Agriculture for Food Security

Textbook for Class XI

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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Preface

Understanding the AgFS Curriculum Design

The AgFS Curriculum for classes IX to XII have been designed to fulfill the aspiration of the Ministry of Education, Royal Government of Bhutan, in its attempt to improve the relevance of Secondary Education through curriculum diversification of 9th Five Year Plan. The curriculum design and development of AgFS was closely guided and monitored annually by the Curriculum Board of the MoE from 2008 to 2011 and approved for implementation by the 26th Curriculum Board meeting in 2012. Accordingly AgFSC was implemented in schools gradually preparing teachers, consolidating text materials developed suitable for the learners from classes IX to XII and its implementation guides for teachers, professionally trained but with little subject knowledge.

The AgFS is designed as a vocational curriculum with strong academic standard. The technical concepts, values and attitudes, and skills of AgFS require students to apply their Scientific and Geography knowledge and skills learned in their lower classes to understand AgFS and strengthen its application in their life outside school. The AgFS curriculum not only provides opportunity to use their prior knowledge but an opportunity to understand Agriculture that generates self-employment entrepreneurship especially when Bhutan is being faced with growing unemployment of the literate youth.

The AgFS as a vocational curriculum is designed to equip students for self-employment for which the learners are to be provided with all the information required to be literate in agriculture. The textbooks are designed to provide all that the learners of AgFS need know, understand and critically practice the 'package of practices' in agriculture and generate innovations, rather than wasting time looking for information and 'reinventing the wheel'.

Aims of AgFSC

The '*Agriculture and Food Security for XI*' is a continuation of course of study from class IX and X. It is aimed at providing more knowledge, procedure skills, and values and attitude towards changing the mind set of educated Bhutanese youths of today towards the world of work. The AgFS offers alternative choice of work opportunities and preparing the students for employment in the Agriculture sector, challenging them to enhance the productivity and sustainability of the farming community using the scientific technology and good practices. Students will also be prepared with the basic foundation for higher studies, specializing in Agriculture at the universities in the SAARC region and abroad.

Content of AgFS

The educational experiences identified through which learning outcomes are expected to attain are developed and made available in the textbooks AgFS XI. This provision is made based on the idea that AgFS is a new and a technical subject, also with a firm belief that the 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 educational experiences, which students are expected to undergo in the classroom and outside in the field are developed and presented in the textbook of AgFS class XI. It begins with *Sustainable Agriculture Development* – basic but enduring understanding of the concepts of sustainable development for the sustenance of a society and the scope that 'Agriculture' ensures for self-employment and entrepreneurship in Bhutan. '*Soil and water management for crop production*' in chapter two equips students with knowledge and skills, which are important requirement of a successful farming for growing different vegetables, fruits, food crop production and rearing of animals in different parts of the country. Bhutanese farmers have small landholding growing limited crops due to lack of marketing facilities. '*Food Processing, Value Addition and Food Preservation Technology*' of Chapter four provides enterprising ideas of saving the farm produce and an incentive to grow more crops and prosper with their continued supply of fresh farm produce and processed food. *Livestock* is an integral part of Bhutanese farming system that supports farmers with products of milk, meat and manures. Integration of *Pasture Development* in the farm for greater sustainability and economic return is being encouraged. *Fisheries* and *Goat Farming* chapters provide additional basic knowledge and skills of livestock that can help Bhutanese farmers adopt a mixed farming mode more sustainably. The *Climate, Climate Change and its Impact on Agriculture* gives farming community, ideas that the farming needs to be carried out creatively, innovatively and progressively since the impact of climate change spare no one. *The Renewable Natural Resources Research and Development* chapter is a resource that the Bhutanese entrepreneurship in farming can avail for additional technical support in enhancing agriculture.

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. Modern farmers need to be experimental to do anything that will work better.

The AgFS is a vocational subject and 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, ARDC of Ministry of Agriculture and Forests are consulted for their *technical* expertise and seek *support* of their services, 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

Enabling condition for AgFSC implementation.

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 more 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.

Thakur S Powdyel,
Minister,
Ministry of Education.

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1 Chapter

Introduction to Sustainable Agriculture

Bhutan has only 2.75% of the land under cultivation, which is operated by 58% of the population. Farmers have developed subsistence oriented mixed farming systems with high degree of self-reliance through integrate cropping, livestock rearing, and use of forest products. As Bhutan entered into 20th Century and modernization, the country was challenged with increasing population and scarce land resource. The need to sustain farming in small land area is best highlighted by the statement of His Majesty the King in 109th National Day Address in 2016.

"*We must ensure that only 7% or 664,000 acres of our total land which is usable is put to the best use for the benefit of our people*". (His Majesty's Address to the Nation during the 109th National Day on 17 December 2016, Kuensel, 18th December 2016).

