazing once in three months so that the dung pit not overloaded. Possibility of using farm manure for bio-gas production should be explored.

Important points to remember

To start a sustainable dairy farm, the following points need to be considered.

- Required pasture and fodder resources should be developed and water required by the farm should be connected before purchase of stock
- Infrastructure such as cattle shed, milk collection and processing unit can be constructed in a phased manner based on budget availability.
- State of art labour saving devices such as milking machines, farm machinery should be used where possible to cut down operation cost
- The low yielder animals are uneconomical to keep; hence these should be periodically culled off. Regular curative treatment has to be done.
- Hygienic milk production should be followed keeping healthy animals, clean surroundings, clean milking practices and clean utensils and replaced by animal of good production history
- Feeding dairy animals on nutritious and high yielding hybrid varieties of forages can be adopted. The surplus forage should be preserved as silage or hay. Feeding during different stage of growth, maintenance, pregnancy and lactation should be practiced
- Provide (muddy water hole where buffalo can rest) wallowing facilities of animals in summer (if buffalo farm is established)
- To prevent any disease outbreak in the animal herd, each new animal should be vaccinated against common diseases before entering the farm and should be regularly vaccinated later
- If expansion of farm is desired, same structure and pasture development model can be adopted after sufficient land is made available and parent stock already procured.

To sum up, dairy farming is a business that does not make anybody rich overnight but it can provide a steady livelihood and income source. No business is easy and one cannot take things for granted. However, with adequate commitment in dairy farming, one can never go hungry. 'Take up dairy farming to serve your GNH society gain food sovereignty'.

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Student Activity

1. Discuss with the class, prepare proposal plans of starting dairy farm in the school campus (if it is feasible) and present to the principal on:
   a. Objectives of starting a dairy farm on the campus,
   b. Location of the dairy house,
   c. structure of the dairy house as given in this chapter, construction materials required, construction to be done by the class, when the work the will begin and aims to complete.
   d. Proposal to develop pasture, sowing grass seeds, and planting fodder trees and developing other facilities.
   e. Who and how cows care and feeding etc. will be managed.
   f. How the dairy produce or economic returns will be utilized.
   g. Identifying cattle breed for the farm and procuring through 'gewog or dzongkhag' agriculture sector.
   h. Support required from the school management such as approval, location, capital for purchase of materials and cattle.
   i. Discuss and share responsibilities of construction work, start construction, procure feed, cattle, etc.
   j. Discuss and managing the dairy after jointly by the class but with appointment of leaders who can ensure cattle farm is taken care with proper records.
   k. Monitor and review cattle care and management of the farm regularly for further improvement.

   Or

2. If a cattle farm exists in the school (as many schools have), review the cattle house, care management and improve the existing dairy farm. Or
3. Plan a field trip to a dairy farm (private or government) to learn all about dairy farm starting from establishment investment, costs, care management and return or economic benefits, write report and assess students' work.

Reprint 2022

6 Chapter

Seed Production and Marketing

Agriculture is the largest employment generating sector and about 54 percent of the country's population depends on it. Agriculture is also a mega industry in which many other industries thrive on Agriculture. 'Seed Production and Marketing' is a booming industry as farmers largely depend on seeds and saplings – the produce of National Seed Production and Marketing, DoA, MoAF. This chapter attempts to provide learners with basic concepts of seeds/sapling of various crops and plants, production procedures of seeds and sapling at different altitudes and different seasons starting with preparation of land, manure, watering and care related management practices before the seeds and saplings are ready for market or use in the farm. The government institutions and private organizations for supporting farmers with seeds and sapling are discussed for enhancing future entrepreneurships on 'seed production and marketing' in the country for realizing food security for our sovereign GNH society. Let's start with basic question of 'what is a seed?'

6.1 Seed

Seed means any material used for sowing or planting and includes seed of food, feed, forages, fruits and vegetable crops. It also includes seedlings and tubers, bulbs, rhizomes, roots, cuttings, all types of grafts and other vegetative propagation materials of foods, fibre, or forage crops or forest plants (MoA, 2000). For this chapter, the seed is exclusively applicable for agricultural and horticultural crops.

a) Importance of Seed

Agriculture started with the domestication of plants and animals by human beings for food some thousands of years ago. Ever since the domestication of plants, human beings strived persistently for selection of seeds of plants with superior and desirable traits to meet the ever changing demands for food. The demand for

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quality seeds has increased as agriculture became more prominent as the source of livelihood. The demand for quality seeds increases even more as subsistence farming progresses towards commercial farming. Quality seed is the most critical and basic input for agricultural output and reported responsible for 25-30 per cent of yield increase. Availability of quality seed is, therefore, one of the most important aspects to ensure maximum and sustainable agricultural production in a country to obtain food security. Seeds protect and sustain life of the people around the world and the power of seed is described as unlimited. Production and supply of quality seeds and planting materials to the farmers at affordable price will be possible only if the national seed system is strong, dynamic and vibrant equipped with adequate human resources and facilities.

Traditionally, the Bhutanese farmers cultivated indigenous crops for their subsistence which were recognized as the '*dru-na-gu*' (rice, maize, wheat, barley, buckwheat, millets, amaranth, mustard and pulses). The farming concept of dru-na-gu or nine crops continued and diversification of other crops remained largely unexplored. Farmers continued to grow indigenous crops which were of low genetic yield potential and prone to pests and diseases. The use of indigenous crops and the lack of seed replacement resulted in lower yields. It is reported that seed quality deteriorates in 2-3 years if farmers continuously use their own saved seeds (Reddy et al., 2007). Recognizing the need for crop diversification and enhancement of crop productivity for food security and livelihood of the farmers, the Royal Government of Bhutan initiated introduction of quality seeds and plants of improved varieties with the establishment of Department of Agriculture during the first five year plan in 1961. The Department of Agriculture then started a number of model agricultural farms, seeds multiplication farms, agricultural research station, and development of extension work. Efforts were made to increase the area under fruit and vegetable cultivation.

b) Seed Development

Indigenous crops are susceptible to pests and diseases, take longer to grow, lodging problems and are of low genetic yield potential. To develop improved high yielding crops, research on crop variety development started in 1982 with the establishment of the erstwhile Centre for Agricultural Research and Development (CARD) which is currently known as the Research and Development Centre (RDC), Bajo, Wangduephodrang. Besides RDC Bajo, RDC Bhur, RDC Wengkhar and RDC Yusipang are currently carrying out crop variety development activities. These

Reprint 2022

RDCs introduce new high yielding superior varieties from other countries and carry out adaptive trial under Bhutanese environmental and cropping conditions. Bhutanese researchers in RDCs also develop new varieties through cross breeding. Bajo Maap 1 & 2, Bajo Kaap 1 & 2, Yusi Ray Maap 1and Yusi Ray Kaap are new rice varieties developed in Bhutan by the Bhutanese Researchers. The newly introduced or developed varieties are first evaluated at the research stations following research protocols and the promising varieties are then evaluated in the farmers' fields wherein farmers are invited to select their preferred varieties. Based on farmers' feedback and the performance of the new varieties the proposal for release of new varieties is submitted to the Variety Release Committee (VRC) of the Ministry of Agriculture and Forests. The National Seeds Centre (NSC) produces the seeds of the new varieties released by VRC and supply to the farmers at affordable price.

c) Seed and Seed System

Seed deterioration occurs with repeated multiplication primarily as a result of mixture and unwanted pollination. Thus, in order to supply quality seeds to the farmers on time, NSC is attempting to follow three-generation system of seed multiplication. The three stages of seed multiplication are breeder seed, foundation seed and certified seed.

i. Breeder seed

It means seed or vegetative propagating material directly controlled by the originating or in certain cases the sponsoring plant breeder or institution, and which provides the source for the initial increase of foundation seed. The breeder seed is produced in the Research and Development Centres (RDCs) and supplied to NSC at regular intervals.

ii. Foundation seed

It means the progeny of breeder seed stocks that are so handled as to maintain specific genetic identity and purity, and that are designated or distributed by the government or private seed companies. The NSC produces foundation seeds from the breeder seed in the NSC farms.

iii. Certified seed

It means the progeny of foundation seed that is so handled as to maintain

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satisfactory genetic purity and identity, and which has been acceptable to the certifying agency which is Bhutan Agriculture and Food Regulatory Authority (BAFRA). The certified seeds are then supplied to the farmers. NSC supplies the foundation seed to the Registered Seed Growers (RSGs) and produces the certified seed for further supply to the farmers.

Seed System may be *formal seed system* referring to seeds or planting materials produced through government or registered seed or nursery growers (registered with NSC or BAFRA) with systematic quality control and certified by the certifying agency BAFRA, whereas, *informal seed* produced by the farmers, used by the producer, or traded between farmers or through traders without formal involvement of government organizations and without documentation on quality.

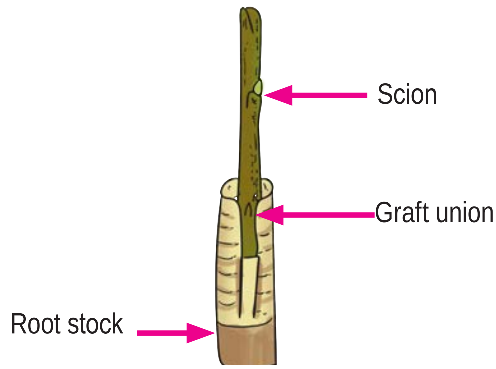
In Bhutan, informal system is the main source of seeds and planting materials except fruit plants. It is reported that 98% of the total seed requirement in the country is met from informal seed system (SAC, 2011). However, with literate young Bhutanese taking up agriculture in more scientific approaches, there will be more entrepreneurs specializing in the seed production industry for the crops production industry that are gaining popularity in Bhutan as well as in the markets of our neighbouring countries.

6.2 Seed and Plant Propagation Methods

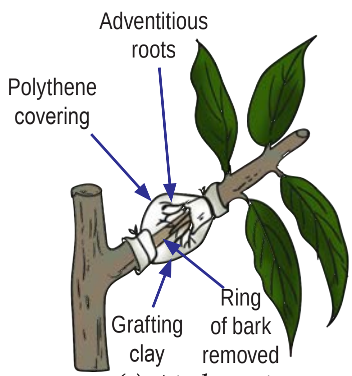
Let us recapitulate plant propagation methods learned from Chapter 3. Plants reproduce asexually or sexually in nature. The asexual method is also called *vegetative propagation* and it is the use of planting materials which are vegetative parts of any plant rather than seeds or spores which are reproductive parts. The new plants are genotypic duplicates of the mother plants. This method is extensively used for the propagation of fruit plants, strawberries, sugar cane, potatoes, sweet potatoes, cassava, flowers and most herbaceous and woody ornamental plants by agriculturalists.

The vegetative propagation is done by cuttings, grafting, layering and tissue culture. A *cutting* (Figure 6.1a) is the use of cuttings from stem, roots or leaves from the desired plant. *Grafting* (Figure 6.1b) is a technique wherein a part of the stem of one plant is mechanically joined to the stem or root of another plant. *Layering* (Figure 6.1c) involves placing a part of the plant stem under conditions favourable for rooting. Once roots have formed the new plant is separated from the mother plant and established in a new location. *Tissue culture* (Figure 6.1d) uses very small cuttings that are sterilized and grown in test tubes under aseptic conditions.

(a) Stem cutting



(b) Grafting



(c) Air layering

(d) Tissue culture

Figure 6.1 Plant propagation

Sexual propagation is a process by which plants reproduce, in which pollen from one plant fertilizes the ovary or ovaries from another, producing one or more seeds. It can be contrasted to asexual propagation in which new plants are created from divided plant parts (cuttings), stolons or runners, storage organs such as bulbs or tubers, or any of a number of other ways. This method of propagation is used for cereals, vegetables, oilseeds, legumes, etc.

Reprint 2022

6.3 Seed Production Infrastructures and National Seed Programme

In order to give more impetus on production of quality seeds and planting materials, a nationally coordinated seed production program in the country was started in 1984 with the establishment of National Seed and Plant Production Programme (NSPPP) in Paro. NSPPP was given the mandate to produce and supply seeds and planting materials of released and recommended varieties.

In 1995, NSPPP was restructured as Druk Seed Corporation (DSC) and given additional commercial mandate. DSC was supposed to generate adequate revenue from the sales for its sustenance. However, DSC was not able to financially sustain on its own revenue which affected supply of quality seeds and planting materials to the farmers. Thus, to revamp the seed programme, DSC was reverted back to the government agency under the Department of Agriculture in 2010 and renamed as National Seed Centre (NSC).

The primary mandate of NSC is to produce and supply quality seeds and planting materials of released and recommended varieties and fertilizers in adequate quantities at affordable price on time to the farmers. In addition to NSC, Bhutan Alpine Private Seed Company was established in 2001 and Reva Seed Enterprise, a private seed company in 2014 respectively. Currently, NSC and the above two private seed companies cater the need of seeds and planting materials in the country.

The NSC headquarter is located at Chundudingkha under Luni geog in Paro. The headquarter is responsible for planning, coordinating, monitoring and mobilization of resources while production of seeds and planting materials are carried out by the eight farms under NSC which are strategically located into four regions:

- West (Chundudingkha, Jeuphu and Bondey),
- West-Central (Bajo, Phobjikha and Nangsiphel),
- East (Jachedphu, Tashi yangtse and Chenary in Tashigang) and
- South (Bhur).

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The Farms located in four regions have been assigned appropriate mandates of producing seeds and planting materials based on their agro-ecological zones. The Figure 6.1, political map of Bhutan indicates the locations of Research and Development Centre in the country with Table 6.1 indicates each farm with the mandate of seeds and planting materials production for different crops depending on the agro-ecological zones and feasibility.

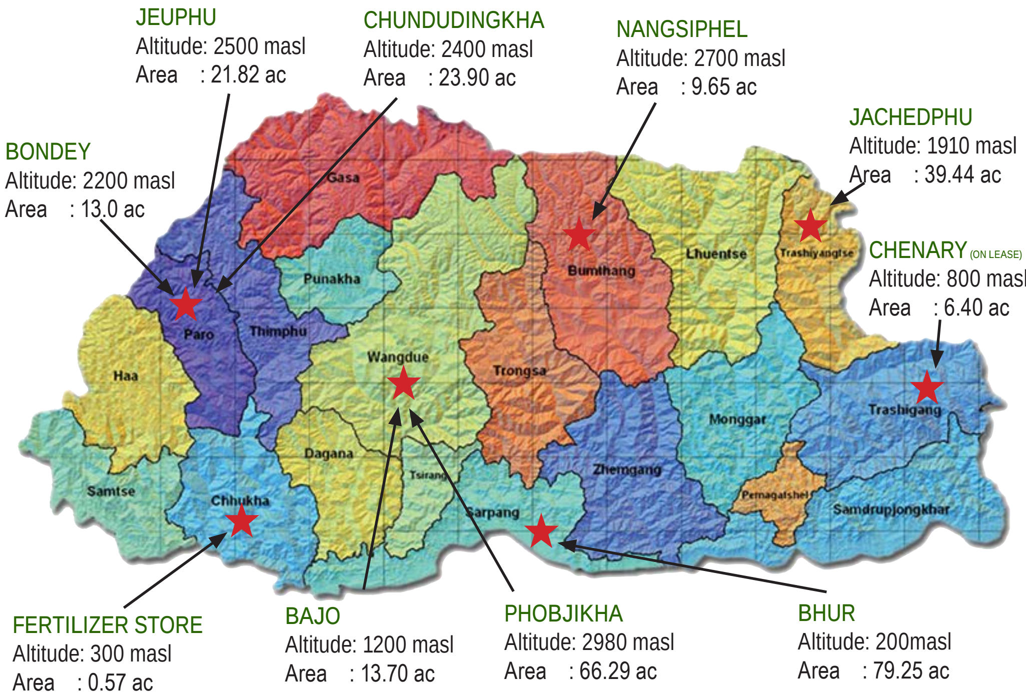

Figure 6.1 Location of the Farms under National Seed Centre

Table 6.1 Mandates of the farms under National Seed Centre

SL no	Farms	Size (Acre)	Focal Crops
1	Chundudingkha, Paro	23.90	*Vegetables*- Brinjal, Cauliflower, Cucumber, Chilli &Pumpkin. Planting Materials- Persimmon, walnut, strawberry *Food Crops* – High altitude rice
2	Bondey, Paro	13.00	*Vegetables*- Onion, Beans, Cabbage, Radish and Coriander. *Planting Materials*- Asparagus seedling

Reprint 2022

3	Jeuphu, Paro	22.82	*Vegetables*- Cabbage *Planting Materials*- Apple, Pear, Plum, Peach, Apricot, Cherry, Almond, Persimom, Chestnut and Asparagus seedling
4	Bajo, Wangdue	13.70	*Vegetables*- Tomatoes, Mustard green, Cauliflower, Carrot, Radish and Spinach. *Food Crops*- Wheat, Mustard and mid altitude Rice. *Planting Materials*- Asparagus seedling
5	Phobji, W/due	66.29	Seed Potatoes
6	Bhur, Sarpang	79.25	*Vegetables*- Tomatoes. *Food Crops*- Low altitude rice. *Planting Materials*- Citrus, Mango, Litchi, Guava, Pomegranate, Areca nut, Banana, Passion fruit, Pineapple and Papaya.
7	Nangsyphel, B/thang	9.65	Seed Potato
8	Jachedphu, Tashi-Yangtse	35.10	*Vegetables*- Beans, Cabbage, Cauliflower, Cucumber, Pumpkin and Radish. *Food Crops*- Soybean, Maize Planting materials- High altitude citrus

a) Registered Seed Growers

To facilitate seed and planting materials production, farmers can register to shoulder the responsibility of producing seeds and planting materials with NSC. They are known as 'Registered Seed Growers' (RSGs). The RSGs are farmers who are trained on seeds and planting materials production and capable of producing quality seeds and planting materials as per the requirement of NSC and the certifying agency. These RSGs are registered with NSC for production of seeds and planting materials specified by NSC.

Certified seeds are produced by the registered seed growers (RSG) under the supervision of NSC and as per the undertaking note established between the NSC and RSG in the beginning of the season prior to the implementation of seed

Reprint 2022

production activities. Certified seeds are produced under RSG scheme since the available land with NSC is not adequate to produce the required quantity and also owing to the difficulty of managing such huge quantities. This practice also reduces the cost since there is minimal involvement of government resources. For such reasons it is a standard practice adopted by national and multinational seed companies worldwide.

As the collaborator, NSC provides certain benefits to the RSGs. The benefit of being a registered seed grower is that they have assured market for their produce at pre-informed price and they do not have to worry about the price fluctuation in the market. The foundation seed especially low volume vegetable seed is supplied to them on recovery basis at the end of the season while the foundation seed for bulky crops such as cereals and potatoes are supplied to them at the purchase price which is lower than the general selling price. Inputs such as fertilizers are also delivered to the nearest road point free of transportation charges.

b) Link with other institutions

One of the primary responsibilities of RDCs is to introduce or develop new crop varieties of superior traits with high genetic potential and which are resilient to climate change. The RDC is responsible for production and maintenance of breeder seed. The breeder seed is supplied to NSC at regular interval for further multiplication and production of foundation and certified seeds. It is crucial to maintain continuous flow of breeder seed from RDCs to NSC in order to produce adequate quantity of quality certified seeds for supply to the farmers. As part of research and development activities RDCs also train farmers and build capacity of farmers on seed and nursery production of various crops. Capitalising on the existing institutional set up, NSC links up with the farmers or farmer groups and register as the RSG for production of certified seeds and planting materials. The gewog and dzongkhag Agriculture staff helps NSC in identifying and linking up the farmers' groups or RSG with NSC. The extension officers also help NSC in monitoring seed production activities and in mobilizing seed collection from the farmers. The extension officers play a crucial role in facilitating and nominating the Agriculture Sales and Services Representatives (ASSRs) for their respective gewogs and dzongkhags to NSC who sell seeds, planting materials and fertilizers of NSC. ASSRs play a key role in delivering adequate quantities of seeds, seedlings and fertilizers to the farmers on time. NSC works closely with BAFRA in maintaining the quality standard of the seeds, planting materials and fertilizers

Reprint 2022

with a timely request of BAFRA staff for field inspections and certifications. NSC has also established linkages with international seed companies particularly for procurement of hybrid seeds and for other seeds and planting materials as and when required to meet the demand of the farmers.

6.4 Production Procedures of Seeds and Planting Materials

In Bhutan, the seeds and planting materials are broadly classified into vegetables, cereals, oilseeds, pulses, potatoes, temperate fruit plants and sub-tropical fruit plants for planning and implementation purposes.

a) Vegetables

A vegetable can be defined as an annual, biennial or perennial herbaceous plant, or part of a plant, which is used as a food (FAO, 1980). Pea, bean, tomato, eggplant /brinjal and chili are annual, cabbage, broccoli, cauliflower, carrot and radish are biennial and asparagus is perennial. NSC is currently supplying more than 25 vegetable species and over 45 varieties. Chilli seed production method is provided below as an example for vegetable seed production.

i. Seed Production Method of Chilli

1. Soil and Climate

The requirement are specific to chilli without which chilli will not have proper yield. An ideal medium for growing chilli is a light loamy soil, rich in lime. Still it can be grown in variety of soils provided they are well drained and rich in organic matter. Chilli is grown in both tropical and sub-tropical areas. A temperature ranging from 20 to 25°C is ideal for chilli (Rashid and Singh, 2000). A warm humid climate favours growth while dry weather enhances fruit maturity.

2. Seed Rate

To achieve optimum plant population 500 of seed with minimum germination of 75% is adequate for one acre (DSC, 2008).

ii. Procedures

Chilli seed production involves a series of activities that are time bound and important for productivity. No farmers or farm workers can afford to compromise or should try to compromise.

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1. *Nursery bed preparation*

Prepare standard nursery beds of 1 m wide and 15-20 cm height with well-pulverised soil. Sow seeds in lines of about 2 cm deep and 10 cm apart. Seeds should be treated with Thiram (fungicide) dust at the rate of 3 g per Kg seed before sowing to protect seedlings from damping-off disease in the nursery. Growing nursery in plastic tunnel will bring forward the growing season by one month in high altitude areas above 1200 masl.

2. *Field Preparation and Transplanting*

Cultivate the field till fine tilth is ascertained. Level the field to facilitate uniform irrigation and drainage. Plant the seedlings on raised bed of 1 m wide and about 15 cm height and length according to the convenience. Raised bed is required to prevent from chilli wilt disease and 1 m wide bed for easy intercultural activities in the later crop stages. Transplant the seedlings of 12-15 cm height on the raised beds at a spacing of 45 cm between the rows and 30 cm from plant to plant along the rows. Transplanting should be done preferably during the evening and irrigation should be applied immediately after transplanting.

3. *Manure and Fertilizer*

In one acre, farmers may apply at least 10 MT of well decomposed farm yard manure (FYM). In addition, farmers may apply 24 Kg of N, 24Kg of P2O5 and 15Kg of K2O per acre before final land preparation which is equivalent to 50 Kg of Urea, 150 Kg of SSP and 25 Kg of MoP as basal dose (DSC, 2008). An additional amount of 50 Kg of Urea may be applied in split application two to six weeks after transplanting.

4. *Weeding*

Chilli requires frequent inter-cultivation. Therefore, two to four weeding and hoeing is necessary depending upon the soil condition and weed pressure.

5. *Irrigation*

Chilli cannot withstand high soil moisture condition. Hence, irrigation should be applied only when necessary. In that case, the number of irrigation depends upon the rainfall and soil moisture condition.

6. *Crop Rotation*

Like brinjals and tomatoes, chillies are also susceptible to many soil borne diseases particularly chilli blight disease. Therefore, a period of 2 to 3 years gap between

Reprint 2022

successive chilli crop or other solanaceous crops is recommended.

7. Isolation

Chilli is considered as self-pollinated crop, but significant cross-pollination does occur if plants are placed together (Rashid and Singh, 2000). A minimum distance of about 400 m between two varieties is recommended.

8. Roguing:

Plants should be rogued based on the plant and fruit characters. Off-types should be removed as soon as they are observed. When the fruits begin to show their final colour of red or yellow, occasional plants with off-colour fruits have to be removed. In addition to off-types, diseased plants are also to be removed.

9. Harvesting and Threshing

The fruits are picked when red-ripe and macerated (soaked and softened) to separate the seeds. Early harvest of immature fruits will affect germination. Seeds are cleaned to free pulp and skins and dried to 8 per cent moisture content before storage.

10. Seed Processing

Seeds are processed using machines such as mini-seed cleaner for grading and cleaning and final cleaning using a gravity separator to remove light materials such as chaffs and dust, broken stems, sticks, stones and other seeds to maintain seed purity. A minimum of 98% physical seed purity is required to be maintained (DRDS, 2002).

11. Seed Storage

Generally, seeds are recommended to dry at a moisture range of 5 to 14%. If the seed moisture is above 14% mould growth destroys seed germination rapidly and below 5% physio-chemical reactions may occur leading to deterioration of seed quality. Temperature also affects the shelf life and viability of seeds. It is therefore, important to maintain the seed moisture depending on the storage temperature (Table 6.2).

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Table 6.2 Safe moisture content of seeds at different storage temperature (DSC, 2008)

Sl. No.	Kinds of seeds	Safe moisture content (in %) for different storage temperature		
		5-10^{0}C	21^{0}C	27^{0}C
1	Bean	15	11	8
2	Cabbage	9	7	5
3	Carrot	13	9	7
4	Cucumber	11	9	8
5	Lettuce	10	7	5
6	Okra	14	12	10
7	Onion	11	8	6
8	Peas	15	13	9
9	Pepper	10	9	7
10	Spinach	13	11	9
11	Tomato	13	11	9

b) Cereals

A cereal is a grass, a member of the monocot family Poaceae cultivated for the edible component of its grain, composed of the endosperm, germ and bran (Fig. 3). Cereals include rice, maize, wheat, barley, millets, oats and sorghum. Seed production method of rice is provided below as an example of cereals seed production.

i. Seed Production of Rice

Rice is the most preferred staple cereal in Bhutan. It is grown in the sub-tropical lowland (150 m) in the south and up to 2700 m in the north. The highest altitude where rice is cultivated is in Bumthang. The Bhutanese farmers cultivate indigenous as well as improved varieties. Seed production of rice requires series of activities unique to rice cultivation.

1. Soil and Climate

Rice can be cultivated under a variety of climatic and soil conditions. For normal growth, a pH range of 5.0-8.0 is suitable. Rice being a tropical and sub-tropical

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plant requires a fairly high temperature, ranging from 20°C to 40°C. The optimum temperature of 30°C during day time and 20°C during night time seems to be more favourable for the development and growth of rice crop. In Bhutan, rice is cultivated under irrigated, rain-fed and upland conditions.

2. *Seed rates*

Depending on the method used for raising the seedlings, an average seed rate of 20-25 kg per acre is recommended.

ii. *Procedures of Seed production*

1. *Nursery Raising*

It involves semi-dry method, wet bed method, tray method and poly tunnel method. All the methods have specific procedures that are similar yet and specific condition to fulfil one's requirement.

Figure 6.2 .Semi-dry bed

Semi-dry bed method is good for areas where irrigation is not assured, shochum (weed) is common, and in areas where low temperature is a problem at the seedling stage. The main stepwise activities are given below:

1. Prepare a well-levelled field with fine pulverized soil.
2. Add about 3 kg of well-rotten FYM to a seedbed of 1 m x 3 m and thoroughly mix with the soil.
3. Raised seed beds to about 10 -13 cm high and 1 metre in width and any convenient length (Fig. 6.4).
4. Broadcast dry seeds uniformly on seedbeds (1.2 kg of seed to an area 1 m x 6 m).
5. Spread a thin layer of fine soil with well-decomposed FYM to cover the seeds.
6. Irrigate the bed immediately after sowing – soaked and never flood.
7. Check the moisture of the seedbed and irrigate when necessary.

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8. Transplant seedlings after 40-50 days of sowing.

Wet Bed method is good for areas where irrigation is assured, and where low temperature is not a problem. This method is not desirable where shochum is very common. The main steps involve are:

Figure 6.3 Wet bed method

1. Plough, add enough FYM, puddle and level a conveniently located plot.
2. Raise beds to about 10-13 cm high x 1 metre in width x any convenient length (Fig.6.5).
3. Soak the seeds in clean water for 12 hours, rinse the seeds, drain and incubate them for 24 hours. Keep the seeds moist and warm in half-filled, loosely-tied sacks during incubation. Drench the sacks and turn them upside down to even out the temperature after every 12 hrs.
4. Broadcast the pre-germinated seeds uniformly on the beds (1.2 Kg of seeds for a seed bed of 1 m x 6 m).
5. Water continuously to saturate the beds for the first week and gradually increase the water level as the seedlings grow. Never let the beds dry out.
6. Transplant seedlings after 20-25 days of sowing depending on the temperature.

Tray method is recommended for mechanized transplanting or when a rice transplanter is to be used. This method is laborious and requires additional materials like tray. Follow these procedures:

Figure 6.4 Tray method

1. Fill a bucket with fresh and clean water.
2. Add common salt and stir the water to dissolve the salt.

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3. Place an egg in the solution to see if the egg floats in the solution.
4. Add more salt and stir solution till the egg floats on the solution.
5. Pour the seeds in the solution of water and salt and stir gently.
6. Remove the seeds floating on the water. They are not likely to germinate. Seeds sunk in solution are healthy and are be used for sowing.
7. Wash the healthy seeds in running water.
8. Soak the seeds in clean water for 12 hours, rinse the seeds, drain and incubate them for 24 hours.
9. Collect acid soil or red soil (virgin soil) from uncultivated areas (to avid weed seeds) and sieve (4 to 5 millimetre) the soil
10. Cover the tray with newspaper to clog the roots before putting soil.
11. Spread the sieved virgin soil onto the tray evenly, sow the sprouted seeds evenly on the soil and cover the seeds with another layer of sieved virgin soil on the tray.
12. Dip the tray in water and drain completely.
13. Heap the trays and keep away from direct sun or rain.
14. Transfer the trays to a shaded house with flat ground, after seeds have germinated to about 1 cm in height and water the seedlings as needed.
15. Transplant the seedlings after 20-25 days of nursery.

Poly-tunnel is used over the bed to protect seedlings from cold and provide higher seedbed temperatures for seed germination and growth while raising seedlings for first crop in double cropping and in areas where low temperature is a problem. Minimum temperature required for the germination of rice seed ranges from 9 to 130C. Normal air temperature during the first week of February in Wangdue-Punakha valley averages only 4 to 80C. A poly-tunnel cover increases the temperature to 10 to 120C, making seed germination and growth possible.

Figure 6.5 Poly-tunnel method

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The main steps of this method are

1. Prepare a well-leveled field with fine pulverized soil.
2. Raised beds to about 10-13 cm high x 1 m wide x any convenient length.
3. Sow seeds evenly on the seedbed as in a semi-dry bed method.
4. Cover the seeds with fine soil mixed with FYM (1:1 mixture).
5. Irrigate the beds to ensure sufficient moisture for seed germination. Sprinkle water or give light irrigation through the channels to soak the beds. Never flood the seedbeds.
6. Placed bamboo hoops over the beds 80 cm apart down the length of the bed, pushing the ends firmly into the soil.
7. Place medium weight transparent polythene sheet over the hoops long and wide enough to cover the beds. The edges of the polythene should be covered with soil to hold them down to the ground.
8. Check the moisture frequently to ensure that there is enough water and whenever necessary irrigate by raising the polythene sheet.
9. Opened the plastic tunnel every morning (9 to 10 am) to let in more sunlight and prevent day temperatures from getting too high once the seedlings emerge. The tunnel should be closed again in the evening (3 to 4 pm) every day to keep the seedlings warm at night.
10. Irrigate the nursery as and when required preferably during the day. Seedling vigour will depend upon the soil temperature and growing conditions.
11. Transplant seedlings upon attaining 3-4 leaf stage or after 40-45 days of sowing.

2. Field preparation

It is the second stage of the seed production. As in the first stage of nursery raising, field preparation has many activities that need to be carried out systematically and wholeheartedly if one needs to be successful in Seed Production industry. The field preparation involves:

1. Pre-irrigate the field, before ploughing if it is dry.
2. Plough/dig the field 20-25 cm deep using bullock-drawn implements, power tiller or tractor depending on land terrain and available farm

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resources. Tilling /digging the field exposes eggs of harmful insects, pests and seeds and rhizomes of weeds and making the soil safe for seed to grow.

3. Dig the corners of the field manually where the plough may not have reached and get rid of the weeds and grasses from the bunds and walls which may later harbour rodents. Bunds should also be repaired for impounding water in the field.
4. Flood the field and keep flooded or saturated for a few days. This will help in decomposition of crop and weed residues.
5. Drain the water slightly and puddle the field using a rotovater or other implements as needed to break clods and ensure a fine soil tilth. Ideally, puddling should be done about two weeks before the date of transplanting. Puddling is an important operation for transplantation of rice to create ideal growing conditions.
6. Repair and maintenance of bunds and the incorporation of chemical fertilizers, if any, should be done before the final puddling.
7. Level the field prior to transplanting using a mechanical leveler or wooden leveler as practiced by farmers. Land leveling improves water management which supports weed suppression and control, crop establishment, nutrient use efficiency, crop uniformity and maturation, drainage and ultimately rice yields.
8. Allow the mud to settle for a day before transplanting to avoid sinking of seedlings, especially if a rice transplanter is to be used, land preparation has to be thorough and seedlings need to be raised in trays.

3. Transplanting

It is the third stage of rice cultivation. The main advantages of transplanting are a good and uniform plant stand, easier crop and water management, good control of weeds and other pests. Transplantation may be done as follows.

1. Transplant seedling at random or in straight rows or lines. In Bhutan random transplanting is the most common method, which requires less labour compared to planting in lines.
2. Avoid wide spacing in random transplanting. A plant density of 25-35 hills per square metres is optimum.
3. Transplant using random method if the weed pressure is expected to be

Reprint 2022

low, herbicides such as Butachlor is intended to be used for weed control and where rice terraces are narrow and small.

4. Transplant in lines if weeds is expected to be done with a rotary weeder. Line planting also enhances the attainment of an optimum plant population and facilitates weeding and other operations.
5. Use rope or guides or makers in line plantation to attain straight rows.
6. Maintain row spacing of 20 cm and plant to plant spacing of 15-20 cm within the rows.
7. Transplant 2-3 seedlings per hill at a depth of 2-3 cm.
8. Increase the number of seedlings per hill if transplanting is delayed or if the seedlings are old to compensate for reduced tillering.

The time of transplanting depends on the altitude regime and also the variety. Use the following guide for rice growing zones:

- High altitude (above 1600 masl): May to early June
- Mid altitude (700-1600 masl) : June to early July
- Low altitude (below 700 masl) : July to early August

4. Manure and Fertilizers

Soil fertility management is one of the biggest challenges for increasing rice production in the country. Traditional management practices such as the sole reliance on farmyard manure or animal manure from tethering are not adequate to exploit the yield potential of rice varieties, especially the high yielding varieties (HYVs). In the southern foothills, soils are generally poor with low organic matter due to leaching of nutrients and insufficient use of FYM or any other nutrient source. Hence proper nutrient management is necessary to increase rice production.

Rice requires a balanced supply of nutrients, water, air and sunlight to grow well. Nutrients can come from either organic or inorganic sources. Organic sources include biological nitrogen fixation sources such as green manures and blue green algae, compost and animal manures. Nutrient composition varies with the sources. Green manures such as *Sesbania aculeata* can accumulate 80–100 kg N/ha in 45–60 days of growth. The advantage of organic sources of nutrients is that they can provide a wide range of nutrients, whereas inorganic fertilizers only produce a single or few nutrients. Organic sources also provide "bulk" matters that are important in the sustenance of soil organic matter. Inorganic fertilizers are easy to use and save labour.

Soil fertility status is subject to change from one location to another and from one cropping season to the next. Ideally, analysis of soil would determine the nutrient requirements of a specific field but may not be possible all the time. For sustainable rice production, follow proper nutrient and crop management practices as outlined below:

1. Make efficient use of all available sources of nutrients, including organic manure, crop residues, as well as inorganic fertilizers according to availability and affordability. It has been found that supplementing the basal use of FYM with Urea topdressing at tillering or panicle initiation stage increases rice yield.
2. Use balanced fertilizers supplying with macro-nutrients (NPK) as well as micro-nutrients such as zinc, iron, boron etc. Farmers tend to use only N which is not a wise practice in the long run.
3. Replace nutrients, particularly P and K, which are removed with grain and straw to avoid nutrient mining.
4. Follow other proper crop management practices such as the use of quality seeds, optimum plant density, Integrated Peat Management, water management, etc to fully realize the benefit of soil management.

Fertilizer recommendations

Based on the field experiments done by the National Soils Services Centre (NSSC) and present knowledge, the following fertilizer recommendations for rice are made for the low altitude southern foothills:

1. For local rice varieties, the general recommended rate is 32-20-8 kg NPK per acre for high resource farmers. Where resources are limited, a rate of 20-16-8 kg NPK per acre is recommended.
2. For improved rice varieties, the general recommended rate is 32-20-12 kg NPK per acre for high resource farmers. Where resources are limited, a rate of 30-12-8 NPK per acre is recommended.
3. Apply the entire dose of P and K as basal dressing during land preparation. If half the N is applied basally, topdress the remaining half at active tillering stage (20-35 days after transplanting) or after first hand weeding. Further splitting of N into equal doses at tilling stage can improve rice yields.

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4. To improve soil structure and water retention capacity, use FYM or compost prior to or during land preparation. Generally, 2-3 tons of FYM per acre is recommended. Supplementing with N topdressing @ 14 kg per acre after 30-40 days of transplanting can lead to higher yields.
5. Wherever possible, use green manures like Sesbania aculeata (Dhaincha) as a pre-rice manure. Sow dhaincha in April-May @ 20-25 kg/acre and incorporate in the soil after 6-8 weeks. Transplant rice after about 2 weeks of incorporation.

Figure 6.6 Dhaincha (Sesbania aculeata)

5. Weeding

Weeds are the worst competitors of rice plant. They compete for water, nutrients, sunlight and other growth requirements for rice, hence reducing grain yield. There weeding is an essential activity in rice cultivation. Use the following guide:

1. Two hands weedings at 20 and 40 days after transplanting are sufficient where weed pressure is expected to be low or moderate. If hand weeding is to be done, plants should be close spaced and the first weeding performed not later than 30 days after transplanting.
2. Rotary weeding where weed pressure is expected to be high. Two rotary weedings at 20 and 40 days after planting are recommended.
3. Butachlor (5% granule) at the rate of 10-15 Kg per acre 3-6 days after transplanting where grass and sedge weeds are expected to be severe (Ghimiray et al., 2011).
4. Weed-free seedbeds and seeds, etc. are useful for control of weeds. Good land preparation and proper water management are key to controlling weeds in the rice field that can reduce rice or seed production.

Reprint 2022

6. Irrigation

Water is a critical input for rice production. It is not necessary to keep the rice fields flooded all the time for higher yields. Keeping rice fields moist or in field capacity saturation without standing water saves water. However, if the soil moisture drops below field capacity, yield potential can be reduced and weeds can compete more freely. There are generally three types of irrigation and water management practices commonly followed, depending on water availability:

1. Continuous flooding with standing water is practised where there is abundant and assured irrigation water. There is continuous water in the field at varying depths of 3-8 cm.
2. Intermittent irrigation involves applying water rapidly in sufficient quantities to the field from 4-7 days. This is then stopped and water is completely depleted until the next irrigation period. It is common in water scarce areas where rotational water sharing is practised by farmers. Intermittent irrigation helps to reduce shochum pressure.
3. Rain-fed water management involves impounding rainwater in the field for irrigation, either directly or through a network of channels. This practice is influenced by the onset and withdrawal of monsoon and the amount of rainfall in the season.

Whatever may be the source of water available for the rice cultivators, water is most critical and important during:

- land preparation, vegetative, reproductive and ripening stages of the rice crop.
- after transplanting keep the water level as minimum as possible for about 3-6 days until the seedlings recover. If drought occurs after the root establishment stage, rice plants can withstand the stress and resume normal growth as irrigation water is reapplied. Water level should be gradually increased as the crop grows ensuring adequate soil moisture from panicle initiation to dough stage.
- flowering is the most critical stage when moisture stress should be avoided. It is beneficial to drain water at maximum tillering stage so that tiller formation is not hampered. Drain water from the field 10-15 days before harvest. This will ensure dry field conditions during harvesting and other operations.

Reprint 2022

7. *Roguing*

Roguing (means removal of plants other than the ones planted for seed) off-type plants (plants other than the one planted) should be done once prior to flowering, at flowering and then at maturity. The major roguing should be done just after flowering and the final when crops are near maturity.

8. *Harvesting*

It includes cutting the rice stalk (reaping), laying out the paddy on the stubble to dry, bundling, stacking and threshing. It is important to harvest the crop when the seed is ripe. Harvest the crop when 80-85% of the grains are straw coloured (i.e. yellow) or when the moisture content of the seed is 20-25% wet basis (Ghimiray et al., 2008).

9. *Threshing*

It is a process of detaching or separating rice seeds from the panicle by stripping, rubbing, striking or against a suitable object or by using a threshing machine. In Bhutan, threshing is done by trampling, flailing and pounding, animal threshing, pedal threshing and mechanical threshing.

10. *Seed processing*

It includes cleaning of the seeds to remove unwanted materials. It is done by winnowing aided by wind, screening/sifting or winnowing using fans to improve cleaning efficiency. Seeds are dried to a moisture level of 12% by field drying, sun-drying or mechanical dryer. Final cleaning and grading of the seed is done by air and screen cleaner machine. The graded seeds are then treated with an insecticide (Cypermethrin) and packaged in the NSC's standard HDPE bags of 20 Kg unit and stored at room temperature for short duration.

c) *Oilseeds*

Oilseeds are crops cultivated for extraction of cooking oil. This includes groundnut, rapeseed, mustard, niger, sesame, perilla, castor, sunflower, etc. Mustard is a predominant oilseed crop grown in Bhutan. Seed production method of mustard is provided below as an example of oilseed production.

i. *Mustard seed production method*

Mustard is the most predominant oilseed crop and it is cultivated in all the 20

Dzongkhags in Bhutan. Farmers cultivate indigenous as well as improved varieties of mustard (Table 6.3.)

Table 6.3 Improved released varieties of mustard and their characteristics

Sl. No.	Name of Varieties	Yr. of release	Releasing Agency	Yield Potential (t/acres)	Maturity (Days after Sowing)	Recommended Agro-Ecology (masl)
1	M-27	1989	RC Bajo	0.4	85-90	<2000
2	Bajo Peka 1	1994	RC Bajo	0.5	145-155	<2000
3	Bajo Peka 2	1994	RC Bajo	0.4	120-130	<2000

1. Soil and climate

Mustard is capable of growing under a wide range of soil conditions varying from sandy loam to clay loam soils but they thrive best on light loam soils. They neither tolerate water logging conditions nor do well on heavy soils. Mustard can be grown in the tropical as well as temperate zones and require cool and dry weather for satisfactory growth.

2. Seed rate

2-3 kg of seed per acre is recommended for optimum production.

ii. Procedure

1. Sowing

It is a common practice in Bhutan to establish mustard by broadcast method. However, for optimum production of seed yield, row sowing with a spacing of 30-40 cm between rows and 4-5 cm between plants is recommended.

2. Manure and fertilizer

Ideally, like for any other crops, fertilizer application should be based on the soil test result. However, in general, 80:40:20 NPK/kg/ha and 7 MT of FYM is recommended (RNRRC Bajo, 1997).