The agriculture sector in Bhutan is largely influenced by demography, income, agricultural productivity, climate change, labour, wild-animal damage, market and dominantly by policies involving these areas. The increasing population pressure and environmental friendly policies, limits expansion and full expression on production potentials of any technologies. One of the greatest challenges is fulfilling the sustainable food self-sufficiency goal while maintaining the clean environment and minimizing agriculture's environmental footprint. Bhutan will need a strategy for "sustainable development" of agriculture sector to produce more food from less land, with less labour, less water and low external inputs.

Food security is critical as it supports political stability, social welfare and economic growth. To achieve food security, crop intensification must be increased. But numerous challenges exist concerning water, energy and food. As countries grow richer, there is an increasing demand for meat, which puts escalating pressure on all natural resources, including valuable farmland.

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This chapter attempts to explore ideas of sustainable development and what it encompasses with its application on sustainable Bhutanese agriculture towards gaining food security. It is important that Agriculture development in Bhutan is sustainable in its approach based on the philosophy of Gross National Happiness advocated and pursed for Bhutan's socio-economic development plans and programmes. The understanding of sustainable development concepts and practices will enable Bhutanese farmers to realise GNH and sustain GNH society in this competitive world of 21st century and beyond.

1.1 What is Sustainable Development?

Sustainable development is multifaceted approach to managing environment, economic and social resources for the long term. Sustainable development focuses on improving the quality of life for all of the Earth's citizens without increasing the use of natural resources beyond the capacity of the environment to supply them indefinitely. As such the concept of sustainable development has emerged from the limitations imposed by technology and society on the environment's ability to meet the present and future needs.

It must be borne in mind that development should not endanger the natural system that supports life on earth. With this attitude towards nature, technological advances increase our ability to use natural resources and thus increase the damage. However, the realization is growing fast that we are in a world of limits and ever increasing growth of material consumption can only damage the life giving physical components of the environment. Presently sustainable development agenda is pursued by the United Nations Conference on Environment and Development (UNCED). The concept of sustainability has been linked to land development practices, population growth, fossil fuel usage, forest management, aquaculture, pollution, global warming, limited water supplies, species diversity and extinction, and the types of resources being consumed.

According to World Commission on Environment and Development (WCED) sustainable development means a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development and institutional change are all in harmony and enhance both current and future potentiality to meet human needs and aspirations. "*Sustainable development is development that meets the needs of the present without* compromising *the ability of*

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future generations to meet their own needs" is the most frequently quoted definition of sustainable development. It is from the report Our Common Future (also known as the Brundtland Report - WCED, 1987). Sustainable development is therefore a concept that will continue to evolve over time but common characteristics underlie the many streams of thought. Broadly, sustainable development emphasizes the need for:

- *Concern for equity and fairness* - ensuring the rights of the poor and of future generations
- *Long-term view* - applying the precautionary principle
- *Systems thinking* - understanding the interconnections between the environment, economy and society

Sustainable Development encompasses the idea that there are three interdependent pillars of development *environmental, economic* and *social.* It must be understood that the objective of sustainable development is to maximise the goals across all three systems and is illustrated by the intersection of these circles. Critically, the model include the understanding that each of the system goals is socially constructed and that achieving sustainable development requires trade-offs; choices have to be made at particular points in time and at particular scales as to what is being pursued and how sustainable development requires recognition of the costs involved for particular interests and for groups of people.

Sustainable development is a development that meet needs of the present without compromising the ability of future generations to meet their own needs. For achieving sustainable development what is needed in global movement as well as significantly increased political will and public pressure in order to persuade industry, governments and institutions to take responsibility for their action locally. As such sustainable development "can be seen as based on a new recognition of the complex web of interconnections between different issues, fields, disciplines and actors," requiring a "holistic and interdisciplinary perspective". It is now clear that there is principally sustainability of three elements:

i. economic,

ii. environmental, and

iii. social, which can be considered as triangle as illustrated in Figure 1.1.