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3. *Weeding*

One hand weeding when the plants are 15 to 20 cm high is required.

4. *Irrigation*

Once at the pre-sowing and another at the flowering stage is recommended for obtaining higher seed yield.

5. *Isolation*

It is the practice of growing different varieties of crops in different plots for the purposes of seed production. Isolation distance is the minimum distance required between two plots growing different varieties of crops (example – maize variety or mustard) to avoid cross pollination and genetic contamination. Isolation distance of 400 m for foundation seed and 200 m for certified seed is recommended.

6. *Roguing*

All off-type plants including diseased plants must be removed before flowering to ensure genetic purity of the seed crop. The remaining off-types should be removed before maturity.

7. *Harvesting and threshing*

It is important to harvest the seed crop soon after plants start turning light yellow. At this stage most of the pods are light yellow and the seed inside the pods are light brown in colour. After harvesting, the crop should be left in the field for two to three days to dry in the field or brought to the threshing floor to dry. Threshing can be done by flailing after plants have dried well.

8. *Seed storage*

Dry the seeds to reduce moisture content to 8% before storage.

d) Legumes and pulses

A pulse is sometimes called a "grain legume". It is an annual leguminous crop yielding from one to twelve seeds of variable size, shape, and color within a pod. Pulses are harvested mainly for their dry seeds to provide protein in human diet. The pulses include groundnut, mung bean, rajma bean, pea, cowpea, soybean etc. Pea seed production method is provided as an example of pulse seed production.

Reprint 2022

i. Pea Seed Production

Pea is an annual plant with slender and succulent stem. In Bhutan, pea is grown for the dry seeds as a source of protein and green pods for vegetable. There are two released varieties of pea that are cultivated by the farmers.

Table 6.4 Released varieties of pea and their characteristics

Variety	Yr.	Releasing Agency	Yield Potential (t/acres)	Maturity (Days after Sowing)	Agro-Ecology (masl) of	Characteristics
Usui	1989	RC Bajo	2.0-3.0	90-100	>1800	Long green pods, smooth round cream coloured large seeds, hardy, tall variety
Arkel	2002	DSC	1.0-2.0	65-75	All AEZ	Short green pods, small wrinkled green seeds, dwarf variety

1. Soil and Climate

Peas prefer a cool moist climate and favourable temperature ranges from 10-20°C. Pea does not grow well in hot weather. The crop is best adapted to well drained, loose and friable loamy soil. Soil pH should be in the range of 6.0-7.7 (Rashid and Singh, 2000). Peas should not be grown consecutively even for two years in the same land as it will favour seedling diseases, blight and also pea nematodes. It is best rotated with cereals.

2. Seed Rate

Use 25-30 kg seed with minimum germination of 75% per acre to achieve optimum plant population and seed yield.

ii. Procedure

1. Land Preparation

Thorough preparation of soil is essential for pea because it is an exhaustive and

Reprint 2022

short duration crop. It helps for the rapid and free spread of roots. Growing on raised beds of 1 m wide and about 15 cm high will ensure good drainage and facilitate good crop husbandry.

2. Manures & Fertilizer

Organic manures and phosphorous application are most important for peas. About 10 MT of Farm yard manures and 20:20:20 N P2O5K2O Kg per acre in the form of Urea, SSP and MoP should be applied as basal dose (DSC, 2003). No additional dose of nitrogen for topdressing is recommended as it may have deleterious effect on nodule formation and thus nitrogen fixation.

3. Seed Sowing

The seeds should be sown at a depth of 3 to 6 cm depending upon the soil moisture. Seeds should be sown in rows about 30 cm apart for dwarf varieties and about 45 cm apart for tall varieties. The plant to plant distance in a row can be maintained at 10 cm.

4. Irrigation

Water requirement of pea is very low and it is sensitive to excess soil moisture. Thus, irrigation should be provided as and when needed. Ensure adequate water supply during flowering. Late irrigation during warm weather should be avoided which may cause sun-scalding (burning) of plants and also plants may tend to lodge and some rotting of vines may occur if the soil is kept too wet.

5. Weeding

Pea should be maintained free of weeds up to 40 days from emergence in case of early dwarf varieties or the stage of appearance of flower buds. Depending upon the weed pressure 2 to 3 weeding and hoeing is adequate.

6. Isolation

Pea is largely a self – pollinated crop with a little natural crossing. Hence, the isolation distance for peas is relatively short and aims mainly to avoid mechanical mixtures. However, the isolation distance may be at least 20 metre from one variety to another for foundation seed and 10 metres for certified seed (Agrawal, 1993).

7. Roguing

The off-type and diseased plants should be rogue out from the seed field. Careful roguing should be done at flowering and after pod formation.

8. Seed Harvesting and Threshing

One of the tests for maturity is to squeeze the seed between fingers. If the cotyledons break away from each other and free moisture is not visible, the crop may be considered mature enough for harvest (Rashid and Singh, 2000). The other indicators of maturity are when pods are dry, turn brown in colour and seeds rattling freely. Vines along with the pods are harvested from the field and sun dried in the field or threshing floor for 2-3 days. Threshing is done by flailing when sufficiently dry. Care should be taken during threshing so that the seed coats are not injured.

9. Storage

Threshed seeds are cleaned by winnowing, dried to reduce seed moisture content to 11% and stored in air cooled rooms.

e) Fruit Plants

Fruit plants are broadly classified into temperate and sub-tropical plants. The temperate fruit plants include apple, peach, pear, plum, apricot, persimmon, cherry, strawberry, chestnut and walnut. Sub-tropical fruit plants include areca nut, avocado, citrus, guava, jackfruit, litchi, mango, papaya, pineapple, pomegranate and passion fruit. Fruit plants are generally propagated by asexual method or vegetative propagation. Apple propagation method is provided as an example.

i. Propagation Methods of Apple

Apple propagation involves several activities such as establishing stock plant, rootstock, grafting of genetically distinct plants to unite and continue growth as a single apple plant and propagated further using the same principles with different methods. Each activity has unique procedures as describe below.

1. Stock Plant

The success of any form of propagation depends on the quality of the scion wood to be grafted. Therefore, establishment of proper stock plant or scion wood mother block is essential. Stock plant (scion wood mother plants) is the nursery plants from which materials for propagation are obtained. Select a site which is fertile

Reprint 2022

with good drainage and free of replant problems to establish stock plants. If it is required to maintain many varieties in the same field, plant in rows of only one variety to ensure easy identity of the varieties. Stock plants need pruning to initiate adequate production of shoots for scion wood.

Collect pencil size scion during the dormant stage in December-January. It is recommended to collect the scion early in the day while temperatures are cool and the plants are still fully turgid (Crasweller, 2005). Collect and use one year old shoot (shoot that grew the previous year) as scion. To keep scions from drying out, getting hot, or freezing, place the scion into plastic bags or wrap it in moist towels as you collect it. Place scion of only one variety in a labelled bag. Scions that will not be used immediately should be bundled, labelled, and placed in moistened sand for storage.

2. Root stocks

There are different methods of producing apple root stocks. The common methods are mound layering, trench layering, hardwood cutting and micro-propagation. In Bhutan, apple root stocks are produced through mound layering which is also known as stooling method. In stooling method spacing of 30 cm between plants and 100 cm between rows are maintained for mechanization purposes. One-year-old rootstock is cut back to near-ground level while dormant (December-January) so that new growth will sprout during the growing season. After the rootstock has sprouted shoots of 15 – 20 cm long, a mound of soil is piled around the rootstock covering up to half the height of the shoots three times a year in April, May and June. By early winter in the next season, these new shoots will have produced roots of their own. The soil mound is then removed, the rooted shoots are cut in December-January and the cuttings are used as root stock for grafting. The fibrous roots of the root stocks that are harvested are covered with moistened moss and stored under the shade.

3. Grafting

It involves joining of two genetically distinct plants so that they unite to continue growth as a single plant. The two parts of the compound plant are known as the root stock and the scion. The root stock refers to the lower part of the grafted plant – the part that produces the root system. The scion is the upper portion that produces the shoot system. Apple trees with desirable characteristics, such as tasty fruit, good colour, good size and of commercial value are often grafted onto hardy, disease-resistant and drought tolerant rootstock from another variety to

Reprint 2022

produce an overall sturdy and highly productive tree. Eleven varieties of apples are released for cultivation in Bhutan. Red delicious, royal delicious and golden delicious are preferred by growers, consumers and exporters for their size, colour and taste. Scions from these released varieties are grafted on to the root stock MM 106 to produce apple grafts. Another feature of the root stocks is that they impart dwarfing effect on the scions and or the tree in general. Rootstocks like MM106 and MM111 are semi-dwarf but M9 is ultra-dwarf root stock used in high density apple plantation. Grafting is necessary to produce true-to-type of a variety. The seeds of each apple are the result of pollination from a different apple tree species or variety. This makes each seedling a genetically unique individual with unpredictable traits. Fruit will be unlike parents in flavor, colour, date of ripening, and many other characteristics which is not a "true-to-type".

Bench grafting and chip budding are common methods of producing apple grafts. Bench grafting is also known as whip and tongue grafting. In Bhutan apple grafts are produced using bench grafting methods. In bench grafting, pencil size scion with 2-3 buds is grafted to the root stock of the same size ensuring the graft union at about 30 cm from the first lateral roots. This method is most successful for grafting apple because of the large amount of cambial contact, it heals quickly and makes a strong union. Grafting is done by making a 2.5 to 5 cm sloping cut (Crasweller, 2005) on the root stock and a downward cut is made into the root stock starting a third of the way down from the top end (Figure 6.7). The scion is prepared in the same manner. The two pieces are then fitted together with the tongues interlocking (Figure 6.8) and the graft is wrapped immediately using a grafting tape or plastic tape (Figure 6.9). The plastic tape is secured by pulling the free end under the last turn around and making the wrapping as airtight as possible.

Figure 6.7 Slope cutting

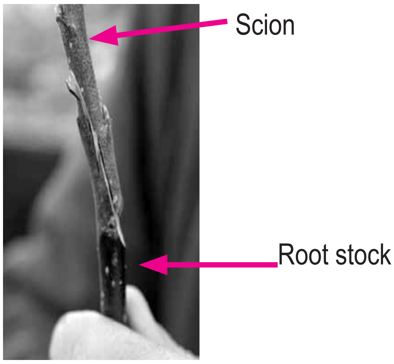

Figure 6.8 Interlocking graft

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Figure 6.9 Plastic wrapping

Figure 6.10 Rootstock and scion shoots

4. Nursery Management

Figure 6.11 A year old nursery

Nursery is a place where plants are raised with special care until they are ready or large enough for transplanting into the field. The apple grafts are planted in a field well prepared with good drainage at a spacing of 15-18 cm between plants and 100 cm between rows in March and maintained in the nursery (Figure 6.11) for one year. De-suckering of shoots grown from the rootstocks is done 3-4 times a year starting from April. Poor shoots are removed and maintained one scion shoot with good vigour. After scion has grown 5-10 cm the grafting tape is carefully slit vertically to prevent girdling (Waterman et al., 1993). Depending on the weed pressure 3-4 hand weeding is carried out and irrigated as and when required.

5. Uprooting and Storing of Grafts

One year old apple grafts are carefully uprooted from the field in February-March. Injured roots are trimmed off, standard size grafts are selected, transported to the storage, covered the roots with moistened moss and stored to prevent from drying. The roots of the grafts are covered and wrapped with moistened moss and hessian cloth while supplying to the customers to prevent the grafts from drying during transportation. The undersized grafts are replanted in the nursery.

Reprint 2022

6.5 Seed Quality Test

Sowing of quality seed is crucial for farmers to achieve optimum plant population and optimum crop yield. Four parameters such as physical purity, germination, health and genetic purity are used in determining the quality of seed. The NSC conducts the following routine tests in ensuring the seed quality.

a) Moisture Content

The two most important factors that influence the viability of seed stocked in the seed store are seed moisture content and temperature. For every 1% decrease in seed moisture, the life of seed is doubled. The Seed Processing and Quality Control Division receive the raw seeds from the field and farms. A seed sample of 300 g for smaller seeds and 1000 g for larger seeds are randomly taken from the well mixed seed lot. These samples are used for conducting moisture content, physical purity and germination tests respectively. The moisture content of the seed is tested using a moisture meter and dried to the right moisture required level using a mechanical dryer depending on the crops.

b) Physical purity

Place the sample on the purity work board/table and separate into pure seed, other crop seed, weed seed and inert matter. After separation, identify individual components of the sample. Seed lot failing to meet the minimum requirement is rejected while those seed lots meeting the requirement are packaged for supply. Physical purity of the seed is calculated as below:

$$\%\text{ of component} = \frac{\text{Weight of individual componenet}}{\text{Total weight of all componenets}} \times 100$$

Germination means the emergence and development from the seed embryo of the essential structures that indicate the seed's ability to produce a normal plant under favourable conditions. It is a standard procedure to use 8 or 16 or 20 replicates of 400 seeds from the above samples depending upon the size of the seed. National Seed Centre conducts routine germination tests such as Top of Paper (TP), Between Paper (BP) or Roll Towel and Pleated Paper (PP) tests in the NSC seed testing laboratory depending upon the seed size as below. The procedure of germination test is done as follows.

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i. Top of Paper (TP)

1. Wash your hands carefully to reduce any contamination.
2. Cut the paper towels into round circles that will fit inside the bottom of the Petri dishes.
3. Moisten the circular pieces of paper towel with as much water as they can absorb.
4. Wipe off excess water droplets.
5. Place one paper into the bottom of each Petri dish.
6. Record the test number on the lid of the container.
7. Using spatula, count exactly 400 seeds onto a paper towel randomly.
8. Place 50 seeds into each Petri dish using tweezers gently.
9. Place the lid/cover securely on the Petri dish. An improperly secured cover will let air into a Petri dish and therefore, change the growing conditions.
10. Place 50 seeds in the remaining Petri dishes using the identical procedure.
11. Place the Petri dishes in the germinator maintained at the desired temperature (28°C -30°C).
12. Maintained humidity at 95-98%.
13. Count seed germinated on the 5 day and recount on 14-21 days depending upon the type of seeds.

ii. Between Paper (BP) or Roll Towel Test

1. Soak the towel paper in water.
2. Remove extra moisture by pressing the soaked paper by hand and holding it in plastic/surgical trays placed on the table top in slanting position.
3. Place two layers of wet paper toweling as substratum.
4. Record the test number, crop and date on the wax paper or tag.
5. Arrange seeds spaced properly.
6. Place one layer of wet towel paper over the seed.
7. Fold two inches of the bottom edge.
8. Roll firmly from left to right and secure with rubber band in the centre.

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9. Place the prepared roll towel in roll towel stand or baskets.
10. Transfer the basket or roll towel stand in the germinator maintained at the desired temperature (28°C -30°C).
11. Maintained humidity at 95-98%.

iii. Pleated Paper (PP)

Seeds are placed in pleated strips. The paper may have 5-10 pleats and each pleat may have 10 seeds. The pleated strips are kept in boxes or directly in a wet cabinet with a flat strip often wrapped around the pleated paper to ensure uniform moisture conditions. This method may be used as an alternative where TP or BP methods are prescribed. Germination of seed is calculated as below.

$$\text{Germination } \% = \frac{\text{Number of seeds germinated}}{\text{Total number of seeds}} \times 100$$

c) Seed Processing

Seeds received from the field often contain high moisture level, trash, inert materials, weed seeds, deteriorated and damaged seeds, off-size seeds, etc. Seed processing is necessary in order to dry the seeds to a safe moisture level, remove undesirable materials, weed seeds, other crop seeds, damaged seeds and grading uniform size seeds to improve the seed quality. National Seed Centre has seed processing and drying facilities in Bhur, Jachedphu, Bajo and Paro. The seeds are processed using Air cum Screen Cleaner, Gravity Separator and Cylinder Separator after the seeds are dried to the required moisture level.

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6.6 Seed Demand and Supply Channels

In Bhutan, farmers select and save part of their harvest as seeds. The exchange of seeds among the farmers in the community is an age old tradition and it is the most common and popular way of getting seeds within the community. Farmers exchange seeds of different varieties of the same crop or seeds of different crops at their established exchange rates. Such informal seed system is the predominant source of seed particularly for major field crop seeds and often more than 90% of the field crop seeds is met through this system. The main advantage of the informal seed system is the availability of locally adapted seeds within the locality and the ease of getting the seeds. In informal seed system, no advance demand placement is required, no cash transaction involved, less risk of getting seeds on time and cheap (non commission or other transaction costs).

*a) Agriculture Sales and Services Representatives **(ASSRs)***

They are the authorized agent for the supply of seeds, planting materials and fertilizers of the National Seed Centre. The ASSRs are nominated from the 'gewog' through the 'Dzongkhag' Agriculture sector depending on their requirement. The NSC reviews the completeness of the formalities, forwards the application to the Department of Agriculture and then appointed by the Department for a period of 1 year. The contract is renewable annually depending on the performance of services and nomination from the Dzongkhags. In order to ensure uniform price across the country the ASSRs are permitted to sale at the rate fixed by NSC as per the rates stamped on the bags. The ASSRs are paid 10% commission by the government for the total sales values. The commission is budgeted under the respective Dzongkhag Agriculture sector and upon submission of documents the ASSRs are paid the commission. There are 82 ASSRs registered with NSC.

Farmers can get seeds and planting materials from the head office at Chundudingkha in Paro and the regional farms. Demand should be placed to the NSC headquarter at Paro or through regional farms 1 year in advance and the payment 3 months in advance to enable the centre in producing and supplying adequate quantity on time. Farmers can place their demand individually or through the gewog or dzongkhag or ASSRs depending on the convenience. Seeds and planting materials are delivered by NSC to the gewog centre, Dzongkhag headquarter or ASSR store based on the demand request.

b) Research and Development Centres (RDCs)

They provide some seeds and planting materials especially the new released varieties for promotion and potential new varieties for demonstration purposes in collaboration with the gewog and dzongkhag agriculture sector. The gewog and dzongkhag agriculture sector also provide seeds and planting materials to the farmers under crop promotional programme. Farmers can have access to seeds and planting materials from the two private seed companies; Bhutan Alpine Seed located in Paro and Reva Private Seed Enterprises in Thimphu. Similarly, there are also private nurseries dealing with planting materials.

To conclude, plant breeding and seed production are an integrated component of Bhutanese traditional farming system. However, production of high-quality seed is fundamental to modern agriculture and has a major impact on potential crop yield. More farmers opt for quality seeds increasing the business opportunities of 'seed production entrepreneurs'. It is also economical for the farmers or farm workers to use quality seed produced by the breeders and suppliers than using degenerated seeds from their own farms. The conceptual knowledge and skills on sample seeds and sapling production are bases for young Bhutanese to take 'seed production entrepreneurs' with the support from RDCs and the NSC.

The government institutions such as RDCs and NSC are established in different regions of Bhutan basically to research, propagate seed varieties that are resilient to climate change, pests and diseases as well as more productive and have better quality nutrition for consumption, and supply to Bhutanese farmers. It is important for the Bhutanese literate farmers and entrepreneurs to avail such facilities and produce their own quality seeds and planting materials supply to other farmers at affordable cost. This can help other farmers to grow food to secure Bhutan's sovereignty of food security through sustained Agriculture. Agriculture business can flourish well in Bhutan providing nutrition to its small population at the cost much lower than the agriculture produce imported from abroad and across the border. Locally produced food shall be safer from chemical as Bhutanese farmers use mostly organic fertilizers such as Farm Yard Manure. There is a high demand for locally produce food especially fresh vegetables in our ever growing urban centres. Such food can be easily produced in the suburbs of urban centres and made available at a lower cost than the imported food. It is an opportunity for the educated and unemployed youth to take Agriculture as their profession and sources of livelihood.

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To conclude on this chapter, *what is your think on the opportunities of Seed Industry in Bhutan? Can it be a profitable venture? Why yes or why not?* Join farming community to serve your nation – a GNH nation.

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Student Activity

1. Discuss with the class to start nursery for supply of seeds and seedling for school agriculture garden and prepare a proposal to be presented to the principal with:
   a. What seeds/seedling/sapling of the crops to produce,
   b. How to go about based on what school gardening requires,
   c. Support required from the school management such as
      i. Land/plot for nursery,
      ii. Materials for constructing nursery shade such as poly-tunnel,
      iii. Procurement of seeds, equipment and tools,
      iv. Commitment to buy seedling/sapling from the nursery,
      v. Some fund on returnable basis.
   d. Seek approval to start nursery.
   e. Discuss with the class and delegate responsibilities,
   f. Start work on nursery referring the text materials whenever needs arise,
      i. preparing of soil for the nursery,
      ii. testing the germination of seeds,
      iii. sowing the seeds and caring for them,
      iv. observe and record work involve, development of seedling/sapling, etc., care required, etc.
      v. harvest seeds, dry them, store and pack them for sale, etc. managing the nursery efficiently.
   g. Fix price and make the seedling/sapling available for the school gardening.
   h. Calculate economic returns and return money to the school management.
2. Divide students into group and assign different techniques of seed germination tests to individual groups. Calculate the % germination and compare the result among groups. Which method was the best?
3. Tryout vegetative propagation with the plants growing in the school campus without destroying them. Grafting same species of flowering with different flower or fruits trees yielding fruits at different time /season – summer and autumn, etc.

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7 Chapter

Mushroom Production and Management

Mushrooms have been part of the Bhutanese cuisine since time immemorial and are one of the highly nutritious and environment friendly crops that carry numerous nutritional and medicinal benefits. There are also many types of wild mushroom collected from the forest which are consumed at home or sold in the market.

Figure 7.1 Collectors selling local mushrooms

Mushrooms are usually collected by people of low income group and children for their pocket money but mushrooms are consumed by all. Mushrooms are expensive as they are popular and therefore a good source of income for the collectors and for mushrooms growers. Mushroom cultivation is gaining popularity in the Bhutanese market as well as abroad. Therefore, this chapter attempts to provide some information about mushroom in Bhutan that are collected from the nature and basic ideas of mushroom cultivation techniques which have been adopted in Bhutan to cultivate mushroom.

Due to the high market demand and price, overharvesting and future sustainability is becoming increasingly a serious concern. Overharvesting of mushrooms in nature can lead to their extinction. However, this can be prevented if we know more about mushroom and their propagation system and above all educate mushroom collectors, growers and consumers on mushroom, what is it? Why mushrooms are sought after or expensive? What can be done to ensure sustainable harvest of mushroom? Here is an extract from Wikipedia, the free encyclopedia. Read carefully and answer questions asked at the end of in this section.

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7.1 Mushroom

Let us read the extract materials from the internet and find out what meaning we can derive from *Lepiota lutea*, the "flowerpot mushroom", from Emile Boudier's *Icones mycologicae* (1901). It starts with a question "What is a fungus?"

A fungus is an organism whose body consists of a mass of root-like threads, each only one cell thick. You can see this in the picture at the right, in the lower left-hand corner. This is what a fungus looks like under the microscope. Let's say that the fungus is growing on wood chips or mulch, as the pictured mushroom often does, indoors, in the United States.

The wood chips, the stuff that the fungus feeds are called the substrate. The fungus grows through the substrate, digesting it as it goes. When the fungus feels that it's grown enough and needs to reproduce, it sends up a mushroom, which functions for the fungus the way a fruit does for a plant. If a mushroom is shaped the way you're used to (like this one), the underside of the cap is covered with radiating blade-like structures called gills. On these gills, the mushroom produces millions of spores. These are essentially single-celled seeds; three of them are shown at the top of the picture, and six at the bottom. These spores are microscopic, so small that they are blown away on the wind. Eventually (hopefully), they land on a suitable substrate, to grow into another fungus.

Fungal fruits come in all sizes and shapes, not just the medium-sized "mushroom" body-type that you know and love. And just as the fruits of plants include things that we don't usually think of as fruits, like the winged fruits of maple and beech trees, fungal fruits include things that look nothing like "normal" mushrooms. In fact, we usually refer to fungal fruits as "fruiting bodies", so as not to get them mixed up with those sweet things that grow on plants. But when a mushroom is up, we often say that the fungus is fruiting, just like one would for a plant.

Figure 7.2 Fomes fomentarius, a tinder polypore, from Emile Boudier's Icones mycologicae (1901)

For instance, conks, those shelf-like or hoof-shaped things that grow from the sides of trees, are also the fruiting bodies of a fungus. These have a number of important differences from mushrooms like the one pictured above.

First of all, conks do not have gills on the underside of the fruiting body; they have a layer of tubes. These can be seen from the side when the conk is cut or broken open, as at the bottom and left-hand side of the picture. But if you just look at the underside of the conk, you will just see the mouths of the tubes, as shown to the upper left of center in the picture. In this view, the tube mouths just look like holes, or pores, and for this reason these fungi are often called "polypores", for "many-pored" fungi. Sometimes the pores are a millimetre or two across, but often they are so small (as with this *Fomes*) that you need to look really closely (or with a hand lens) in order to see the pores; otherwise the underside just looks like a solid surface.

Figure 7.3 Conks

Another thing that's different about polypores is that they usually last a long time. Ordinary mushrooms, like plant fruits, usually decay quickly. Polypores, on the other hand, often remain on the tree for several months, and some of them remain basically indefinitely, adding a new layer of growth each year, the way a tree adds rings. With this *Fomes*, you can see the layers of growth on the cap, and at the bottom where it's been cut away, you can see that there are layers of growth both in the upper shell and in the tube layer. The white layer at the very edge of the fruiting body is the only one that is actively growing this season. Some large polypores have been found that have twenty or thirty layers!

The main body of the fungus – the part that's digesting the substrate, is called a mycelium, and the threads that make it up are called hyphae (HIGH-fee). The fruiting body of the fungus is also made up of hyphae: the "fibers" in the stem of a mushroom are made up of hyphae running in parallel to make the stem strong; the cap of the mushroom is made of hyphae so tightly interwoven that they seem to be one solid mass; and even a hard conk is made up of hyphae that have been specially strengthened with material from the host tree, to make them hard and woody.

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The *Fomes* picture also shows in more detail how these fruiting bodies bear their spores. Inside the tubes, large bubble-shaped cells called basidia form (one by itself is called a basidium). The basidia grow four points on top, like a crown (see the picture to the right). From each of these points (called sterigmata) grows a spore. In the center of the Fomes picture above, you can see a the tough, parallel hyphae that make up the conk, and bubbling out above them are the basidia, two of which have grown sterigmata and spores. At any given time during its fruiting season, there are always a few basidia that are growing spores, some that have already shot their spores off, and at the same time, some that haven't begun the process yet. The layer of bubble-shaped cells where this all occurs is called the hymenium.

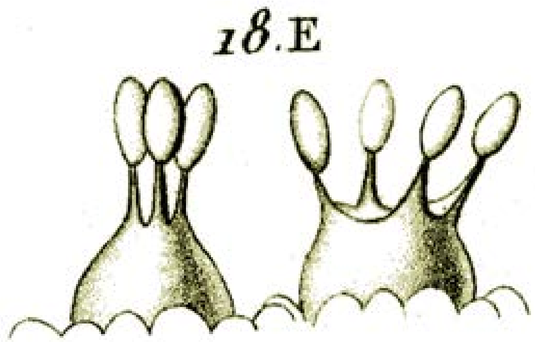

Figure 7.4 Typical basidia -by Joseph Henri Léveillé

Figure 7. 5 Trametes versicolor, the "Turkey Tail." - by John Denk

You should not think that all polypores are hard, or that all polypores with color zones remain for years, piling up layers. The Turkeytail is a very common polypore; you have probably seen it in the woods already, without knowing what it was. It grows out in a single season, and is thin and leathery, rather than hard and woody. Its zones are formed in a single burst of growth (colored differently in each one) rather than the result of yearly layers piling up on one another.

Figure 7. 6 Suillus grevillei, one of the "Slippery Jacks". -by Mrs. T.J. Hussey

There is even a group of fungi that have "normal" mushroom-shaped fruiting bodies, and grow on the ground, but have pores

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underneath the cap, like a polypore. These mushrooms are called boletes. Some of the most prized edible mushrooms in the world, like the famed porcini, are boletes.

In Figure 7.7, you can see the tube mouths (pores) showing in the overturned mushroom on the left. Slicing through the cap of the mushroom (lower right) shows you the lengths of the tubes in profile.

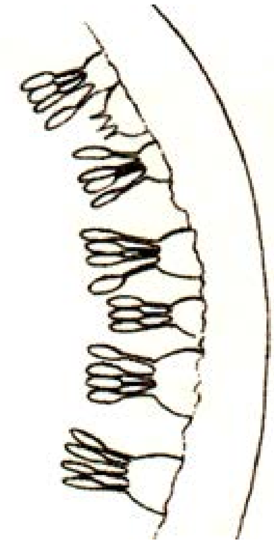

Figure 7.7 Interior of a bolete tube-by Joseph Henri Léveillé,

Looking at a cross-section of a tube under the microscope, we would see (as with a polypore) basidia with their spores (one has already shot them off, and remains with just its "crown" protruding) sticking out into the interior of the tube, as shown in the drawing to the right. This by no means exhausts the forms of fungal fruiting bodies. There is, for example, a whole other phylum of fungi that form their spores inside sacs called ascii, instead of on basidia. These fungi, called Ascomycetes, are actually more numerous than the more familiar Basidiomycetes, and have more species. Morels, truffles, and most lichens are just a few of the Ascomycetes that you may have heard of. Also, basidia have other shapes besides the simple "bubble" one that we have shown here. One of the few sure things in working with fungi is that there is always more to learn.

Are Mushrooms Good for You?

Although they are not really vegetables, mushrooms can be a valuable addition to your diet.

Are Mushrooms a Vegetable?

A mushroom is neither a fruit nor a vegetable; technically mushrooms aren't even plants. They are a special type of fungus – a notion that puts some people off. If you don't mind the fungus part, though, mushrooms are a great addition to a healthy diet – not to mention totally delicious.

There are many different types of edible mushrooms, everything from Japanese shiitake and enoki to Italian porcini to the common white button mushroom and the ever-popular portabella, also known as crimini. The various kinds of

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mushrooms all have different flavors, shapes, and textures – which is fun for culinary types. Although the nutrient profiles vary from type to type, most mushrooms are good sources of vitamins B, selenium, iron, and other minerals.

Mushrooms are also quite good at neutralizing free radicals, those renegade molecules that can otherwise get up to no good. In fact, you might be surprised (as I was) to learn that when it comes to antioxidant power, the plain old white button mushroom beats out even colorful veggies like green peppers, carrots, green beans, and tomatoes! Best of all, mushrooms contain antioxidants that are not deactivated or destroyed by cooking.

Do Mushrooms Fight Cancer?

In addition to being antioxidant powerhouses, mushrooms contain unique compounds that appear to boost your immune defense. For example, there has been a lot of interest in the cancer-fighting potential of various compounds and extracts of mushrooms. Mushroom extracts have been demonstrated to have anti-tumor activity – at least in test tubes. In humans, mushroom extracts have been shown to increase immune system activity. (- *See more at: http://www.quickanddirtytips.com/health-fitness/healthy-eating/ are-mushrooms -good-for-you#sthash.CniF2KK8.dpuf*)

Let us now reflect on our reading and answer question which we started this section '*What is a mushroom?*' and move on to ask more questions to understand mushroom more, such as '*On what type of substrate do mushrooms grow? What impact would the farmer's practice of collecting 'leaf litters' from the forest have on the mushroom growing in the forest? What can you do to support mushroom collectors on sustainable harvest of mushrooms?* The section that follows may answer the last question.

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7.2 Mushroom cultivation

Mushroom cultivation as seen today evolved actually from its natural growth in the wild. The artificial cultivation is an adoption of its ecology in the nature. It is believed that Shiitake mushroom cultivation originated in China during the Sung Dynasty (960-1127 AD). Early mushroom cultivation depended on the spores to transfer mushroom to the new substrate. Shiitake mushroom growers gathered logs bearing mushrooms and placed them near freshly cut logs, relying on airborne spores to infect the new logs. Methods of inoculation – the process of introducing mushroom to new substrate were improved over the years. Cutting the bark of new logs increased colonization by mushroom spores. In the 1920s pure cultures called spawn, consisting of genetically uniform mycelium were developed. In 1943 sterilized wooden wedges colonized with pure cultures were used inserted into slashes in the logs. In the recent past more developed and mechanized methods have been introduced.

In many countries, due to scarcity of wood logs alternative substrates for shiitake mushroom cultivation are being sought. Commercial shiitake mushroom cultivation on sawdust/wood chips and other cellulose containing materials is increasing worldwide. Unlike mushroom cultivation on fresh logs, these materials need to be sterilized which entails mechanization and higher costs which are not convenient for small growers. However, mechanization is possible with the use of this medium in mushroom production. There is a similar story about cultivation of button mushroom (Agaricus bisporus) being developed in France over 400 hundred years ago.

a) Mushroom in Bhutan

Collection of wild edible mushroom during the season has been a common activity and it is gaining popularity across the country, from an altitude range of 300 to over 5000 masl (metre above sea level). From ancient time wild edible mushrooms have been collected and consumed by the Bhutanese. Some of the very popular wild edible mushrooms include *Rozites caperatus (Dungshing shamong), Auricularia spp.*

Figure 7.8 Auricularia spp. (Bjili namcho)

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Some of the popular mushrooms of Bhutan

(a) Matsutake spp. (Sangay shamong)

(b) Chanterelle spp.(Sese shamong)

(c) Ramaria botrytis(Bjichu kangru)

(d) Pleurotus ostreatus(Changma shamong)

(e) Suillus Pictus spp) (loeshamu)

(f) Sparassis Crispad (Meto shamo)

(g) Shiitake mushroom (Sokey shamong)

Figure 7.9 Mushrooms of Bhutan

There are many more mushroom species growing wild in nature and many are poisonous. Quite a few Bhutanese lost their lives consuming poisonous mushroom. It is therefore important to identify edible mushrooms from poisonous ones. There may be mushrooms that are solutions to many diseases and cancerous cells.

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However, Bhutanese scientists need to do further studies on medicinal values of mushroom. This provides young Bhutanese literate to explore opportunities to discover cure for many of the deadly diseases which the scientist of world is trying to find. It is an opportunity not only to be become rich and famous but savior of human race against the diseases also discover by the scientist that plague the living world. Till then it will be necessary to avoid mushrooms that are not edible growing in different parts of Bhutan.

Some of the poisonous Mushrooms found in Bhutan

(a) Amanita virosa

(b) Turbinellus floccosus

(c) Amanita phalloides

(d) Naematoloma fasciculare

(e) Russula emetica

(f) Agaricus-arvensis

(g) Amanita porphyria

(h) Amanita muscaria

(i) Amanita pantherina

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(j) Psilocybe-argentipes

(k) Amanita pseudoporphyria

(l) Panaeolus-papilionaceus

Figure 7.10 Poisonous Mushrooms found in Bhutan

7.3 Mushroom Cultivation in Bhutan

Different types of mushrooms – edible and poisonous grow in nature, where the environment fulfills its specific requirement for mushroom to grow. Mushrooms grow depending on the suitability of the nature of substrate, climatic conditions and season which are difficult to create artificially. Therefore, not many species of mushrooms can be cultivated. Mushroom cultivation has not picked up well in Bhutan till date, mainly due to abundantly available mushrooms in nature as well lack of advocacy of mushroom cultivation. However, mushroom cultivation is gaining popularity.

As of today, two types of mushroom cultivation methods are being promoted depending on the use of the substrate on which the mushroom is grown. Wood logs (Lentinula edodes or oak or shiitake mushroom) and straw (Pleurotus spp or Oyster mushroom) methods are currently used in Bhutan.

a) Mushroom cultivation on wood logs

Shiitake mushroom is the second most cultivated mushroom in the world. In the last seven to eight decades shiitake mushroom cultivation has grown to become a worldwide multibillion dollar industry. For centuries this mushroom has been grown in Asia using traditional methods. By adapting traditional methods and

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developing new ones, growers around the world are successful at different scales, from back yard hobbyist to part-time farmers to large corporate endeavors.

Shiitake mushroom is also called oak mushroom for the reason that it grows best on Quercus species. In Bhutan, the preferred species for its cultivation are Quercus griffithii, (Sisi in Dzongkhag,) which is followed by Q.semicarpifolia (Bjishi), Q.lanata (Ghum in Dzongkha). Q. glauca, (Thomp in Dzongkha) and Castanopsis species (Sokeshing) are also a very good medium for shiitake mushroom production although it may not last as much as the oak species. Normally 7 to 25 years old trees of the above mentioned tree species are preferable for the cultivation but the choice depends on the availability of raw materials. Top, lops and ideal branches are used regardless of age.

i. Materials required for growing mushroom on logs

A mushroom grower would requires wood – medium on which to grow mushroom, mushroom spawn, shed that can maintain moisture and temperature, and the following equipment.

1. Electric drill to drill holes into logs
2. Drill bits
3. Spawn injector
4. Bee wax/ candle wax
5. Brush for waxing
6. Plastic sheet
7. Bipod or tripod stand and
8. Power generators would be required where electric facilities are not available, especially for drilling holes into logs.

ii. Procedures of growing Mushroom

Mushroom could be grown throughout the year but the best season for felling logs for shiitake mushroom cultivation is during autumn and winter. The wood is dormant then and the bark is firm compared to the season when the sap is active in the plant As far as possible, it is encouraged to cut the logs during the winter months. Mushroom growing involves simple procedures but need to be done precisely. They are:

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1. Collect wood in winter when the trees are dormant of about diameter of 6 cm to 20 cm. Larger logs are too heavy to be handled and smaller logs can break or get drilled through creating a problem during spawning. Emphasis is also made to inoculate the logs with mushroom spawn before it dries up too much.

Figure 7.11 Cutting wood

2. Cut wood of length 90 cm to 120 cm long after dipping in water tank.
3. Keep the logs cut in the shade or room to protect logs losing moisture that can reduce the growth rate of mycelium, invite undesirable or harmful fungi and thereby delay the logs from maturing and for fruiting.
4. Drill 7 and 8 holes in rows on each log with the help of electric drill which has a diameter of 12 mm and a length of 20 mm with a drilling machine shown above.

   The holes are therefore 12 mm wide and 20 mm deep spaced at an interval of a matchstick length between the rows. The holes are alternate as shown in the diagram below (Figure 7.5).

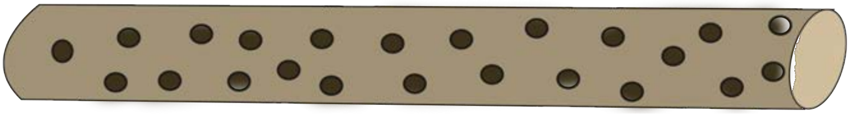

Figure 7.12 Alternate hole on log

5. Spawn the log immediately after drilling holes. It is also to avoid holes being exposed to disease and other competitive fungi besides drying up. Mushroom spawn is inoculated with the help of a hand injector or automatic injector, which are designed to press adequate spawn to fill the holes. Care should be taken not to overfill or lack spawn filling as shown in Figure 7.12.

Figure 7.12 Spawn filling

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Use of right type of injector for the specific holes has to be practiced for proper spawn inoculation. It will provide proper contact of spawn with the surface of wood in the holes and enhance penetration of mycelium into the logs. On the contrary, loose contacts do not allow mycelium growth besides causing damage to the spawn while waxing.

6. After inoculating spawn in the holes, it is required to be sealed to prevent the spawn from drying up and to protect it from disease and other competitive fungi. Wax and resin are placed in a container at a ratio of 4:1 and then heated to 100 to 120^{0}C. It is then poured over the exposed spawn with a brush or a cotton plug thereby sealing the holes. After completion of waxing, the logs are termed as billet(s).

Figure 7.13 Sealing holes with wax

iii. Incubate the Billets

Autumn through winter is the coldest time of the year and it is during this season that billeting works are done. The billets have to be stacked to provide ideal temperature and moisture as in the picture on the right. The optimum temperature required ranges between 18 and 25^{0}C and 60-65% moisture is essential for mycelium inside the billets. The main purpose of this process is to provide a favorable condition for mycelium to spread properly at a time when other disease and fungi are inactive.

In order to provide such conditions, the following points need to be considered.

- Clean and disinfect the site chosen for incubating the billets with stones soling to prevent the billets getting soiled by mud sole.
- Stack the billets in upright position and place pine leaves or similar materials on top of the logs to provide moisture and to prevent the plastic sheet from directly touching the billets.
- Keeping the billets upright helps to maintain the

Figure 7.14 Stacking billets

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bark relatively dry and prevent infection. Place pine needle or other absorbent materials on the top of the billets to maintain moisture.

- Wrap the billets well with plastic sheet and cover the stack with insulating materials.
- While covering the billets and plastic, provide air passages by not covering the logs too tight.
- Water periodically to provide moisture and it is enough to just keep the pine leaves moist. It is not good to add excess water as it will lower the temperature and invite infection from competitive fungi. Turn the billets upside after every month till they have become light, soft to touch and the end of the logs have turned from white to brown.

Figure 7.15 Wrapped billets

iv. Dipping billets

Under the good conditions (temperature and humidity) mentioned so far, the billets should take about 6 months for it to mature. The maturity could be observed by the softness of billet condition and by looking at the colour of mycelium. When the logs are ready the shiitake mushroom mycelium at the end of the billets will turn brown. The billet is then ready for dipping in water tank for a period of 12 to 24 hours depending upon dryness of billets. Normally, during the winter months the billets are dipped in water for a period of 24 hours and about 12 hours in summer time.

Figure 7.16 Billets under tight cnditions

After completion of dipping, water is drained out from the tank and the billets are wrapped with plastic sheet. Within 3 to 6 days depending on temperature, mushroom (pin heads) will start to sprout from billets, which are then stacked for cropping. Covering the soaked billets with plastic sheet over long duration and not providing aeration can invite infection from competitive fungi which grow well under conditions with high humidity and low aeration. Sprinkling water is a better method if sprinklers could be arranged.

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v. Harvesting mushroom

After stacking the billet for cropping, mushroom will mature within 4 to 8 days. The billets are then restacked in a criss-cross position as shown in the picture on the right and given a rest period of one to two months. It is again soaked in water tank and sprouting induced. Likewise, the cropping pattern is repeated till the billets get exhausted.

Figure 7.17 Mushroom ready for harvest

b) Construction of mushroom shed and cultivation of mushrooms

There is no thumb rule about the construction of a mushroom house but it should provide certain requirements. Mushroom propagates in the substrate at about 60-65% moisture but fruits at over 90% humidity. The temperature requirement is between18-20^{0}C. The shed should provide the required temperature and humidity. It is also very important that it should be cost effective. One of the major constraints in mushroom cultivation is the cost of infrastructure. The initial investment is very high compared to other agricultural products due to the requirement of climatic or environment control to suit the mushroom.

Figure 7.18 Mushroom shed

Where climate is mild there is no requirement of elaborate structures but in Northern Bhutan the climates are cold during winter and in the south it is too hot during the summer months. Recommendations of construction of shed are made based on the climate as well as keeping the cost low using locally available materials – soil/mud and stones.

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c) Mushroom cultivation on straw

Paddy and wheat straw, grass and other agriculture residues can be used in mushroom cultivation. Mushrooms like oyster mushroom (Pleurotus spp.) and paddy straw mushroom (Volvariella volvacea) can be cultivated on straw. Additives such as rice bran etc. is added on straw or grass to provide additional nutrients.