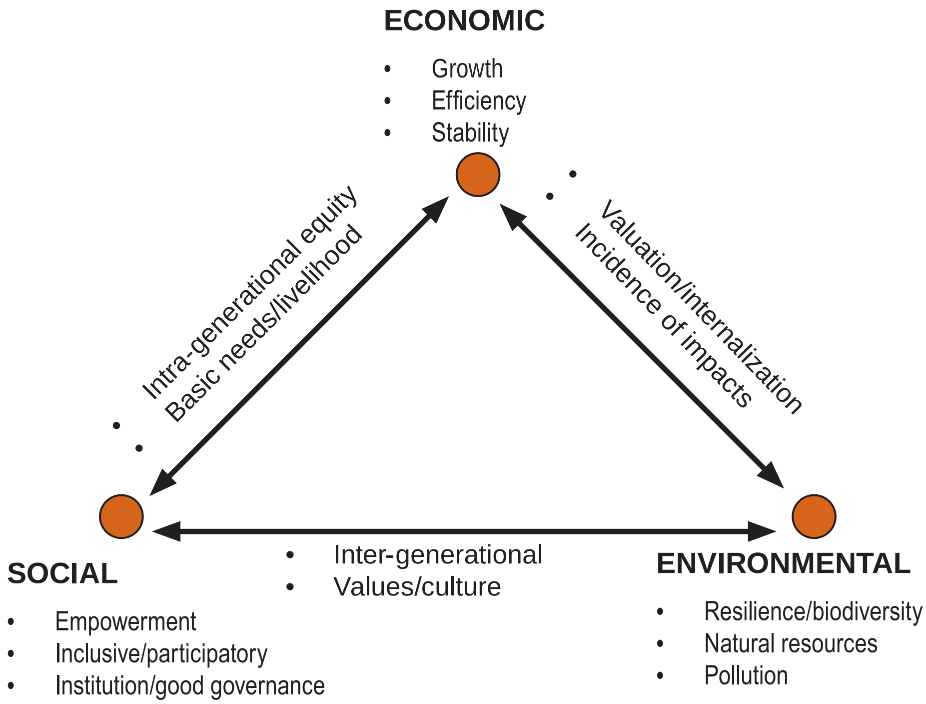

Figure 1.1 Sustainable development triangle – key elements and interconnections

Economic sustainability seeks to maximize the flow of income that could be generated while at least maintaining the stock of assets (or capital) which yields this income. It is argued that unrestrained economic growth is unsustainable, and point out practical limitations in applying the economic sustainability rule without additional environmental and social safeguards. Economic efficiency plays a key role in ensuring optimal consumption and production. Economic system resilience is better judged by the ability to deliver key economic services and allocate resources efficiently in the face of major shocks, ensuring stability.

Environmental sustainability focuses on the overall viability and health defined in terms of a comprehensive, multi-scale, dynamic, hierarchical measure of resilience, vigour and organization both in natural and managed systems (e.g. agricultural, rural and urban areas). Resilience is the potential of a system state to maintain its structure/function in the face of disturbance which is related to the ability of a system to return to equilibrium after a disruptive shock. Some of the destructive forces are natural resource degradation, pollution and loss of biodiversity.

Social sustainability stresses the ideas of reducing vulnerability and maintaining the health (resilience, vigour and organization) of social and cultural systems

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to withstand disturbance that may break the social setup. The resilience of social systems and governance can be improved by education, institutions and strengthening social values. Social sustainability can be increased by strengthening social cohesion, network, empowerment and reducing social conflicts. Sustainable development needs to have a system and a systemic approach.

1.2 Sustainable Agriculture Systems

In the present world there is no more important question before us than that of sustainability of agricultural systems. Desertification, deforestation, pollution of air, water and soil are of increasing concern in many ecosystems. Over the centuries agriculture systems has evolved into a complex representation of ecological stability and reliance, economic viability, the quality of life, and human welfare. In parallel, there are also instances that some agricultural systems once popular have disappeared over time as they could not sustain for variety of reasons.

Modern farming using high yielding crop varieties and synthetic agro-chemicals (fertilizers, pesticides) has helped in increasing crop productivity and food production. However, the hazards of using agricultural chemicals that cause ecological degradation have prompted many to think rationally and evolve alternatives. Pesticides are not specific to the target organisms but kill many useful organisms, thus upsetting the food web in nature. The pesticide residues in the food chain have endangered life sustaining systems. Synthetic fertilizers pollute the environment through nitrate poisoning and killing beneficial soil micro-organisms. Therefore, the need for sustainable and ecological agriculture is increasingly felt.

Sustainable agriculture is the production of food, fibre, or other plant or animal products using farming techniques that protect the environment, public health, human communities and animal welfare. This form of agriculture enables us to produce healthy food without compromising the ability of future generations to do the same. Sustainable agriculture can also be referred by other names such as alternative agriculture, ecological agriculture and natural farming. It is an agricultural production system, which avoids or excludes the use of factory-made fertilizers and pesticides. To the maximum extent feasible, it relies upon crop rotations, crop residues, animal manures, legumes, green manures to maintain soil productivity to supply plant nutrients. It advocates alternative methods of pest-control like pest resistant cultivars, bio-control agents and cultural methods

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of pest control.

To sum up, sustainable agriculture can be defined as "an agriculture that can evolve indefinitely toward greater human utility, greater efficiency of resource use, and a balance with the environment that is favourable both to humans and to most other species". Thus any agriculture developmental activity needs to be guided by its objectives.

Sustainable agriculture systems aim to maintain or enhance biological and economic productivity of crops, enhance the efficiency of inputs, 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 to:

- Satisfy human food and fibre needs.
- Enhance the environmental quality and natural resource base upon which the agricultural economy depends.
- Make the most efficient use of renewable resources and on-farm resources and integrate, where appropriate, natural biological cycles and controls.
- Sustain the economic viability of farm operations.
- Enhance the quality of life for farmers and society as a whole.

Sustainable agriculture systems need to be understood as "an integrated system of plant and animal production practices which over the long term satisfies human needs for food and fibre; enhances environmental quality and the natural resource base; uses renewable resources and on-farm resources efficiently; integrates natural biological cycles and controls; sustains the economic viability of farm operations; and enhances the quality of life for farmers and society as a whole."

A sustainable agriculture must provide a fair and reasonably secure living for farm families. It should minimize harm to the natural environment. It should maintain basic natural resources such as healthy soil, clean water, clean air, and support viable rural communities and fair treatment of all people involved in the food system, from farm workers to consumers.

It implies that sustainable agriculture broadly have three goals of fulfilling the economics, environmental, and social needs. If we relate the sustainable agriculture to the three elements of sustainable development as explained in earlier section, it can be best illustrated by a 3-legged stool (Figure: 1.2), that to make agriculture sustainable, economic, environmental, and social factors are important. For instance, what happens if one of the leg breaks, or one leg is missing entirely?

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The whole stool falls over. The 3-legged stool has become a metaphor for the need to consider the economic, environmental, and social impacts of agriculture (or any of our actions).

If our agricultural system has unacceptable impacts in any one of these spheres, it cannot support producers and contribute to the community over the long term. Sustainable agriculture system is:

Figure 1.2 Three pillars of Sustainable Agriculture

a) Good for families and communities

It promotes opportunities and cooperative relationships for family and community members. For example, a local food marketing system called community supported agriculture (CSA) offers opportunities for people to get into farming without major capital investment; provides work for family members,

b) Good for a sound environment

It preserves the quality of basic natural resources that the farms, businesses and the surrounding environment rely on, including soil, water, and air. Agriculture affects natural resources. Cooperating with natural resource systems instead of trying to overpower them can offer benefits to food production as well as the natural environment.

c) Economically sustainable

Agriculture should provide a secure living to farm families and others employed in food production and processing. An economically sustainable approach also provides access to good food for all people.

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1.3 Practices of sustainable agriculture

The Sustainable Agriculture System (SAS), like any other system is based on scientific concepts, procedures and appropriate technology that enable the system to work well. It is critical to understand the concepts, procedures and technologies of SAS and employ them innovatively in any sustainable agriculture activity or entrepreneurship. There are eight interdependent prerequisites for sustainable rural development on the basis of analysis of apparently successful and sustainable projects in the developing world. They are as listed below:

Table 1.1 Technologies/practices of sustainable agriculture (Conway, 1997)

Intercropping	The growing of two or more crops simultaneously on the same piece of land. Benefits arise because crops exploit different resources, or interact with one another. If one crop is a legume it may provide nutrients for the other. The interactions may also serve to control pests and weeds.
Crop Rotations	The growing of two or more crops in sequence on the same piece of land. Benefits are similar to those arising from intercropping.
Agro-forestry	A form of intercropping in which annual herbaceous crops are grown together with perennial trees or shrubs. The deeper-rooted trees can often exploit water and nutrients not available to the herbs. The trees may also provide shade and mulch, while the ground cover of herbs reduces weeds and prevents erosion.
Silvi-pasture	Similar to agro-forestry, but combining trees with grassland and other fodder species on which livestock graze. The mixture of browse, grass and herbs often supports mixed livestock.
Green manuring	The growing of legumes and other plants in order to fix nitrogen and then incorporating them in the soil for the following crop. Commonly used green manures are Sesbania and Azolla, which contains nitrogen-fixing, blue-green algae.
Conservation tillage	Systems of minimum tillage or no-tillage, which reduces the amount of soil disturbance and so lessens run-off and loss of sediments and nutrients.
Biological control	The use of natural enemies, parasites or predators, to control pests and diseases.

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Integrated pest management	The use of all appropriate techniques of controlling pests in an integrated manner that enhances rather than destroys natural controls. If pesticides are part of the programme, they are used sparingly and selectively, so as not to interfere with natural enemies.

The eight technologies or practices of SAS are discussed in more detail in the later chapters of this book. The eight practices of SAS listed above and discussed briefly need to guide our agriculture practices, especially for Bhutanese subsistence mix farming system. The SAS has however, its own problems.

a) Threat to agriculture sustainability

Sustainable agriculture is constantly under serious threat as a result of declining arable land and forests, intense competition for water, the development of bio-fuels, spread of genetically modified (GM) crops, and climate change for which strong policy and practices are required to mitigate the threats but they need to be understood first.

i. Land degradation

It is the most critical threat to sustainable agriculture. In South and South-East Asia, around 74 %of agricultural lands have been severely affected by erosion, by wind or water or chemical pollution. In the worst cases, particularly in dry-land ecosystems, farmland can turn to desert. Most land degradation is caused by intensive agriculture and excessive use of chemical fertilizers.

ii. Shrinking forest

Forests provide critical ecosystem services to the agricultural sector, including pollination and watershed protection, and support to livestock and fisheries. Rapid deforestation is depriving people of food, fibre, fodder and other resources. Most critically, it has caused drying of water sources, reduction of wildlife and loss in biodiversity.

iii. Competing for water

The demands for water by domestic and industrial uses immensely affect water for agriculture. Collectively, all users whether domestic, industrial or agricultural have been consistently withdrawing more water than the natural hydrological cycle's renewable capacity.