Figure 7.19 Mushroom on straw

i. Cultivation procedures

1. Chop the straw or grass into small pieces of 5-6 cm long.
2. Soak the chopped straw/grass in water for certain duration, depending on the type of straw. In case of paddy straw, a few hours of soaking is enough but wheat straw and grass need to be soaked for longer duration.
3. Heap the soaked straw to drain out excess water. Water content in the substrate should be around 65%.
4. Add rice bran to the straw in the ratio of 1:10 (1 kg of rice bran in 10 kg of straw) and mix thoroughly.
5. Transfer the mixture of straw and rice bran into gunny bags.
6. Add a small amount of water in a drum, place wooden frame at the bottom and place the gunny bags with mixture on it.
7. Steam the bags of straw with additives to sterilize. Sterilization removes disease causing microorganisms and other competitive microorganisms. Sterilization can be done in boiling water but boiling may dissolve nutrients and additives and wash away.
8. Sterilization of straw begins once water starts boiling. Cover the open end of the drum with a plastic sheet and boiling for 30 minutes to an hour. There can be other types of sterilization which can be applied depending on the situation and the technical capacity of the mushroom grower.
9. Take out the bags of straw and allow cooling to a temperature of about 25^{0}C.
10. Add Mushroom seed to the cooled, sterilized material either by 'thorough

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spawning or layer spawning'. In thorough spawning, spawn and straw are mixed thoroughly. The thorough spawning is practiced where the cultivation size is big and it is normally mechanized. In layer spawning, a layer of straw is added to the container, pressed down over which a small quantity of spawn is added. Number of layers depends upon the size of the plastic bags. The quantity of spawn added is about 3% of the soaked substrate used.

11. Place the spawn substrate in the shade maintaining appropriate moisture and temperature as discussed under Plastic bag and Block size methods.

1. Plastic bag methods

The National Mushroom Center of Bhutan has promoted two methods of cultivating mushroom – the 'Plastic bag and Block size' methods.

In Plastic bag method the sterilized straw is layered with the spawn broadcasted evenly on the top of each layer until the bag is filled. The mouth of the plastic bag is tied after placing a ball of cotton in it to allow aeration. The plastic bag is kept in room away from direct sunlight for incubation. The ideal temperature during this time is between 20^0C and 25^0C. In a week or two, white cotton like fluffy mass will grow through the substrate. This indicates good mycelium run. After three week or so the whole substrate should turn white indicating the completion of the spawn run or incubation.

The temperature has to be brought down by watering and by providing air circulation to initiate pinhead formation. The plastic sheet or bag is either removed or holes made to enable the mushroom (fruit body) to grow. Watering is done depending upon the humidity of the straw and the environment. Care should be taken to prevent the water from collecting at the base, as this will eventually instigate infection. Once the mushrooms become fully developed they should be harvested without damaging the substratum.

Figure 7.20 Mushroom in plastic bags

After the first harvest, the substratum should be kept in a dry and cool place for resting for about a week after which

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it can be made to sprout again by spraying water. This growing pattern is called flush. There can be three or four flushes after which substratum can be thrown away or used for production of manure. The size of the substratum will go on reducing after every flush as it gets consumed by the mushroom mycelium. Figure on the right shows *Auricularia spp*. (Bjili namcho) grown on straw-blocks.

2. Block size' methods

In Block size method, a plastic sheet is placed on the floor to make straw bed. Boxes with open ends are placed over the plastic sheets. The straw are layered 3-4 cm high with spawn broadcasted evenly on top of each layer and this process is followed till the top of the box is full. The straw has to be pressed down properly either with hand or by stamping in every layer. Once the last layer has been spawned, the bed is ready. The box is then removed without disturbing the layer and can be used to prepare other blocks. The bed or block thus prepared should be covered with plastic sheet and kept in incubation or spawn run. In apple box size blocks four layering with spawn is recommended. The rest of the procedure is same as in the case of plastic bags.

ii. Post-harvest technology

Mushroom has very short life and can deteriorate fast once they mature. Mushroom needs proper storage to maintain quality. Normal procedure to keep mushroom fresh is to store it at low temperature (4-5^{0}C). The container also needs to be rigid and has to be aerated well. Grading of mushroom is done by separating young mushroom from the mature or over matured ones. Over matured mushroom are considered as low/poor quality.

Traditional practice of drying mushroom is either in the sun or over the hearth when it is raining or when the atmospheric condition is too wet. Drying over the hearth using fuel wood cause the mushroom to be sooty and bitter. Many dryers were designed by National Mushroom Centre in the nineties which many farmers in Zhemgang and Trongsa adopted. These were fuel wood based stove with a chimney to let out the smoke separately. The National Post Harvest Centre of Department of Agriculture also developed similar dryers using electric heaters with blowers. There heaters with blowers are more efficient, user friendly and are popular amongst many mushroom collectors and producers.

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7.4 Disease Management of mushroom cultivation

About 150 species of fungi can affect the log and mycelium. These fungi can be divided into three categories namely disease fungi, competitor fungi and weed fungi. Insect pests, animal pests, bacteria and viruses can cause problems for mushroom cultivation.

A holistic approach looks at the overall system and tries to solve the problem at the source and not just focus on the symptoms. Air normally contains spores of wood-fungi, among which Trichoderma is most prevalent.

Preventive measures are:

1. Provide conditions that encourage strong growth of shiitake at each stage of its life.
2. Recognize and eliminate conditions, which lead to the establishment of disease and pests.
3. Trichoderma outbreak is often attributed to over wet conditions, especially during the wet conditions as well as over dry conditions.

a) *Disease Fungi*

They are capable of attacking and killing shiitake mycelium. They secrete anti-fungal compounds, which inhibit the growth of shiitake mycelium and can parasitize and kill shiitake hyphae. All the serious diseases are Ascomycetes. If the fungi infect the log before the spawn has established they can kill the spawn before it can grow into the log. This results in the total loss of the log.

i. Example: Trichoderma

- They are member of Ascomycetes, genus Hypocrea and their asexual stages. Trichoderma and Gliocladium are most serious and widely distributed disease fungi.
- They occur naturally under forest soil; some species prefer logs in warm, dry locations, other do well under moist in both warm and cool conditions.

Figure 7.21 Trichoderma

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1. Symptoms


Figure 7.22 Green molds

- Trichoderma and Gliocladium are referred to as "Green Molds" and start as white patches of or pads of fluffy mycelium.
- They initially appear in cracks in the bark, on the spawn, on wounds, on the ends of the logs and cut surfaces.
- As they age and colored conidia produced, the colonies appear green to rich forest green.
- Hypocrea may appear as fleshy cushions of fungal tissues called stroma, which range from cream yellow to reddish brown.
- Wood colonized by Trichoderma appears darkened and discolored and in advanced cases, the entire barks fall off.
- Trichoderma can cause the spawn to turn black, and the shiitake mycelium may disappear giving the spawn hole a dead look.

2. Conditions favouring Trichoderma colonization


Figure 7.23 LMC

- Invasion by the disease prior to colonization by shiitake.
- RH above 90% when shiitake is weakened by environmental stress.
- Prolonged high or low LMC(Log Moisture Content)
- Direct sunlight on the bark.
- Low sugar content.

3. Prevention

- Maintain bark dry while maintaining high LMC.
- Provide good air circulation among logs.
- High nitrogen content favors Trichoderma.

ii. *Example:* Hypoxylon


Figure 7.24 Hypoxylon

- Theyare widespread group of Ascomycetes causing serious problem in shiitake. They invade logs during early spring month.

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1. Symptoms

- Fruiting bodies start as tiny dark spots usually in cracks.
- These spots gradually develop into hard brick red to black mold.
- In the later stage, barks fall off.

2. Prevention

- Hypoxylon levels can be decreased by shading logs from direct sunlight. Severely infected logs should be removed to lower spore concentration.

b) Competitor Fungi


Figure 7.25 Competitor fungi

Competitor Fungi do not attack shiitake but they do diminish the crop by occupying space and living on nutrients of the logs. Most of them are member of Aphyllophorales. Example is Coriolus (polyporus) versicolor.

Symptoms are formation of leathery fruiting bodies often colonizing the end of shiitake log. Fruiting bodies do not appear until the end of spawn run.

Porodisculus pendulus: High temperature, low humidity

c) Weed Fungi


Figure 7.26 Weed fungi

It include both Basidiomycetes and Ascomycetes. Although these fungi may slightly decay the wood, the damage is minimal. These fungi are often specific to trees and the area. Examples of weed fungi are Bulgaria inquinans – common canker forming fungus on living oak. They are active at medium temperature and high humidity.

d) Post-Harvest Fungi (PHF)


Figure 7.27 PHF

They attack mushroom either on logs or during storage and usually over mature and excessively wet mushroom are affected. Examples of PHF are Gliocladium deliquescens which forms green colonies with slimy conidia. Affected mushroom

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failed to open fully, turn brown and becomes soft and shriveled. Other problems include bacteria, viruses and insect pests. Bacteria are seldom problem in shiitake cultivation. However, browning disease of mushroom caused by Pseudomonas fluorescence may be severe under warm conditions. High RH, warm temperature and poor ventilation favor bacteria. Viruses are known to cause disease such as "Die- Back", and are found in common button mushroom.

e) Insects and other pests

1. *Termites* eat and consume shiitake logs. They can be controlled by chemical treatment or by keeping logs off the ground.
2. *Bark Beetle larvae* feed on the cambium layer and leaves small holes in the bark and tunnels. Larvae are apparent under the bark. Heavy infestation can make the bark fall off.
3. *Ambrosia beetles* leave small holes in the bark often with small pile of sawdust beneath it. Attracted to freshly cut logs and may appear in the early part of spawn run.
4. *Fungus beetles Erotylidea* and *endomychidae* larvae and adults feed on the mushroom directly.

Mushrooms are highly nutritious, often considered to have medicinal properties with high demand in the local as well as outside the country. They are either collected from the forest or cultivated artificially. Although the cultivation of mushroom is quite simple, proper procedure has to be followed in order to produce mushroom that has good acceptance by the consumers and to have economic gain. Mushroom cultivation was introduced in Bhutan in the mid-eighties. Since then it has been adopted in many parts of the country. Although mushroom production in the country has been increasing over the years, the production has not been able to keep pace with the demand. As such the majority of the mushroom sold in the local market is currently imported from neighboring countries. Fresh oyster mushroom is imported from India and dry shiitake enters the country from Thailand. Button mushroom normally comes in the canned form.

For artificial production of mushroom many substrata can be used according to the nature of the mushroom being selected. Some grow on wood, some on saw dust and some on straw or grass. Yet some others are grown on fermented straw called compost, like in the case of *Agaricus bisporus*, commonly called button mushroom.

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Many edible wild mushrooms are found in the forest of Bhutan. Also, there are also a few which are considered toxic or even deadly poisonous. The National Mushroom Centre under the Ministry of Agriculture and Forests conducts awareness on mushroom poisoning periodically.

To conclude this chapter, we need to analyse what Bhutanese shopkeeper have in their grocery shops. We can easily find dry mushrooms and canned mushrooms available for sale. It is important to find out from where these goods come and study the cost of the commodities. They are expensive as these goods have to travel from their places of produce to our market and the shopkeepers charge the transportation charges of these goods, house rent and their livelihood expenses on us. *Why paid more when we can easily produce ourselves? What do you think is attributing to the shortage of mushrooms in our market? Do you think Mushroom Cultivation is a lucrative business idea? What can you do to substitute import of huge quantities of mushroom?* Growing our own can save money for ourselves as well as for the nation.

Student Activity

1. Discuss with the class to start a mushroom cultivation in the school campus and a plan to get endorsement from the principal and the school management with:
   a. Objectives of growing mushroom in the school campus by AgFS students,
   b. Plans of how to go about growing mushroom in the campus:
      i. Construction of a mushroom shed with locally available materials,
      ii. Construction to be done by the class on the weekends and clubs periods,
      iii. Straw of Rice /wheat/grass and oak branches to be used a substrate,
      iv. Seek support from the RNR centres, Gewog, Dzongkhags and National Mushroom Centre for seeds and other technical and professional ideas besides the textbook.
      v. Manage growing of mushroom and marketing with the guidance from the Principal and the management of school.
   c. Support required from the Principal and the management team:
      i. Resources – a small plot but convenient for the class to work,

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   ii. A small fund on returnable basis (from the sale of mushroom),
   iii. Official correspondence with officials of the gewog, dzongkhag and NMC,
   iv. Procurement of mushroom seeds and plastic sheets and bags, wax and resin (if oak trees are available),
   v. Hire of experts making local bricks with mud,

d. Identify a land area for construction of mushroom shed,
e. Seek and hire a local expert to help build mushroom shed,
f. Procure materials for the construction, lighting and equipment for regulating temperature and moisture, mushroom seeds, substrate and plastic sheets and bags.
g. Rags or benches, knife for cutting straw, and pots for boiling straw,
h. Start construction on an auspicious day, disinfect the rooms and furniture and start growing of mushroom following the procedures in the text,
i. Monitor and manage mushroom cultivation, analytically, maintaining records of development and care required and provided,
j. Limit visitors into the mushroom shade, ensure visitors wear visitor's shoes and do not touch anything in the room.
k. Involve principal and the students in pricing the mushroom and marketing the mushroom.
l. Assess the experiences gained by the students and the economic returns of the mushroom cultivation.

2. Plan for a field to a mushroom cultivation centre to study the mushroom cultivation and marketing system, through questionnaires, observations and sharing of experts' ideas and experiences of mushroom cultivation in the country, write reports, assess students' knowledge, procedural skills and values and attitudes of growing mushroom.

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8
Chapter

Farm Mechanization in Bhutan

Bhutan is a small country landlocked between China and India with land area of 38,394 sq km of which 72.5% is forest cover (NSB 2006). The agriculture sector is the dominant sector with 58% of the population engaged in farming, contributing about 16% of gross domestic product (GDP). Aside from agriculture products, timber, electricity, handicraft and tourism are the main contributors of Bhutan's per capita income amounting to US$ 870 (World Bank 2006).

Of the total land area, 2.93% is used for agriculture purpose. The average land holding of 90% of the farming community is less than 5 acre (1acre = 0.4ha). Although Bhutan has a favorable climate for wide range of crop cultivation, it has been limited due to geographic terrain and scarce labour. Among the various crops cultivated, rice cultivation is predominant and is second to maize cultivation in the whole country. Potato is one of the main cash crops grown in the higher altitude. Various fruit crops like mandarin (commonly called oranges), pear, plum, apricot, guava and apples are also grown.

For a small population, Bhutanese should be able to grow enough food for themselves as in the olden days. However, Bhutan has a growing population in the civil service, business community, monastic body and a large number of youth in schools and other educational and vocational training institutions and above all a very large number of expatriates working in the socio-economic development projects and programmes. This requires import of food commodities well above what Bhutanese farmers are able to produce, threatening the food sovereignty of Bhutan.

This chapter attempts to educate students on the needs and scope of 'farm mechanization'. It provides information on what the Ministry of Agriculture and Forests through Agriculture Machinery Center (AMC), Paro and its Regional AMC (RAMC) do to support famers in their farm works. Attempts have been made to explain the concept of mechanization in different farming activities. It

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includes modification to improvisation of tools and farming machinery suitable for Bhutanese farmlands, facilitating purchase of machinery for farmers, training and hiring services of machinery to farmers during peak seasons. The chapter ends with information on the support mechanism extended by the AMC and its RAMC for needy farmers in promoting Agriculture.

8.1 Farm Mechanization

To understand farm mechanization better, it is important to start with basic concepts of 'what is farming?', 'what does farm mechanization mean?' and 'why is there a need for farm mechanization?' Let us start answering the questions that have been posed to us.

Farming is the act of using land to grow crops and/or rear animals for human consumption. It is the business of cultivating land.

Mechanization refers to use of machinery (technology) in farming activity. A mechanized farming is where farm machines replace human labour or assist humans in different farming activities by machines or technology. It is important to understand farming activities before the need to mechanized farm is being discussed.

The 'need for farm mechanism' cannot be understood unless the definition of farming is understood. From the above definition, farming here will refer to the business of cultivating land – growing of crops for human consumption. It involves a series of activities which may be in a very high altitude with cold climatic and mountainous and rugged terrain or in hot and wet topical low land. Similar activities, such as land preparation, sowing/planting, weeding, harvesting and post harvesting activity such as milling and threshing are done before converting into consumable food items. All these activities require manpower. This can be better discussed under farm operation.

a) Farm Operation

For example, rice cultivation in Bhutan is carried out as high as 2800 metre above sea level – masl (in Bumthang). It is associated with drudgery and is labour intensive. At large, farming is still carried out by use of animal and human power. The average labour days of 189-237 per ha is much higher compared to countries like Philippines which uses 70-100 person days per ha for rice cultivation. Many households respond to labour shortage by scaling down their activities, reducing the area under cultivation (by up to 50%) and growing a limited range of crops. They struggle to keep pace with the seasonal calendar which results in taking short cuts and has become the normal ways of doing farming in Bhutan. Studies have shown that transplanting take the maximum labour share (18%) followed by harvesting, threshing and land preparation (Kencho et al. RC Bajo, 2003). The pie graph (Figure 8.1) shows the distribution of work rice cultivation.

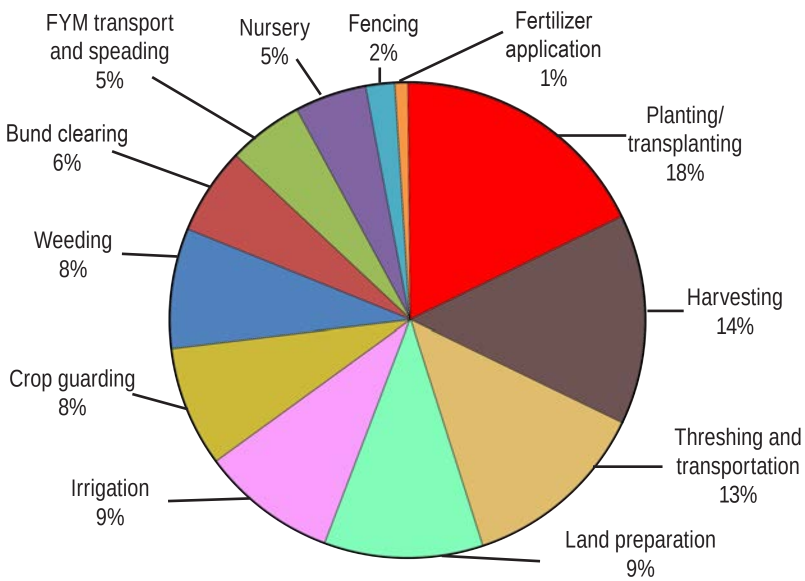

Figure 8.1 Work distribution % of rice cultivation

On top of shortage of labour, farming community is affected by the continuous rural to urban migration. The migration, however, is not due to better employment opportunities in terms of the income and satisfactory jobs available elsewhere, but rather to a large extent due to the attraction towards modern amenities. Due to this factor, only small amount of human labour is left for farming in the rural areas, thereby, creating huge potential for mechanization. This situation is likely to change in the near future as there is growing unemployment of youth, especially the literate ones. It is hoped that literate youth with scientific knowledge of agriculture and the dire needs of employment will return to their farms to take up Agriculture. Farm mechanization is a motivation for the Bhutanese farmers and mechanization is for all farming activities listed below.

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b) Mechanization in Land preparation

Traditionally, land preparation is done by digging the surface with the help of a spade or a hoe or by ploughing using draft animals (Figure 8.2). With the use of improved plough there is almost 2.5 man-days saved from the use of traditional plough. Undermining the major repair and maintenance cost, there is almost 4 times bigger area coverage by using power tiller in ploughing than by animal power (AMC's Annual Report, 2006). Much of the drudgery is alleviated and labour productivity improved but due to small terraces and steep slope (>18%) use of such machinery is restricted only to few flat lands.

Figure 8.2 Modified Bull plough

Figure 8.3 Two-wheel tractor

c) Mechanization of Seeding and Transplanting

Rice transplanting is done mostly by women as shown in Figure 8.4. It is a hard job involving hours of bending to reach the ground as they plant the seedlings and sow in the seeds. Nursery are raised either traditionally (dry bed method) or by modern method with poly tunnels, green house etc.

Figure 8.4 Manual Transplantin

Figure 8.5 Machine planting

With traditional method 18% of the total labour requirement is used for rice transplanting. With new methods of transplanting, machines and line planting, the transplanting job is much easier and more efficient and more labour saving (Figure 8.5) than traditional methods.

d) Mechanization of Weeding

Weeding is a critical activity and a physically demanding job with a major determinant factor of final grain yields. Weeding is done manually by women using hand hoe or uprooting manually as shown in Figure 8.6. Weedicides are used only in very limited scale. Also in few paddy fields, weeding is done using manual type rotary weeder making work easier and more efficient.

Figure 8.6 Manual weeding

Figure 8.7 Rotor weeder

e) Mechanization in Harvesting

Manual harvesting is common in many crops. For cereals crops, sickle is commonly used. In paddy and wheat, serrated sickle is more efficient and has become popular

Figure 8.8 Harvesting with Sickle

Figure 8.9 Machine harvesting (Reaper)

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among the Bhutanese farmers (Figure 8.8). A study has shown that 14% additional labour is required in paddy harvesting by local methods.

Few farmers have started using walking type reapers (Figure 8.9) and have shown to save about 20 labour days in a hector of paddy. This technology is gaining popularity in Bhutan but due to lack of source of such machine, the popularity and advantages are yet to be fully experienced by many farmers.

f) Mechanization of Threshing

After harvest, paddy along the straw are kept in the field for two to three days and then threshed. Some farmers carry the un-threshed paddy and stack for months prior to threshing. Threshing is done manually by treading with feet, beating with long sticks and beating on flat stones and logs. Substantial amount of grain is lost or damaged in this process. With the introduction of pedal thresher, as high as 60% of the total labour required for threshing is saved (Rice cultivation in Bhutan, 2003).