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iv. Demand for bio-fuel

As the fossil fuel becomes more scarce and costly, demand for bio-fuel is increasing. Production of bio-fuel may displace food crop.

v. Genetically modified crops

Although genetic modification has been considered as means to increase crop yield and its resistance to specific pest, disease and chemicals, the side effects of GM crops to health and environment is a controversy.

vi. Climate change

It is one of the serious threats to food security and sustainability of agriculture. Changes in temperature, rainfall and overall meteorological conditions will change water regime and ecological condition altering the timing and length of growing seasons. The climate variability and extreme weather conditions like intensities and frequency of rainfall and floods, wind storms, drought and snowfall will pose enormous threat for agricultural production.

The threats of sustaining agriculture can however, be addressed with the demand for policy change and educating Bhutanese farmers to change their practices of agriculture in line with the sustainable agriculture systems' practices. It may not be an easy task but with determination and concerted efforts, sustainable agriculture system can take root in Bhutanese system of agriculture, if Bhutanese understand the importance of 'food security' for the sovereignty of this GNH nation.

1.4 Food and Nutritional Security

Across Asia and the Pacific, millions of people are still food insecure and children are dying from causes related to malnutrition. Nutrition for children is very critical, as poor nutrition will make children more susceptible to fatal diseases. In case of adults, poor nutrition will reduce their capacity to work and live healthy. Across Asia and the Pacific, around 3.8 million children die each year before reaching the age of five (UNICEF, 2009) , and around half of these deaths, over 1.9million, are from causes related to malnutrition, poor hygiene and lack of access to safe water and adequate sanitation (ESCAP, 2009) .

a) Food security

According to a widely accepted definition from the Food and Agriculture

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Organization (FAO), *food security* is achieved when "*when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life*." Thus, we are food secure if we have safe, nutritious and enough food to eat at all times to lead a healthy and productive life. There are several other related concepts as well, such as *food self-sufficiency* being to meet consumption needs (particularly for staple food crops) from our own production rather than by buying or importing. If food is imported from other countries using the money earned from other enterprises, then we have *food self-reliance*. Food security is defined in different ways.

- World Food Summit in 1996: "*Food security exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food which meets their dietary needs and food preferences for an active and healthy life*".
- The Food and Agriculture Organization (FAO) of the United Nations: "*Food security exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food which meets their dietary needs and food preferences for an active and healthy life.*"
- The United States Department of Agriculture (USDA): "*food security as access by all people at all times to enough food for an active, healthy life.*"

From the above definitions of food security, it is clear that food security has four key elements: availability, access, utilization and stability. It is important to understand these key elements. These elements can be considered as four pillars (or dimensions) of food security.

i. Food availability

It relates to the supply of food through production, distribution, and exchange. Food production is determined by a variety of factors including land ownership and use, soil management, crop selection, livestock breeding and management and harvesting. Crop production can be impacted by changes in rainfall and temperatures. Crop production is not necessary for a country to achieve food security. Many nations like Singapore or Japan do not have natural resources required to produce crops in order to achieve food security. Because food consumers outnumber producers, food must be distributed to different regions or nations. Thus food distribution involves storage, processing, transport, packaging, and marketing of food. Food-chain infrastructure and storage technologies can impact the amount of food wasted in the distribution process. Poor transport infrastructure can increase the price of moving food to national and global

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markets. Around the world, few individuals or households are continuously self-sufficient in food. This creates the need for a bartering, exchange, or cash economy to acquire food. The exchange of food requires efficient trading systems and market institutions. Per capita world food supplies are more than adequate to provide food security to all, thus food access is a greater barrier to achieving food security.

ii. Food access

It refers to the affordability and allocation of food, as well as the preferences of individuals and households. Often times, the causes of hunger and malnutrition are not due to scarcity of food but an inability to access available food due to poverty. Poverty can limit access to food, and can also increase how vulnerable an individual or household is to food price changes. Access depends on whether the household has enough income to purchase food at prevailing prices or has sufficient land and other resources to grow its own food. Households with enough resources can overcome unstable harvests and local food shortages and maintain their access to food. There are two distinct types of access to food: *direct access*, in which a household produces food using human and material resources, and *economic access*, in which a household purchases food produced elsewhere. The assets of a household, including income, land, products of labour, inheritances, and gifts can determine a household's access to food. Household population and education levels of members can determine and influence the types of food that are purchased. Sometimes, a household's access to food may not assure adequate food intake of all household members, as intra-household food allocation may not sufficiently meet the requirements of each member of the household. Access to food should be ensured in socially acceptable ways, without, for example, resorting to emergency food supplies, scavenging, stealing, or other coping strategies.

iii. Food utilization

The other pillar of food security is food utilization, which refers to the metabolism (or consumption and digestion) of food by individuals. Once food is obtained by a household, a variety of factors impact the quantity and quality of food that reaches members of the household. In order to achieve food security, the food ingested (or eaten) must be safe and must be enough to meet the physiological requirements of each individual. Food safety impacts food utilization, and can be impacted by the preparation, processing, and cooking of food in the community and household. Nutritional values of the household determine food choice. Access to healthcare is another determinant of food utilization, since the health of individual control

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how the food is metabolized. For example, intestinal parasites can take nutrients from the body and decrease food utilization. Sanitation can also decrease the occurrence and spread of diseases that can affect food utilization. Education about nutrition and food preparation can impact food utilization and improve this pillar of food security.

iv. Food stability

It refers to the ability to obtain food over time. Food security can be transitory, seasonal, or chronic. In transitory food insecurity, food may be unavailable during certain periods of time. At the food production level, natural disasters and drought result in crop failure and decreased food availability. Civil conflicts (war) can also decrease access to food. Instability in markets resulting in food-price hikes can cause transitory food insecurity. Other factors that can temporarily cause food insecurity are loss of employment or productivity, which can be caused by illness. Seasonal food insecurity can result from the regular pattern of growing seasons in food production. Chronic (or permanent) food insecurity is defined as the long-term, persistent lack of adequate food. In this case, households are constantly at risk of being unable to acquire food to meet the needs of all members. Chronic and transitory food insecurity are linked, since the reoccurrence of transitory food security can make households more vulnerable to chronic food insecurity.

Food security is monitored by counting how many people are going hungry, and broadly two principal measures are used. Two indicators for nutrition are:

- ***Proportion of population undernourished*** – The proportion of the population consuming less than the minimum level of dietary energy requirement. FAO estimates this for each country using three key parameters: the minimum number of calories required for an average person, the average amount of food available per person for human consumption, and the level of inequality in access to that food, based on income.

- ***Prevalence of underweight children*** – The proportion of children aged 0-59 months that fall below the median weight for age of the WHO standard reference population by more than three standard deviations. In a normally distributed population, only 0.13per cent of children would be expected to fall below this standard.

The first measure addresses consumption, typically by assessing the proportion

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of the population whose food intake falls below the minimum dietary energy requirement. The second involves physical 'anthropometric' measurements to assess the nutritional status of children under five, to arrive at the proportion who is underweight– who weighs less than they should do for their age.

Food insecurity is often related to poverty. The poorest and most food insecure people are those who lack decent work, who have low levels of health and education, and who generally have few economic opportunities. Some of the causes of food insecurity are:

- ***Food production***: the modern commercial and organized crop production systems have displaced small holder farmers and made them farm worker and earning extremely low income.
- ***Increasing demand***: The demand for food by middle and upper class has become very high with the increase in income. This increase has deprived the lower income group.
- ***Security through trade***: Food security is influenced by international trade.
- ***Food policies of the developed countries***: Food availability in developing countries is also affected of course by the policies of the developed countries.
- ***Market-based food insecurity***: The problem of food insecurity, like that of poverty, is thus frequently related to market failures.
- ***Food absorption and utilization***: Even when food is available in the household, some family members may not be able to take advantage of it – hampered by inadequate water supplies and poor standards of sanitation which reduce the quality of their food or make it hazardous.
- ***Food price***: high food prices hurt marginalized groups, especially the rural landless and the urban poor, who tend to spend half or more of their family budgets on food.

b) *Impact of food insecurity*

The most general impact of food insecurity, and particularly rising prices, is an increase in poverty. Poverty often compel people to mortgage or sell assets, migrate elsewhere in search of work, or remove their children from school so that they can work to contribute to the household income. In extreme situations, parents may even give up children for adoption, or marry off their daughters early to reduce the number of mouths to feed. Many studies have shown that, when households come under pressure of declining food supplies and rising prices, people adopt many strategies but targeting to change of quantity and quality of food. Some of the strategies as per the studies conducted in Bangladesh, Nepal and Sri Lanka

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by WFP (2008), Raihan (2008), and Herath (2008) are as follows:

- reduce food-intake,
- shift to less costly food,
- reduce number of meals in a day,
- reduce proportion of food,
- reduce saving,
- take loans to buy food,
- reduce non-food expenditure,
- sell/mortgage assets,
- children employment,
- out-migration.

The impact of food insecurity adversely affects the quality of life people lead in a society and most importantly the food insecurity could threaten the sovereignty of our nation. The food security status of Bhutan and its policy may help us to understand the future of Bhutan and the progress that we are making towards gaining food security.

1.5 Food and Nutritional Security Status in Bhutan

Food security in Bhutan is an important, cross-cutting theme that includes agriculture, forestry, livestock, urban and rural population, national and local interventions, and community and household actions. There is a long-standing debate on whether food self-sufficiency is a useful strategy to achieve food security. Supporters of this proposition argue that relying on the market to meet food needs is a risky strategy because of volatility in food prices and possible interruption in supplies. The opposing view is that it is costly for a household (or country) to focus on food self-sufficiency rather than producing according to its comparative advantage and purchasing some of its food requirements from the market (self-reliance).This debate is reflected in the evolution of food policy in Bhutan through the Five Year development plans. Current food security strategies address the links between sustainable development, poverty reduction and the promotion of food security in food insecure areas. Bhutan advocates a broad definition of food security based on the principle of self-reliance and comparative advantage.