Figure 8.10 Manual threshing

Figure 8.11 Pedal threshing

Power threshers are not very common as they are expensive and also not available. Moreover, with small land holding, owning the power threshers individually is not economically feasible. Group users or custom hiring are encouraged for such machines. Combine harvester are popular amongst farmers with large terraces (Figure 8.12).

Figure 8.12 Harvest machine

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g) Mechanization of Post-harvest operation

Often, farmers store their harvest right after threshing. Most common method of paddy storage is use of bamboo baskets, wooden boxes, gunny bags, oil drums, plastic containers and mud structure (see Fig. 10.13). Losses as high as 30-40% have been noted with this method but the farmers have no other alternatives.

Figure 8.13 Traditional store

Efforts are made for proper storage and drying techniques like air-forced dryer and metal silos (Figure 8.14), while other processing machines are introduced and adoptability is being studied.

Figure 8.14 Modern store

Small scale rice mills (Figure 8.15) imported from India are mostly used in place of traditional pounding methods. Stored paddy is either sun dried or directly milled. Although 50-60% broken rice (local red) is seen with the use of this type, farmers still prefer this type as the initial investment is low. As many as 3000 units are presently used throughout the country.

Farm mechanization discussed above are some of the examples of evolving Bhutanese farms looked after by farmers with little or no education. In the similar manner mechanization has been introduced in livestock and horticulture. However, changing mindset of Bhutanese farmers takes time. With educated youth taking up Agriculture in near future and with the support of AMC and RAMC of MoAF, Bhutan to secure its food sovereignty is attainable. This takes us to another avenue of study i.e. to learn the kind of support that the future Bhutanese farmers can avail from the AMC and its RAMC pertaining to the farm mechanization. Let's start questioning 'what AMC and RAMC stand for', 'purposes of their existence?' and 'what kinds of support can Bhutanese farmers avail from them?'

Figure 8.15 Rice mill

8.2 Agriculture Machinery Center (AMC)

AMC was established in 1983 in Bondey, Paro by the Ministry of Agriculture, with the vision to realize national food self-sufficiency. This vision places the Bhutanese farmers at the core of all agriculture development activities. AMC aligns itself strategically to contribute towards the achievement of the vision through enhanced effectiveness and efficiency in Bhutanese farming practices. It embarks on the program to mechanize Bhutanese agriculture through use of appropriate farm machinery, equipment and tools.

Over the years, AMC has partnered itself with the Bhutanese farmers to choose, create and innovate agricultural technologies and farming practices which are appropriate to the Bhutanese farm terrain and ecological conditions. It has not only contributed significantly in the national goal of food self-sufficiency but has also been an instrumental agent in alleviating drudgery in Bhutanese agriculture. In a nutshell, AMC exists to fulfill its vision through its objectives of:

- Modification and innovation of indigenous farming tools suitable to Bhutanese farms.
- Promotion of improved agriculture mechanization technology in the country.
- Effective and efficient distribution of agriculture equipment to the farmers.
- Capacity development of the farmers in the use of improved mechanization technology and farming practices.
- Act as the regulatory body of quality and safety of farm machineries.
- Under the guidance of the Department of Agriculture (DoA) of MoAF, AMC carries out research and development of equipment and tools, develop/ purchase machinery and supply, train the Regional Agriculture Machinery Centers (RAMC) staff on the use and maintenance of tools and equipment (who in turn train needy farmers) and control quality of machinery /tools supplied to the farmers by the AMC/RAMC and private companies.

AMC has a network of RAMC in Bondey (Paro), Bajo (Wangdue), Khangma (Tashigang) and Bhur (Sarpang). The RAMCs function under the guidance of AMC to support farmers in the procurement of quality equipment/tools and farm machinery, availing training in the use and maintenance of equipment/ tools and machinery, and above all to coordinate and avail hiring of machinery for agriculture activities during the peak seasons.

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a) *Supporting Bhutanese farmers*

At present a coherent and a holistic policy approach from all sectors are inbuilt for creation of convenient and wholesome agricultural development. Strong support from the government is there for promotion of farm mechanization.

The Ministry of Agriculture, through its "triple gem" concept seeks to improve agriculture by enhancing productivity, improving accessibility and strengthening marketing. This concept is geared in support of the objective of poverty reduction. Various service institutions with strong linkages have been set up like Research Centers, extensions etc. in support of the farm mechanization program.

b) *Interventions in Agriculture mechanization*

Mechanization in Bhutanese farming is aimed at ending drudgery, saving costs and improving yield through the use of suitable farm machinery, tools and implements and sustainable farming practices. The largest support in farm mechanization is through the second KR (Kennedy Round – KRII) Grant. Machinery received through the KRII grant is sold at subsidized rates to farmers. Of the total machinery sold from AMC so far, 96% comprises machinery received through Japanese KRII grant.

The opportunity for income generation from owning machines such as a power tiller, rice mill, flour mill, oil mill, etc. are substantial besides reducing labour constraint and drudgery associated with farm works. Few of the machinery which have gained popularity in the country and are highly demanded at present as shown in Table 8.1.

Table 8.1 Farm machinery, tools and implements supplied till from1984-2013

Sl. No	Description	Total (nos)
1	Tractor	215
2	Power tiller	2613
3	Power thresher	189
4	Power Reaper	118
5	Paddy transplanter	102
6	Water pump	231
8	Oil mill set	2097

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9	Rice mill	2037
10	Flour mill	1205
11	Corn flake machine	387
12	Pedal Thresher	1286
13	Tools & Implements	363143

Source: AMC, Data Manager,2013

Based on the available land and the numbers supplied for the last ten years for the two wheel tractors, there is still huge requirement of the two wheel tractors as per AMC's estimates. However, it has to be noted that it does not necessarily mean that the two wheel tractors can be used in all available land.

c) Manufacturing and workshop facility

The viable solution for long-term sustainability of farming is to increase the labour productivity, alleviate drudgery and improve the outlook with improved technologies. It would be either by developing within the country or procuring from outside and introducing in the country. However, setting up large scale industries in Bhutan is limited by resources and markets. Small fabrication, like metal silo, plough parts, pedal threshers, manual winnower, plough and hand tools etc. are carried out at present. Besides, the private firms are mostly involved in importing the farm machines and supplying to the farmers. Repair workshops are very limited and the repair works are done at government owned facilities.

d) Machinery Hiring Services

A revised Guideline for hiring of farm machinery was approved by the MoAF in 2014. The objectives are to mitigate farm labour shortage and agricultural feminization (out migration of male farm labourers leaving behind females to manage farming); optimize land utilization, land intensification and promote agricultural commercialization; generate rural employment and enhance income of farming community; cover larger agricultural areas under mechanized farming; and improve accessibility of farm machines to poor and marginal farmers. AMC will provide hiring services until such time that the private sector is capacitated and enabled to take up the services with capacity development by AMC.

Farm machineries available for hiring are classified as follows:

- *Land preparation:* Power tillers and tractors, with accessories such as

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reversible and rotary ploughs for power tillers; disc, harrow planters and rotary attachments for tractors.

- *Transplanting:* Transplanters of different capacity or size
- *Harvesting:* Reapers, mini combine harvesters, potato harvesters
- *Threshing:* Pedal threshers, power threshers
- *Transportation:* Power tillers and tractors with trailer
- *Water pumping:* Portable water pumps

The modality of machine hiring has been improved. Hiring services are made available from AMC's Farm Machinery Service Centres (FMSC), Regional AMC or RDCs. The District Agriculture Officers are provided information on the hiring services. The RNR Extension staff of Geogs put up requisition for hiring services in consultation with Gups. Preference is given to registered farmer groups over individuals, and accessibility and irrigation facilities are considered. At the field level, hiring services is managed by a committee consisting of the Extension staff, Geog Tshogpa and AMC representative. Machine operators and fuel are provided by AMC. The hiring service is available for a minimum of 1-day work and hiring rates are determined from time to time based on machine costs, depreciation and operational costs. Current applicable rates (per day), for instance, are as follows: Power tiller: Nu 1400, 50 hp tractor: Nu 3100, 34 hp tractor: Nu 2400, 18 hp tractor: Nu 1900, transplanter: Nu 1100, reaper: Nu 1600, water pump: 2000 and thresher: Nu 400. These hiring rates are much below existing market rates and farmers are encouraged to avail the services to the fullest extent.

With the farm mechanization gaining ground amongst Bhutanese farmers, farming in Bhutan will not be drudgery. Agriculture in Bhutan will become sustainable economy in the services of the GNH nation. The organic agriculture produce will capture not only the Bhutanese market but the farm produce well sought after in the global market. This will not be a distant dream of Bhutanese farmers but a reality, if literate Bhutanese youth take up agriculture rather than seeking jobs in other countries. We need to save our arable land from expanding urbanization, continue inventing suitable farm technology that can till the slopes, grow food, medicines, fibre, etc. and preserve agriculture produce adding food value for our customers, all the year round and at reasonable rate. *Can we do it? Is it possible for the Bhutanese youth? What can we do it? How do we do that? Who will do and when do we start?* May be, think about buying a power tiller for your family, instead of buying a car for your own comforts.

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Student Activity

1. Discuss in the class to carry out and an awareness or advocacy survey on the use of farming technology in the community around your school on the farming tools and technology they use and available in the market.
   a. Identify areas of studies such as tools currently use, awareness of better tools and technology, willingness to explore for better tools and adopt better tools, requesting to help them supply better tools and technology, forming cooperatives to invest buying machinery for the community, awareness of farming mechanism available with the support from MoAF and its agencies in the gewogs and dzongkhags.
   b. Carryout survey, collect data, compile, analyse and display for students and teachers and also submit to the government through Gewogs and dzongkhags for supporting the farmer, if the report is worth sending.
2. Plan a field trip to nearby RDC or AMC to study the work on mechanizing the Bhutanese farming system, importance, how students can support the AMC and the farmers do better farming.
3. Discuss with class to explore scientific ideas of developing farming tools for digging, lifting, cutting, watering the garden, weeding, etc. from the internet that can be used on the land scape of Bhutan.

Reprint 2022

9

CHAPTER

Agro-meteorology

Agro-meteorology is an important subject of study not only to the people concerned with the agriculture but for all walks of life. It is, however, a new science to the traditional farmers of Bhutan, who relied on nature for everything and left to the nature to take the course of their lives. With education and improving communication system, ways of lives are changing rapidly in Bhutan. This chapter on Agro-meteorology will make sense to the farmers and help them do well in Agriculture and in other spheres of life in Bhutan. This chapter begins with the basic meaning of meteorology, agro-meteorology and the history and present status of agro-meteorology in Bhutan.

To understand the agro-meteorology and its importance better, this chapter explores the exciting phenomenon of weather and climate and the effects on agricultural production. Climatology – the atmosphere and its composition as well as various factors that affect weather and climate of a place, elements of weather such as solar radiation, temperature, wind, air pressure and humidity are discussed. In later part of the chapter, how clouds are formed and bring about rain on earth, how rain can be artificially prepared, weather forecast and its utility to farmers is discussed. The chapter concludes with some information on Agro-meteorology services centres in Bhutan and how information may be availed to plan one's agriculture activities with which Bhutanese agriculturists sustain their business – their vocation.

9.1 Meteorology

Meteorology is derived from a Greek word "*Meteoro*" means 'above the earth's surface' (atmosphere) and "*logy*" means "*study or science*". It is a branch of physics dealing with atmosphere. It studies the individual phenomenon of the atmosphere. In other words, it is concerned with the study of the characteristics and behaviour of the atmosphere. It explains and analyses the changes of individual weather elements such as air pressure, temperature and humidity that are brought about due to the effect of radiation from the sun received by earth's surface.

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a) *Agro-meteorology*

Agro-meteorology refers to *Agricultural meteorology*. It is a branch of applied meteorology, which investigates the physical conditions of the environment of growing plants or rearing animals. It is an applied science, which deals with the relationship between weather/climatic conditions and agricultural production or it is a science concerned with the application of meteorology to the measurement and analysis of the physical environment in agricultural systems. Agro-meteorology deals with the behaviour of weather elements, which have direct relevance to agriculture and their effect on crop and animal production. Weather and climate are the important factors determining the success or failure of agriculture. Weather influences agricultural operations from sowing of a crop to the harvest and particularly rain-fed agriculture depends on the mercy of the weather. Hence, agro-meteorology is very important and it helps in:

- planning cropping patterns/systems
- selecting of sowing dates for optimum crop yield
- reducing losses of applied chemicals and fertilizers. Eg. Avoid fertilizer and chemical sprays when rain is forecast
- planning judicious irrigation of crops
- reducing or eliminating outbreak of pests and diseases
- managing weather abnormalities like cyclones, heavy rain, floods, drought etc. This can be achieved by weather forecasting
- mitigation measures such as shelter-belts against cold and heat waves, effective environmental protection etc.
- planning for crop harvest

The Agro-meteorology, the branch of applied science involves study of relationship between the environment and the climatic conditions of a place. Therefore, it may be easier to begin with the term such as hydrological cycle, climate system, climatology (factors affecting weather & climate and atmosphere), elements of weather and climate, clouds and formation of rain. Let us begin with the study of hydrological cycle – one on the bases of weather formation that determines the climate of a place. The hydrological cycle has been an area of study in Geography. Let us revisit 'hydrological cycle'.

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b) The Hydrological Cycle

Most of the earth's water sources get their water supplies from precipitation, which may fall in various forms, such as rain, snow, hail and dew. Rains no doubt form the principal and the major part of the water supplies. The primary sources of water include: rainwater, surface water (stored in lakes, streams, and ponds), and groundwater. The distribution of water, however, is quite varied; many locations have plenty of it while others have very little. Water exists on earth in three forms solid (ice), liquid and gas (water vapour). Oceans, rivers, clouds and rain, all of which contain water, are in a frequent state of change (surface water evaporates, cloud water precipitates, rainfall infiltrates the ground). However, the total amount of the earth's water does not change much. Water is essential to life. Without it, the biosphere (life forms on earth) that exists on the surface of the earth would not be possible. The movement of water on the earth's surface and through the atmosphere is known as the Hydrological Cycle. Water is taken up by the atmosphere from the earth's surface in vapour form through evaporation. It may then be moved from place to place by the wind until it is condensed back to its liquid phase to form clouds. Water then returns to the surface of the earth in the form of either liquid (rain) or solid (snow, sleet, hail stone) precipitation. Water is stored in the following reservoirs: atmosphere, oceans, lakes, rivers, glaciers, soils, snowfields and groundwater. Water moves from one reservoir to another by processes like

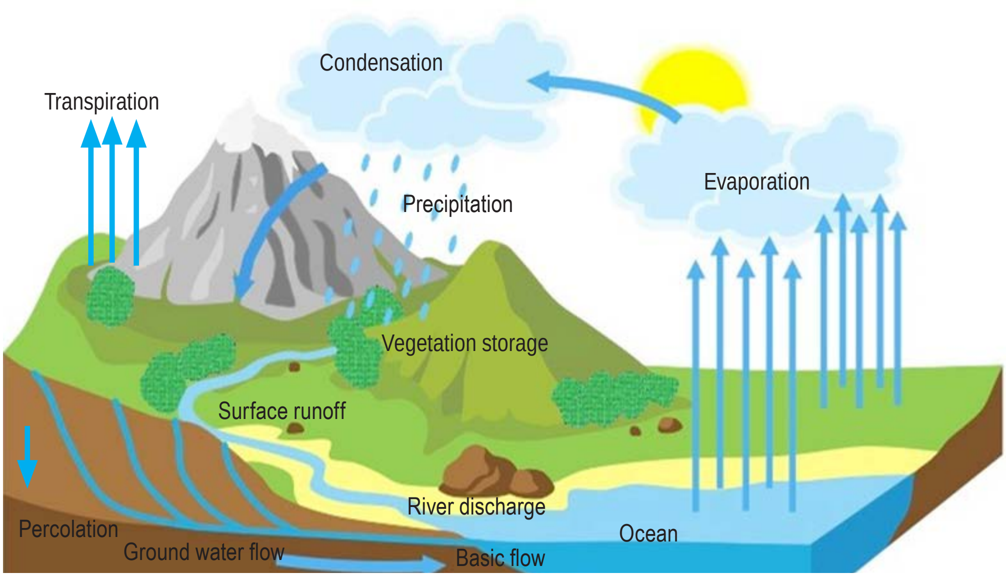

Figure 9.1 Depiction of a hydrological cycle

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evaporation (liquid to vapour), condensation (vapour to liquid), precipitation (rain or snow), runoff (surface flow), infiltration (absorption by ground/soil), sublimation (solid to vapour), transpiration (liquid to vapour by plants) and groundwater flow by gravity. This movement of water in different forms or states from one place to another is the hydrological cycle (see diagram above). As we will see later in the chapter, weather and climate are greatly influenced by the hydrological cycle.

c) The Climate System

Our earth has five major components. These are the atmosphere (gaseous envelope surrounding the earth), the hydrosphere (liquid water like ocean, lakes, and underground water), the cryosphere (solid water like snow, sea ice, glaciers, ice sheets), the lithosphere (land surface or solid outer part of the earth) and the biosphere (living organisms). The *atmosphere* is composed of gases like nitrogen, oxygen, carbon dioxide, argon, methane, nitrous oxide and ozone. The atmosphere also contains water vapour, clouds and aerosols (solid and liquid particles) and

- provides oxygen which is useful for crop respiration
- provides CO_2 to build biomass in photosynthesis
- provides N, which is essential for plant growth
- acts as a medium for transportation of pollen
- protects crops and human beings from harmful UV rays'
- provides rain to field crops.

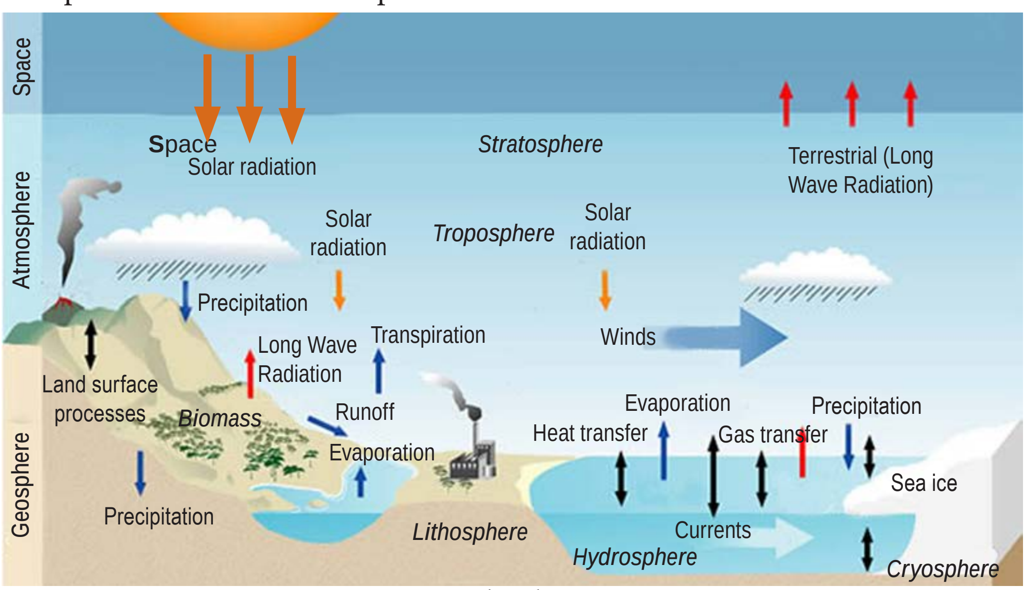

Figure 9.2 The climate system

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The *hydrosphere* is the component comprising all liquid surface and subterranean water, both fresh water, including rivers, lakes and aquifers, and saline water of the oceans and seas. The oceans cover approximately 70% of the earth's surface.

The *cryosphere* includes the ice sheets of the Polar Regions, continental glaciers and snow fields, sea ice and permafrost (permanent frost in temperate areas). Because the ice sheets store a large amount of water, variations in their volume are a potential source of sea level variations. The lithosphere is the solid, outer part of the earth and it consists of three main layers (core or inner layer, mantle or middle layer and crust or outer layer). The *lithosphere* is broken into huge sections called tectonic plates. When one plate moves beneath another, or when two plates rub together, they can create earthquakes and volcanoes.

The *biosphere* is made up of all that is living on earth, from the smallest bacterium to the largest whale. It includes between 3 and 30 million species of plants, animals, bacteria and fungi. The above five physical components (atmosphere, hydrosphere, cryosphere, lithosphere and biosphere) of the earth make up our *Climate System*. It can be defined as an interactive system consisting of the five major components, forced or influenced by various external forcing mechanisms, the most important of which is the Sun (solar radiation – the ultimate energy source). The direct effect of human activities on the climate system results in climate change. Many physical, chemical and biological interaction processes occur among the various components of the climate system on a wide range of space and time scales, making the system extremely complex. As an example, the atmosphere and the oceans are strongly coupled and exchange, among others, water vapour and heat through evaporation. This is part of the hydrological cycle and leads to condensation, cloud formation, precipitation and runoff. Thus the five physical components of the earth as influenced by the energy from the sun are responsible for the climate and its variations.

d) Climatology

Climatology is compounded of two Greek words, "*klima* + *logos*"; *klima* means slope of the earth, and *logos* means a study. In brief, climatology may be defined as the scientific study of climate. In the early civilization, Gods were often assigned to the climatic elements. Many communities still hold ceremonial worships and dances to Gods to produce rains at times of drought. Weather refers to the state of atmosphere at any given time denoting the short-term variations of atmosphere in terms of temperature, pressure, wind, moisture cloudiness, precipitation and

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visibility. It is highly variable, constantly changing, sometimes from hour to hour and at other times from day to day. The afore-mentioned properties of the atmosphere are subject to constant change and their state at any time determines the state of the weather. However, weather elements are not separate rather they are closely related with each other. Climate on the other hand, is the sum or total of the variety of weather conditions of place or an area. It may be defined as the sum of all statistical weather information of a particular area during a specified interval of time, usually several decades. The World Meteorological Organization (WMO) suggests a standard period of 31 years for calculating the climatic averages of different weather elements.