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According to the World Food Programme, food availability in Bhutan varies among and within different *dzongkhags* and *gewogs*, and is often influenced by site-specific factors. The reasons for food shortages are usually linked to food and agricultural productivity. About 70% of reasons for food shortages are related to land (inadequate, unproductive). Since large portions of the population are dependent on subsistence agriculture, increasing productivity is seen as a key factor in achieving food self-sufficiency. Those who do not produce enough cereals for the whole year rely on cash procurement of food or borrowing of food or barter of livestock products for cereals. Cash is earned through cash crop, sale of livestock or livestock products, collection of forest products for sale, labour or cash remittances received from relatives or others.

The Poverty Analysis Report 2017 states that 8.2% of people in Bhutan suffer from food poverty or consume less than 2,124 kilocalories per day. However, the food basket taken for this food poverty line includes expensive products like confectionary, milk powder, fresh and dried fish, beef, walnuts, tea and juice. A more realistic food poverty line for 2,124 kilocalories per day can be based on basic food items like cereals, pulses and vegetable oil. Generally, this indicates a relatively food secure population but certain areas in the country do experience food insecurity and seasonal hunger. Of the total food consumption in Bhutan, urban populations are responsible for 37% of food intake; the rest is consumed in rural areas. The share of meat consumption and food consumed outside the home is higher in urban areas than it is among rural households. Rice accounts for a higher share of food consumption in rural households than in urban households, indicating potential risks for protein and micronutrient deficiencies and poor nutrition status in rural households.

Since the start of planned development in 1961, the health sector has made tremendous achievements in the expansion of basic health services. Today, it is estimated that more than 90% of the country has access to health services. In 2017, the National Health Survey estimated life expectancy at 69.8 years, an improvement from 45.6 years in 1984. The infant mortality rate declined from 70.7 per 1000 live births in 1994 to 25.6 in 2017. However, it still remains a challenge to address disparities regarding nutritional status among communities and regions of the country.

Food security in Bhutan is an issue of access to resources and economic opportunities. For rural households, who constitute about 62.2% of the population,

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difficulties arise from an inconsistent lack of access to land and water, preventing them from growing their own food in adequate quantity. For urban, non-farming rural and the landless populations, vulnerability stems largely from unpredictable employment opportunities. Food access issues in the country are inter-linked with extreme topographical variation, wide ecological, agricultural and economic diversity, and poor connectivity. Despite increased rice and maize yields, production has only been able to meet rural demands, while increased urban requirements are mostly met through imports. This is mainly because agriculture in Bhutan has remained at subsistence levels because of limited arable land, inadequate market access, and high transaction costs. Some other difficulties are the prevalence of natural calamities such as landslides, floods, droughts, crop failures, pests and diseases, wildlife crop damage, poor irrigation infrastructure, and an imbalance between rural labour supply and demand.

1.6 Agriculture sustainability and food security

Green revolution in 1960s and 1970s principally provided a very high crop production through two means. Firstly the use of high yielding crop varieties and farm inputs like chemical fertilizers, pesticides, water and machinery, and secondly the application of genetic engineering in crop modifications (genetically modified organisms – GMO). The green revolution while providing a much needed food production, it forced small farmers out of subsistence agriculture into urban slums resulting in higher per capita hunger. The intensive high input agriculture relying on fossil fuels and chemicals degrade the environment in many ways leading to reduced crop production ability of the land. It is often stated that, depending on such unsustainable agriculture systems will increase food insecurity.

Figure 1.3 A progressive effect of food insecurity

As shown in Figure 1.3, food insecurity is an inevitable trap, which is part of a continuum which includes long-term lack of food security resulting in deprivation of food (*hunger*), deficiencies, imbalances, or excesses of nutrients (malnutrition), and a severe shortage of food resulting in widespread hunger on a population level

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(famine). In addition to hunger leading to malnutrition, it can also be caused by poor health, poor care for children, or an unhealthy environment. As per United Nations, famine is declared only when "at least 20%of households in an area face extreme food shortages with a limited ability to cope; acute malnutrition rates exceed 30%; and the death rate exceeds two persons per day per 10,000 persons."

While the driving force to food insecurity is lack of resource to purchase food, poverty combined with other socio-economic and political problems creates the bulk of food insecurity around the globe. An unhealthy or poor population produces less and may be forced into practices damaging to the environment like cutting down trees for firewood, polluting surrounding waters (WHO/UNEP, 1986). Poverty therefore has environmental dimensions. According to World Resource Institute (WRI, 2002), the greatest environmental vulnerabilities that poverty brings is a high dependence on natural resources for subsistence.

Poverty compels people to cultivate marginal land, live in unsafe housing, and exploit natural resources and forest in order to survive in the short term, often with detrimental effects on the resource base and their own longer-term livelihoods. A simple representation of cause and effect of declining access to productive land in rural areas provides a clear relationship between poverty and environment (Figure 1.5).