9.2 Factors affecting Weather and Climate

a) Latitude

Based on latitude, the climate has been classified as: (i) Tropical, (ii) Subtropical, (iii) Temperate and (iv) Polar. The tropical climate is characterized by high temperature throughout the year. Subtropical is also characterized by high temperature alternating with low temperature in winter. The temperate climate has low temperature throughout the year. The polar climate is noted for its very low temperature throughout the year.

b) Altitude (Elevation)

The height from the mean sea level creates variation in climate. Even in the tropical regions, the high mountains have temperate climate. The temperature decreases by 1.8°C for every 300 m from the sea level. Generally, there is a decrease in pressure and increase in precipitation and wind velocity. The above factors alter the kind of vegetation, soil types and the crop production.

c) Precipitation

The quantity and distribution of rainfall decides the nature of vegetation and the nature of the cultivated crops. The crop regions are classified on the basis of average rainfall which is arid, semi-arid, sub-humid and humid.

d) Nearness to large water bodies (Nearness to sea)

The presence of large water bodies like lakes and sea affects the climate of the surrounding areas, particularly of islands and coastal areas. The movement of

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air from earth surface to water bodies and from water bodies to earth surface modifies the climate. The extreme variation in temperature during summer and winter is minimized in coastal areas and islands.

e) Topography (relief)

The surface of landscape (levelled or uneven surface areas) produces marked changes in the climate. This involves the altitude of the place, steepness of the slope and exposure of the slope to light and wind.

f) Vegetation

Kind of vegetation characterizes the nature of climate. Thick vegetation is found in tropical regions where temperature and precipitations are high. General types of vegetation present in a region indicate the nature of climate of that region.

9.3 Elements of Weather and Climate

The main elements of weather and climate are solar radiation, temperature, wind, atmospheric pressure and water vapour or atmospheric humidity. These elements are briefly described below.

a) Solar radiation

Solar radiation is the primary source of energy on earth, and life depends on it. Solar radiation is defined as "the flux of radiant energy from the sun". It is the total frequency spectrum of electromagnetic radiation produced by the sun, and covers visible light and near-visible radiation, such as x-rays, ultraviolet radiation, infrared radiation and radio waves. The visible light and heat of the sun is the daylight or sunshine. The earth's atmosphere (ozone layer) filters the majority of the harmful radiation. The total radiation varies from one site to another on the surface of the earth, so does the distribution of plants and animals. Solar radiation provides energy for all phenomena related to biomass production like

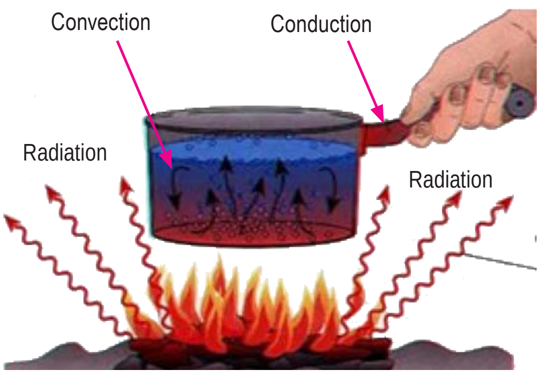

Figure 9.3 Modes of energy transmission

photosynthetic processes and all physical processes taking place in the soil, plant and environment.

Sun transmits its energy through three processes. *Radiation* is the process of transmission of energy from one body to another without the aid of a material medium (solid, liquid, or gas). Example: The energy transmission through space from the sun to the earth. *Conduction* is the process of heat transfer through matter without the actual movement of molecules of the substances or matter. Heat flows from the warmer to cooler part of the body so that the temperatures between them are equalized. Example: The energy transmission through an iron rod which is made warmer at one end. *Convection* is the process of transmission of heat through actual movement of molecules (liquid or gas) of the medium. It is usually the dominant form of heat transfer in liquids and gases. This is the predominant form of transmission of energy on the earth as all the weather related processes involve this process.

Radiant energy is transmitted in the form of electromagnetic waves by the sun. The energy from the sun is spread over a very broad band of wavelengths known as solar spectrum. It is also known as electromagnetic spectrum. The part of the spectrum which is visible is known as `light'. It is the part of the spectrum which is essential for all the plant processes and ranges from 0.4 to 0.7 microns.

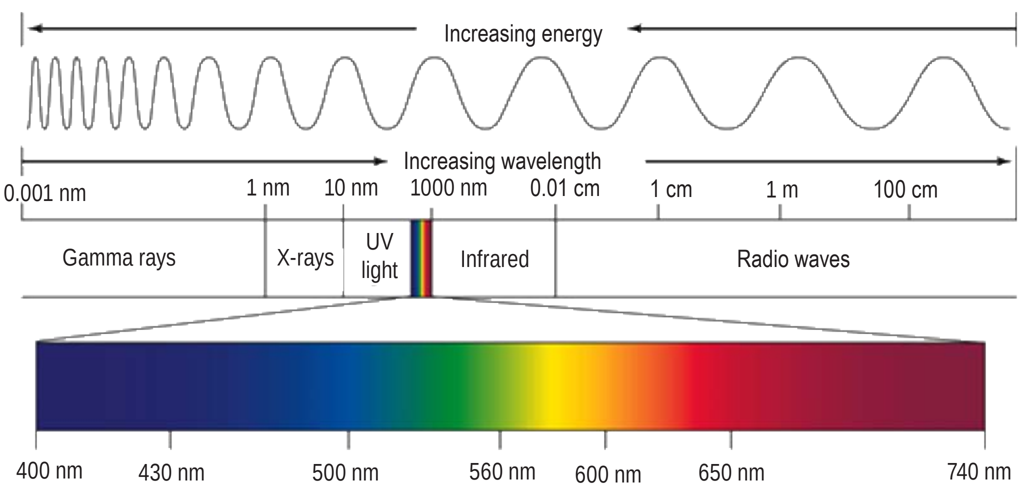

Figure 9.4 The electro-magnetic spectrum

The third part of the solar spectrum is known infra-red band. This is essential for thermal energy of the plant (the source of heat to the plant). Solar radiation is commonly measured with *pyranometers*, which measure the shortwave incoming radiation in a solid angle in the shape of a hemisphere oriented upwards. Most commonly, "glassed dome" pyranometers are used.

Sunshine duration is most commonly recorded with the Campbell-Stokes heliograph or sunshine recorder. A glass globe focuses the radiation beam to a special recording paper and a trace is burned on the paper as the sun is moving. No records occur when no bright sunshine is sensed.

b) Temperatures

Temperature is defined as "the measure of speed per molecule of all the molecules of a body" whereas heat is "the energy arising from random motion of all the molecules of a body". The temperature of a body is the condition which determines its ability to transfer heat to other bodies or to receive heat from them. In a system of two bodies the one which loses heat to the other is said to be at a higher temperature. Heat measures total molecular energy. Temperature measures average energy of individual molecules. In agriculture, both air and soil temperatures are important. Air temperature influences distribution of crop plants and vegetation, as well as growth and development of plants. Temperature affects flowering and fruit/seed formation, and governs physical and chemical processes within plants like photosynthesis and respiration.

There are three points of temperature which influence the growth of crop plants. These are termed as 'cardinal temperature'. A minimum temperature below which growth ceases is called minimum cardinal temperature, an optimum temperature at which the plant growth proceeds with greatest rapidity is the optimum cardinal temperature, and a maximum temperature above which plant growth ceases is known as maximum cardinal temperature. Different crops have varying cardinal temperatures. Plant injury occurs below minimum temperature level. In higher latitudes, drought occurs under cool temperature conditions known as *physiological drought*. This is due to excessive transpiration and absence of absorption of moisture from the soil, when the soil is in extremely low temperature conditions. The internal water content of crop plants is depleted which may result in death of leaves. *Chilling* injury can kill plants. This injury is common in temperate climates where delayed growth and sterility are common symptoms. Moderate wind speeds when the air temperature ranges from 0 to 10^{o}C tend to cause very rapid fall in the activity of metabolic processes, especially respiration in crop plants.

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Freezing damage is caused by the formation of ice crystals in the intracellular and extracellular spaces. Ice within the cells cause injury by mechanical damage and plant parts or entire plant may be killed or damaged. Plant injury also occurs at very high temperatures. High air temperature results in the desiccation (drying) of crop plants. The injury caused because of short period fluctuation (within a day highest in noon and lowest at early morning) in air temperature is known as *sunclad*. The scorching of stem near the soil surface known as *stem girdle* is another injury at high air temperatures. Transpiration is the most effective process in plants to avoid high temperature injury in many natural situations.

Air temperatures are measured with the use of *thermometer* placed at a height between 1.5 to 2 m above the surface. For agricultural purposes, air temperatures are sometimes needed at lower heights such as for the study of night frost just above ground level. Temperature is expressed in degree Celsius (°C) or in Fahrenheit (°F). Conversion factor: 0°C = 32°F. Maximum and minimum temperatures are observed and recorded.

Soil temperature is one of the important factors influencing plant growth. The seeds sown, plant roots and microorganisms live in the soil. Extreme soil temperatures injure plant and affect growth. Soil temperature governs uptake of water and nutrients needed for photosynthesis. It controls soil microbial activities (optimum range being 18-30°C) and influences seed germination and root development.

Soil thermometers are used to measure soil temperature. Soil temperatures are normally observed at standard depths below the surface at 5, 10, 20, 50 and 100 cm. It is desirable to measure soil temperatures under both bare and cropped conditions.

c) Wind

Air in horizontal motion is known as wind. Winds are caused by differences in air pressure: air flows from higher to lower pressure areas. Winds are named by the direction they come from. Windward refers to the direction a wind comes from and leeward is the direction towards which it flows. Winds are important to crop plants. Winds transport heat from lower to higher latitudes. They provide moisture from water bodies (sea) to land masses which is necessary for precipitation or rainfall. A moderate turbulence promotes the uptake of carbon dioxide by plants for photosynthesis. Wind dispersal of pollen and seeds is natural and necessary for certain agricultural crops and natural vegetation. However, winds also cause

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damage or erosion. Strong wind blows away loose and course soil particles (sand) and dust over long distances. In some areas all the soil may be blown away and no cultivation can be possible.

There are many factors affecting wind motion. *Pressure gradient force* results from horizontal pressure differences caused by unequal heating of earth surface. Wind moves from higher pressure to lower pressure areas. Thus, pressure differences cause the wind to blow, and the greater these differences, the greater the wind velocity. *Coriolis force* is produced by the rotation of the earth and is directly proportional to the sine (angle/tilt of earth) of the latitude. That is why the Coriolis force is zero at the equator and maximum at the poles. It causes all winds in northern hemisphere to move towards the right and those of southern hemisphere to move towards left to earth rotation. *Centrifugal force* is developed when the motion of the air is along a curved or circular path, which tends to pull the air outward from the centre of curvature. Theoretically, the pressure gradient force tends to move air in a straight line, but as soon as motion begins, the Coriolis force causes it to move in a curved path. Examples of winds blowing in a curved path are cyclones or anti-cyclones. *Frictional force* is caused as the roughness of the surface provides frictional resistance to the air motion, acting in opposite direction and reducing wind speed. At or near the earth's surface friction is an important factor affecting wind. But its effect is confined to only a few thousand metres from the surface. Friction is relatively lower over the ocean surface.

Wind direction is measured using a wind vane. Most wind vanes consist of a long arrow with a tail that moves freely on a vertical shaft. The arrow points into the wind and gives the wind direction. Wind Speed is the rate at which the air moves past a stationary object. Anemometers measure wind speed. Most anemometers consist of three or more cups that spin horizontally on a vertical post. The rate at which the cups rotate is related to the speed of the wind.

d) Atmospheric Pressure

Technically pressure is defined as the "force per unit area". Atmospheric pressure is defined as "the pressure exerted by a column of air with a cross sectional area of a given unit i.e., a square inch or a square centimetre extending from the earth surface to the upper most boundary of the atmosphere". The atmospheric pressure varies continuously over a relatively small range and the average of these fluctuations is very close to a value adopted for certain standard conditions defined

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as "Standard atmosphere". At a temperature of 15°C and at 45 degree latitude the standard normal pressure is 1013.2 millibars which is equivalent to 760 mm of mercury at the sea level, which is considered as standard atmospheric pressure.

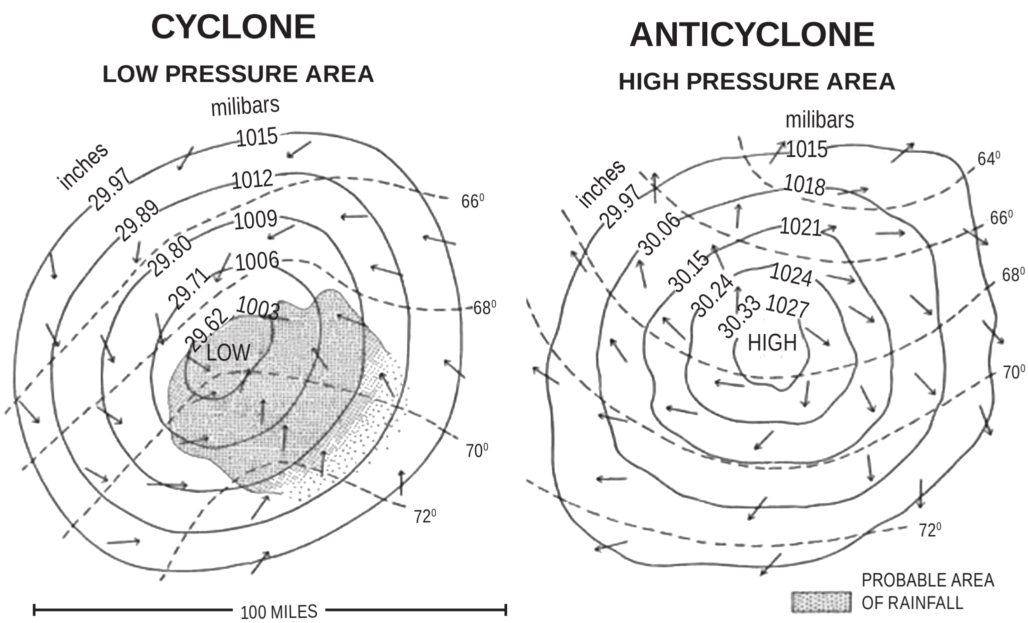

Figure 9.5 Cyclones and anti-cyclones

These are various smaller pressure systems closely identified with daily weather changes. These are seen on daily weather maps. Low pressure systems are called cyclones. When the isobars are circular or elliptical in shape, and the pressure is lowest at the centre, such a pressure system is called "low" or "depression" or "cyclone". The word "cyclone" is derived from a Greek word "cyclos" meaning the coils of a snake. The gales or strong winds accompanying a cyclone give rise to torrential rains and usually approach the coast at 300 to 500 km per hour.

A single severe cyclone can destroy hundreds of human lives, animal populations and submerge thousands of hectares of standing crop. The diameter of a cyclone ranges from a few hundreds to 2000 kilometres. Floods can result because of the cyclones. The devastation could be attributed to the absence of timely warning systems, inadequate preparedness and poor response to the disaster. When isobars are circular, elliptical in shape and the pressure is highest at the centre such a pressure system is called "high" or "Anticyclone". Anticyclones have the highest pressure at the centre and it decreases towards the outer rim gradually. Compared to cyclones they are less destructive. Rainfall is almost negligible. Wind velocities are much lesser than in cyclones.

e) Atmospheric Humidity

The amount of water vapour in the air is called humidity, or it is the invisible vapour content of the air. Water vapour is added into the atmosphere from water bodies such as oceans, lakes, rivers. Water is transpired into the atmosphere by crop plants, trees and vegetation. Wind also carries water vapour into the atmosphere from different places. The percentage of water vapour is highly variable, changing according to season and proximity to land or sea. Humidity is an important factor in crop production and it is not an independent factor but closely related to rainfall and temperature. It plays a significant role in weather and climate and in agriculture.

- Humidity determines the vegetation of a region
- Humidity is a major determinant of potential evapo-transpiration, so it determines the water requirement of crops
- It influences certain physiological phenomena including transpiration
- Change in relative humidity can produce various morphological and anatomical changes in the plants. For example, orchids grow abundantly in humid forests as epiphytes drawing their moisture supply using aerial roots. Xerophytes in desert region where relative humidity is low show certain adaptations to conserve water
- High relative humidity can prolong the survival of crops under moisture stress
- Relative humidity plays a significant role in the outbreak of pest and disease epidemics. High humidity promotes the growth of some saprophytic and parasitic fungi and bacteria which cause various plant diseases
- Very high or very low relative humidity is not conducive for higher yields.

There are some important terminologies such as Relative humidity, Specific humidity, Absolute humidity, dew point and hygrometers to determine degree of humidity in the atmosphere.

Relative humidity (RH) is the amount of water vapour present in a given volume of air and the amount of water vapour required for saturation under a fixed temperature and pressure. It is expressed as percentage. The RH of saturated air is 100%. *Specific humidity* is the amount of water vapour in the air to the amount of dry air. It is expressed as gm per kg of water vapour in a gm/kg of moist air.

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Absolute humidity is the actual amount of water vapour that is saturating the air. Absolute humidity is expressed as grams of water vapour per cubic metre. *Dew point* is the temperature below which water vapour in a volume of humid air at a given constant pressure will condense into liquid water and form dew. At dew point, the invisible water vapour begins to condense into visible form like water droplets. The dew point is associated with relative humidity. Relative humidity of 100% indicates the dew point is equal to the current temperature and that the air is maximally saturated with water.

Hygrometers or psychrometers are instruments that measure relative humidity. Most frequently used in field stations are the wet and dry bulb hygrometers. Such hygrometers use two basic mercury thermometers, one with a wet bulb and one with a dry bulb. Evaporation from the water on the wet bulb causes its temperature reading to drop, causing it to show a lower temperature than the dry bulb. Relative humidity is calculated by comparing the readings using a calculation table that compares the ambient temperature (temperature given by the dry bulb) to the difference in temperatures between the two thermometers.

The questions that we need to ask ourselves is *'How do these knowledge help us in our daily life? Would it make any difference if we have no knowledge about the weather, climate and cyclone, etc.? If a place is prone to cyclone, what kinds of crop would you as a farmer cultivate? What do we do to protect our crops from excessive temperature and loss of water from the soil? What if we have no rain during the season our crops need water?* We need to be critical and creative enough to find solution for sustaining our agriculture. It is important to question ourselves about the utility of the knowledge that we gain and make best use of them in agriculture. Learning only to forget is not worth the efforts.

9.4 Clouds

Cloud is defined as "an aggregation of minute drops of water suspended in the air at higher altitudes". The rising air currents tend to keep the clouds from falling to the ground. Before we learn about clouds, we need to understand the basic concept of condensation because cloud is a product or form of condensation. Condensation is the process in which water vapour is converted into liquid. This process is the opposite of evaporation, where liquid water becomes vapour. Condensation occurs when the air is cooled to its dew point or it becomes so saturated with water vapour that it cannot hold any more water. There are certain conditions for

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condensation to take place. The *presence of water vapour* or adequate amount of water vapour to bring about saturation of air to 100% RH is the first condition. Second, *condensation nuclei* such as dust particles, sodium chloride injected into the atmosphere by sea-spray, sulphur dioxide and nitrous oxide from industries which act as a base for condensation must be present. Water vapour deposits and condenses on these particles due to hygroscopic nature (water affinity). Third, cooling of air up-to or below dew point is necessary for saturation of atmospheric air with water vapour. The ideal conditions for dew are a still, clear night, high humidity in the air. The absence of cloud allows the ground to radiate much of the heat it has absorbed during the day and cool sufficiently for condensation to occur. There are many forms of condensation.

Frost is one of them. When the temperature of atmospheric air falls below 0oC before dew point is reached, water vapour is directly converted into crystals of ice called frost. Water vapour is directly changed into solid form without changing into liquid form. Frost can be harmful to crops.

Fogs are extremely small water droplets suspended in the atmosphere and they reduce horizontal visibility. Fog begins to form when water vapour condenses into tiny liquid water droplets in the air near the ground. Smog is the combined effect of smoke and fog that reduces visibility.

a) Cloud Formation

Clouds are formed when air containing water vapour is cooled below dew temperature and the resulting moisture condenses into droplets on microscopic dust particles (condensation nuclei) in the atmosphere. The air is normally cooled by expansion during its upward movement. Upward flow of air in the atmosphere may be caused by convection resulting from intense solar heating of the ground, by a mass of cold air near the ground causing warm air to rise, or by a mountain range. When the ground is heated by the sun which heats the air in contact with, it causes air to rise. The rising air cools to form clouds. This is called *surface heating*. Sometimes, the topography can force air to rise over a barrier of mountains (*topography or orographic forcing*), air cools as it rises and forms clouds. Clouds are formed when a mass of warm air rises up over a mass of cold, dense air over large areas along fronts or boundary between warm and cold air (*frontal clouds*). Streams of air flowing from different directions are forced to rise where they flow together, or converge. This can cause cumulus cloud and showery conditions (*convergence*).

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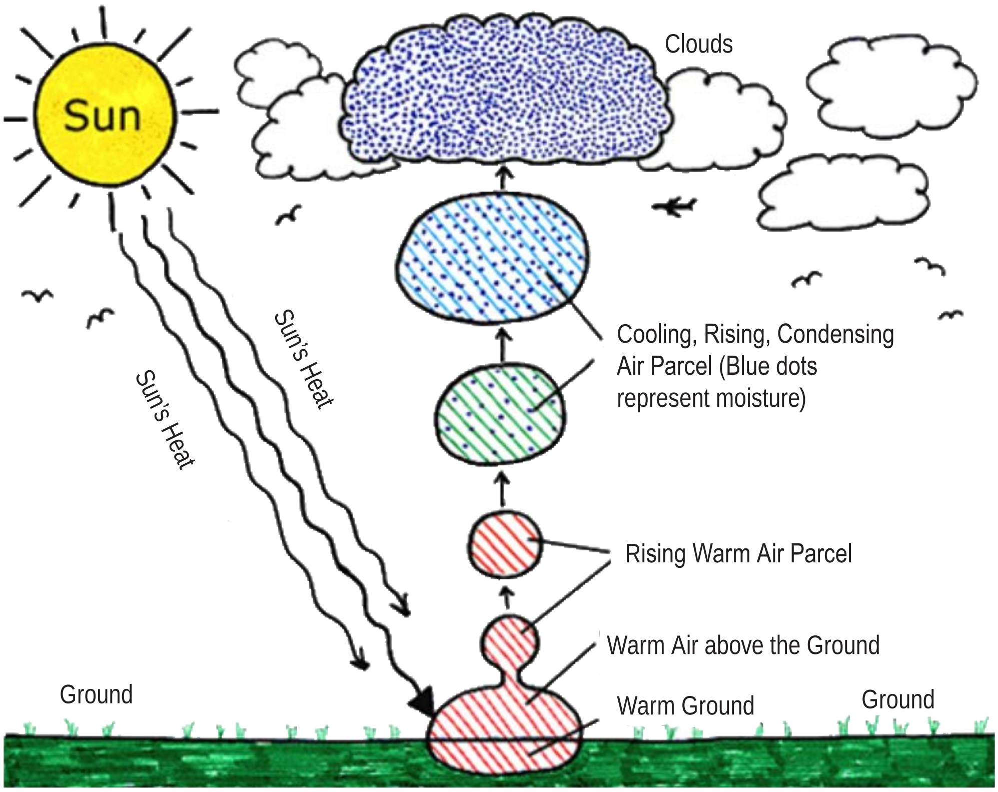

Figure 9.6 Process of cloud formation

b) Basic Types of Clouds

There are four basic types of clouds. A combination of the basic types can form cloud sub-types. Cirrus (Ci) means 'curl' which is recognized by its veil like feathery form. This is the highest type of cloud, ranging from approximately 7 to 12 kilometres in altitude, in tropics and sub-tropics. It normally does not produce precipitation. Cumulus (Cu) means heap or globular mass. This cloud is wooly with rounded top and flat base (looks like cauliflower made from wool). This is seen mostly in summer months. The height varies depending upon humidity of the atmospheric air. Stratus (St) cloud looks like fog covering entire portion of the sky. It gives steady precipitation and is the lowest in height from the ground. Nimbus (Nb) cloud looks dark and ragged. Precipitation occurs from this cloud as the prefix "nimbus" is associated with precipitation.

Reprint 2022

c) Precipitation

For general purpose, precipitation and rainfall are used as synonyms. Technically, precipitation is defined as "earthward falling of water drops or ice particles that have formed by rapid condensation in the atmosphere and are too large to remain suspended in the atmosphere". There are different types of precipitation, either in liquid or solid form.

The liquid form of precipitation is called *rain*. Rain can be defined as "precipitation of drops of liquid water". The cloud consists of minute droplets of water and when these droplets combine and form large drops that cannot remain suspended in the air they fall down as rain. The size of rain drops is more than 0.5 mm. *Drizzle* is more or less uniform precipitation of very small and minute rain drops. These drops can be carried away even by winds. Diameter of drizzle drops is less than 0.5 mm. *Shower* is kind of the precipitation lasting for a short time with relatively clear intervals. Solid form of precipitation includes snow, hail and mixed forms. Snow can be defined as "precipitation in solid form or small ice crystals". It occurs only when the condensing medium has a temperature well below freezing (0^oC). It is also seen in the form of flakes which are aggregates of many crystals. *Hail* is the precipitation of solid ice. These are pellets of spherical shape with concentric layers of ice. Hail is often associated with thunder and storm. Rainfall associated with hail is called hailstorm. The mixed forms of precipitation are sleet and glaze. *Sleet* is the simultaneous precipitation of a mixture of rain and snow. Occasionally, half frozen drops also fall as sleet when rain drops are frozen as they fall through a layer of cold air. Freezing rain is known as *glaze*. It is formed at sub-freezing temperatures when rain falls on objects or ground.

d) Process of rain formation

Rain is formed from water vapour in the atmosphere. Water vapour forms when the heat of the sun evaporates water from oceans and other water bodies or through transpiration. The warm and moist air cools down as it rises into the atmosphere. This reduces the amount of water vapour that the atmosphere can hold. When the temperature drops below the dew point, some of the water vapour condenses into liquid water. Water droplets form on tiny particles called condensation nuclei, which are made up of dust, salt from ocean spray and chemicals given off by industrial plants and vehicles. The formation of raindrops is explained by two theories: the coalescence theory and the ice-crystal theory.

Reprint 2022

i. Coalescence Theory

It accounts for most of the rains that form over oceans and in the tropics. This theory states that different sizes of water droplets are formed. The larger water droplets fall faster than the smaller ones. As a large water droplet falls, it will collide and combine with smaller ones. This process is called coalescence. The combined droplets become heavy for the air to support. Some fall to the ground as rain, while others tend to split up into smaller water droplets. These smaller water droplets will then rise up if the clouds are rising. As the water droplets begin to grow again, coalescence is repeated.

ii. Ice-Crystal Theory

It accounts for most of the rain in the temperate zones. This process occurs in clouds with surrounding air temperature below 0°C (freezing point). In these clouds, ice crystals are formed on microscopic ice nuclei. Ice crystals are formed when droplets of super-cooled water freeze on the ice nuclei. As the ice crystals fall, they may collide and combine with other ice crystals or super-cooled droplets. This makes the ice crystals heavier. When the ice crystals are too heavy for the air to support, they fall to the ground. The crystals become raindrops when they fall through air that is hotter than 0°C.

There are three types of rainfall known as convectional rain, orographic rains, cyclonic and frontal rains.

1. Convectional rain

The air near the ground becomes hot and light due to heating. Then it starts upward movement. This process is known as convection. As the air moves upward it cools at about 10oC per km. As it becomes saturated, RH reaches 100% and dew point is reached whereby condensation begins. First, cloud is formed. Then, further condensation results into precipitation. Such rains are known as convectional rains and mostly occur in the tropics.

2. Orographic rains

When moist air coming from the sea or ocean strikes a mountain it is forced to rise. When the air rises upward, it cools down, cloud is formed and condensation starts giving precipitation. These rains are known as orographic rains. These are also known as `relief rains” as the rains also occurs when the air from sea or ocean

Reprint 2022

strike or pass over relief barriers. Due to these processes rains with high intensity are possible on the windward side of the mountain.

3. *Cyclonic and frontal rains*

The rains received from cyclones are known as cyclonic rains. When two opposing air currents with different temperatures meet, vertical lifting takes place. This convection gives rise to condensation and precipitation which is known as frontal precipitation.

9.5 *Importance of rainfall on crop plants*

Water is a universal solvent and it plays an important role in crop plants as the plants get their nourishment from soil only in solution form. Water is essential for all life processes of crop plants. It helps in regulation of temperature of crop plants. Rainfall influences the distribution of crop plants and vegetation, as the nature of vegetation of a particular place depends on the amount of rainfall. *Rain gauges* are instruments that measure rainfall. The standard rain gauge consists of a funnel-shaped collector that is attached to a long measuring tube.

These days, scientists can make artificial rain. This process is called *Cloud Seeding*. It is defined as a process in which precipitation is encouraged by injecting artificial condensation nuclei through aircrafts or suitable mechanism to induce rain from clouds. Either cold clouds or warm clouds can be seeded to make rain. Seeding of cold clouds involves two methods.

1. *Dry Ice Seeding:* Dry ice remains as it is at -80°C and evaporates but does not melt. Dry ice is heavy and falls rapidly on top of clouds. An aircraft flies across the top of cloud and 0.5-1 cm dry ice pellets are released in a steady stream. A sheet of ice crystals is formed as dry ice falls. Rains occur from the ice crystals as they act as condensation nuclei.
2. *Silver iodide seeding:* In this process, minute crystals of silver iodide produced in the form of smoke act as condensation nuclei. Such nuclei can be released from the ground as they travel upwards into the clouds, or can be released from an aircraft. Only small amount of silver iodide is required.

Reprint 2022

Warm clouds can also be seeded to make rain. It involves two techniques.

1. *Water drop technique*: Coalescence process is mainly responsible for growth of rain drops in warm clouds. Basic assumption is that large water droplets are needed to initiate coalescence process. So water droplets or large hygroscopic nuclei are introduced in the cloud. Water drops of 25 cm are sprayed from aircraft @ 30 gallons per minute and rain occurs within few hours.
2. *Common salt technique:* Common salt is a suitable seeding material for seeding warm clouds. Salt is used either as 10% solution or solid. Spraying is done by power sprayers and air compressors. Balloon bursting technique is also used. Salt and gun powder are arranged to explode near cloud base dispersing salt particles that act as condensation nuclei to make rain.

a) Weather Forecasting

Weather is the most important factor, which influences agricultural operations and crop production. A substantial portion of crop is lost due to aberrant or abnormal weather. Weather forecast is the prediction of weather for the next few days to follow.

When an accurate weather forecast is given for the needs of agriculture it contributes immensely to the benefits of the farmers in several ways.

1. *Short term adjustments in daily and weekly agricultural operations:* If heavy rain occurs immediately after sowing of seeds the seeds are washed away. If a hail storm occurs during harvesting it causes shedding of grains and fruits. If warned in time the farmer would hurry up some of the operations or postpone them suitably adjusting the cropping operations to weather conditions.
2. *Minimizing input losses resulting from adverse weather* (seeds, chemicals, fertilizers, diesel or electric power used for irrigation): The critical periods for normal growth of the crop can be adjusted for healthy growth and development of crop.
3. *Markedly improve the yields of crops both qualitatively and quantitatively:* The yield of the crop is determined by weather conditions to a greater extent, and use of inputs such as seeds, chemicals fertilizers etc. If weather is predicted in advance the amount spent on inputs and labour can be

Reprint 2022

reduced or prevented from wastage. If a farmer knows when the monsoon rains are likely to commence and how the rainfall could be from time to time in the season he or she would be able to plan agricultural operations like preparation of seed bed, manuring, inter-cultivation, drying and threshing of the produce.

The prime requirements for weather forecasting are a good data set and a good method which can be used to forecast. Weather data used in forecasting include air pressure, temperature, wind (speed and direction), humidity, rainfall, cloud (type and amount), present and past weather etc. the type of weather forecast include:

1. *Short range:* upto 72 hours, main users are farmers, general public; prediction includes rainfall, temperature conditions, thunder storms etc.
2. *Medium range:* upto 10 days, mainly for farmers; occurrence of rainfall, temperature intensity, occurrence of events like storms, cyclones etc.
3. *Long range:* weeks, months or a season, mainly for planners; weather deviations from normal.

Would the knowledge gained from this section useful to you as a farmer? How would you use these knowledge? What will you do? Keep asking these question and learn reflectively.

b) Remote Sensing

The word "Remote sensing" was coined by Fischer in 1960. Remote sensing is defined as the "collection and interpretation of information about a target without being in physical contact with it". According to Lilesand and Kiefer, remote sensing is "the science and art of obtaining information about an object, area or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area or phenomenon under investigation".

Principles of Remote Sensing

- Every material on the earth absorbs and reflects solar energy.
- In addition, they emit certain amount of internal energy. The absorbed, reflected and emitted energy is detected by remote sensing instruments or sensors, which are carried in aircraft or satellites.

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- The detections are made by characteristic terms called "spectral signatures" and "images". Remote sensing systems in common use, record radiation in the form of electromagnetic spectrum, i.e., visible range (0.4–0.7 nm), near infrared (0.7–1000 nm) and microwaves (0.8-1 nm).
- The proportion of energy reflected, absorbed and transmitted will vary for different earth features, depending on their material type and condition. These differences permit to distinguish different features on an image.

There are many sensors used in Remote Sensing.

i. Photographic systems

are the most commonly used in sensing systems. The film records the energy reaching it at the exposure time in the visible and near infrared ranges of the spectrum. The photographic technique is used to identify soil types, plants grown, disease incidence, drainage patterns etc.

ii. Line scan and related system

uses the visible and near infrared portion of the spectrum. In this system, a mirror is rotated parallel to the direction of the movement of the aircraft or satellite. The mirror reflects the radiation received on to a detector and the data is recorded. Some sensors also record the thermal infrared radiation emitted by the earth proportional to the surface temperature.

iii. Microwave system

The microwave radiation is used by microwave sensors in a wavelength of about 1 nm–1000 nm. The sensors record the microwave radiation through complex antennae. These are used in weather satellites. The active microwave systems are known as radars. Radars are used to study soil characters, plant condition, soil moisture and runoff slopes etc.

iv. Remote Sensing Platforms

Three platforms are generally used for remote sensing techniques. They are *ground* based, *air* based and *satellite* based. Infrared thermometer, spectral radiometer and balloons are some of the ground-based remote sensing tools. Aircrafts, balloons and rockets are air based remote sensing tools. Space satellites are used for satellite based remote sensing. The digital image processing, using powerful computers,

Reprint 2022

is the key tool for analyzing and interpretation of remotely sensed data. Space based remote sensing obtains information about the earth from the instruments mounted on the earth observation satellites (EOS). The satellites are subdivided into two classes or types.

1. *Polar orbiting satellites:* These satellites operate at an altitude between 550 and 1,600 km along an inclined circular plane over the poles. These satellites are used for remote sensing purposes. LANDSAT (USA), SPOT (France), and IRS (India) are some of the remote sensing satellites.
2. *Geostationary satellites:* They have orbits around the equator at an altitude of 36,000 km and move with the same speed as the earth, so as to view the same area on the earth continuously. They are used for telecommunication and weather forecasting purposes. INSAT series are launched from India for the above purposes. All these satellites have sensors on board operating in the visible and near infrared regions of the electromagnetic spectrum.

v. Applications of remote sensing in agriculture

Remote sensing is an effective tool in assessing the damages to crops and their management in:

1. *Monitoring season agricultural operations:* All farm operations like sowing inter cultivation; harvesting etc. can be monitored effectively by remote sensing.
2. *Crop identification:* By using sensors crop identification on regional scale is possible.
3. *Crop acreage estimation:* By using stratified sampling methodology crop acreage estimation is done to a high level of precision.
4. *Crop yield estimation:* Crop yields are estimated by analyzing satellite based vegetation indices and related data.
5. *Monitoring of crop phenology and stresses:* The crop condition is affected by several factors like deficiency of nutrients, acidic and salinity problems of soil, nutrient deficiencies, adverse weather conditions etc. All these can be detected by remote sensing.
6. *Damage assessment and command area management:* The damages due to floods, cyclones, and water logged areas in command area can be detected and managed effectively by using remote sensing.

Reprint 2022

7. *Land degradation and watershed management:* The remote sensing technology is highly useful in identifying and delineating degraded lands. Also, it facilitates in delineation of watershed areas.
8. *Drought detection and management:* Assessing drought realistically and ways to manage the adverse effects is possible through remote sensing.
9. *Desertification:* Remote sensing provides information to identify the important indicators of desertification. Based on this action can be taken by planners at different levels.
10. *Water availability and soil moisture estimation:* The surface and sub-surface water availability for irrigation and the amount of moisture stored in the upper few centimetres of soil can be found to a greater accuracy.

9.6 Agro-meteorology in Bhutan

Agro-meteorology is a branch of applied meteorology, which investigates the physical conditions of the environment of growing plants or rearing animals. It is an applied science, which deals with the relationship between weather/ climatic conditions and agricultural production. Agro-meteorology deals with the behaviour of weather elements, which have direct relevance to agriculture and their effect on crop production. Weather and climate are the important factors determining the success or failure of agriculture. Weather influences agricultural operations from sowing of a crop to the harvest and particularly rainfed agriculture depends on the mercy of the weather. Hence, agro-meteorology is very important in planning cropping patterns/systems, selecting of sowing dates for optimum crop yield, reducing losses of applied chemicals and fertilizers, judicious irrigation to crops, reducing or eliminating outbreak of pests and diseases and managing weather abnormalities like cyclones, heavy rainfall, floods, drought etc. This can be achieved by weather forecasting.

There was no central agency responsible for hydro-meteorological data collection prior to 1990. The hydro-meteorological data were collected by the respective line agencies to fulfil their own requirement along with the implementation of projects. It was only during the implementation of the Bhutan Power System Master Plan (PSMP) project by the erstwhile Department of Power (DoP) under the Ministry of Trade and Industry (MTI) in 1990-1993, the national hydro-meteorological network covering whole country was established. A central agency for hydrology

Reprint 2022

and meteorology was established and mandated with national responsibility for hydro-meteorological data collection, archiving, analysis and dissemination. The meteorology functions were also taken over by DoP from the Ministry of Agriculture (MoA). Before 2011, the Meteorology Division was a section of the Hydro Met Services Division (HMSD) under the erstwhile Department of Energy. It was then upgraded to the Department of Hydro-Met Services (DHMS), which is recently renamed as the National Centre for Hydrology and Meteorology (NCHM). It is an autonomous agency.

The NCHM is responsible for agro met in Bhutan. The objective of the agency is to observe and understand weather, climate, and hydrology to provide appropriate meteorological, hydrological, flood, glaciers and related services in the country. NCHM provides weather, water, climate and related environmental services to a wide range of sectors, including agriculture, water, energy, tourism, transport and health, to help them reduce risks and derive economic benefits from the associated conditions. The services provide:

- daily forecasts of temperature, humidity and weather outlook and severe weather warnings, which is important for planning and implementing programs and services.
- early warnings and alerts of extreme events including Glacier Lake outburst Floods (GLOF).
- Agro-meteorological services to the agricultural community to help improve production and reduce risks and losses.
- forecasts and warnings of floods and related information both within the country and to neighboring states.
- Hydro-meteorological data for the country to all interested agencies for planning, development and monitoring.

NCHM owns and operates infrastructure that is needed for observing and providing the weather, climate, water and related environmental services for the protection of life and property, economic planning and development, and the sustainable utilization and management of natural resources. Currently, NCHM operates 25 hydrological stations. The rivers gauge measurements at those stations are done by cableway or traditional float methods. Ten sediment sampling stations are also in operation. There are 15 Flood Warning Stations which monitor river

Reprint 2022

levels across the country. The river level data thus collected are communicated through wireless VHF systems. The meteorological monitoring network consists of 20 Agro-meteorological stations and 76 Climatology stations covering the whole country. There is an operational GLOF Early warning system in the Punakha-Wangdue valley. Observations at most of the stations are done manually (twice a day) and the information sent by post to the head office in Thimphu. Some Automatic stations have loggers to record information which is then downloaded every month, while about 15 automatic stations transmit data real-time and near real-time data to Thimphu on pre-set time intervals through GSM/GPRS/satellite telemetry. The following broad strategies are:

- Maintaining and upgrading the monitoring network, telecom and data processing facilities, and keeping traditional functions for basic data collection, processing and analysis
- Ensuring well managed hydro-meteorological and flood warning services network and database
- Developing and facilitating easy access to database, resources and experts
- Adopting scientific and rigorous methodology and putting in adequate resources for timely information and services for flood forecasting and warning
- Promoting human resources development and effective utilization of resources and use of ICT
- Working with the private sector to develop public-private partnership in hydro-meteorology
- Promoting and strengthening cooperation and collaboration with national, regional and international organizations
- Promoting research and development.

To conclude, most of the earth's water sources get their water supplies from precipitation, which may fall in various forms, such as rain, snow, hail and dew. The movement of water on the earth's surface and through the atmosphere is known as the Hydrological Cycle. Our earth has five major components. These are the atmosphere, hydrosphere, cryosphere, lithosphere and biosphere. These physical components of the earth make up our Climate System. Weather refers to the state of atmosphere at any given time denoting the short-term variations of atmosphere in terms of temperature, pressure, wind, moisture cloudiness, precipitation and visibility. Climate, on the other hand, is the sum or total of the variety of weather conditions of place or an area. Factors affecting weather and climate include latitude, altitude, precipitation, nearness to sea, topography and vegetation. The main elements of weather and climate are solar radiation, temperature, wind, atmospheric pressure and water vapour or atmospheric humidity.

The question that you need to ask yourself are '*How would you as an informed farmer like to use the weather forecasting in your farm management? What adjustment do you think you may have to make in your farm management?*

Reprint 2022

Student Activity

1. Discuss with the class on carrying projects that support agriculture work to face the challenges of uncertainty of weather due to climate change and the changes that human activities bring to the environment.

   a. Divide the class into smaller group of five members,

   b. Identify one or two factors such as too much rainfall or no rainfall (water shortage), windy, blazing sun or foggy, etc. affecting agriculture in Bhutan,

   c. Groups need to innovate ways /technologies/ideas to address the factors and carryout agriculture in Bhutan. These ideas need to be planned and modelled with landscape design for exhibition. It can be on an area within school campus where students work will not be disturbed. A temporary shade may be built or use a room that is not used by others frequently.

   d. Permit students to use internet facilities to get the ideas and adapt to Bhutanese situation for agriculture in Bhutan.

   e. Provide adequate time for the project work preparation.

   f. Inform the Principal and the school management team about the exhibition well ahead of time, fix exhibition on a Saturday for staff and students.

   g. Monitor and support groups in their work – especially to identify factors affecting agriculture, and ways of how Bhutanese can carry out agriculture ut problems.

   h. Prepare programme for exhibition on the date decided (Saturday), notify staff and students of the school, and start with a small opening of the exhibition programme welcoming the Principal, staff and the students, address by the principal and vote of thanks by the AgFS teacher/students,

   i. Groups explain their own projects work and keep the exhibition on till the staff and students have visited and listen to their project.

2. AgFS teacher may assign any conservation of soil, water and soil nutrient project that can be tried out in the school campus in groups with different ideas to see which ones work better.

Reprint 2022

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