As the productive land becomes scarce due to population growth, agriculture development, and disparity in distribution of land, it compels people to either cultivate unproductive areas (hills and dry land) or migrate to urban areas leaving their farm. This results in serious ecological impacts like land degradation, desertification, and emergence of slums in urban areas. Most of these impacts directly become a threat to the well-being of the resource poor people. In the recent times, the climate variability and natural disasters which is associated with climate change has become one of the prime causes of food insecurity.

Figure 1.4 gives a clear indication that agriculture which provides livelihood to large share of population and can also be one of the principal causes of making the rural people vulnerable to the changes.

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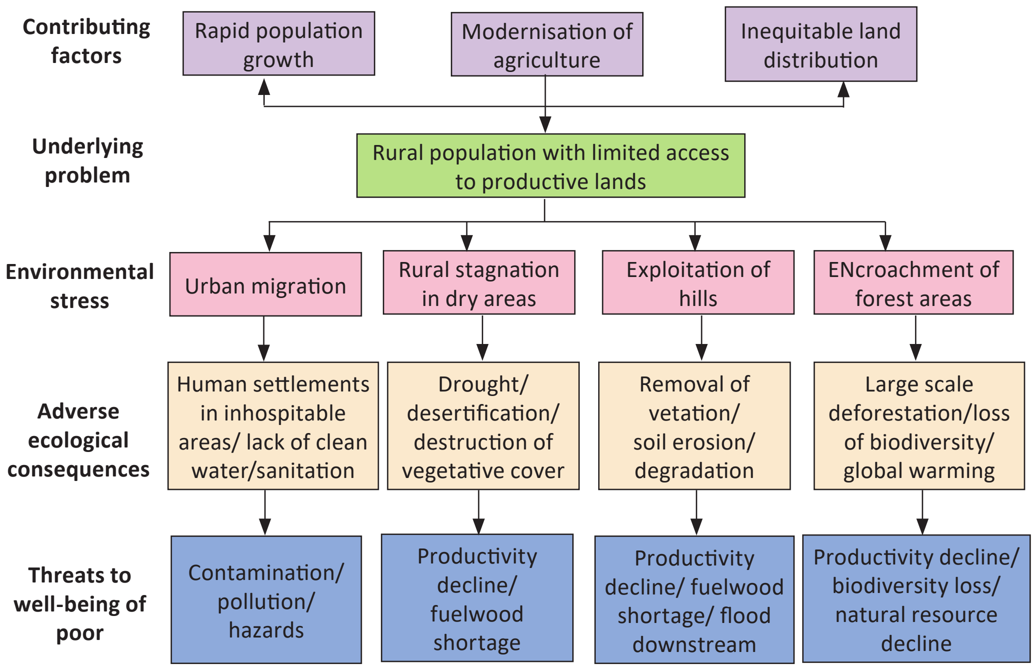

Figure 1.4 Poverty and environment connection

It is important to understand the rural livelihood system which is comprised of various components as illustrated in Figure 1.5.

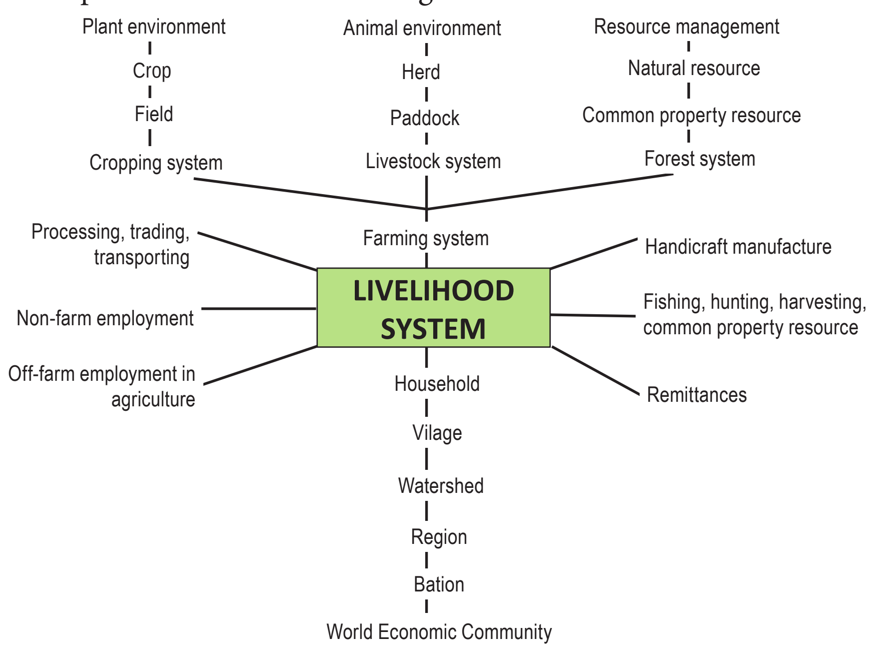

Fig. 1.5 Hierarchies of agro-ecosystem (Source: Adapted from Conway, 1987)

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It displays that farming is only one option for securing basic needs for food and cash in rural areas, and that farming is an integrated system of agriculture, livestock and forestry. Rural livelihood is becoming more and more dependent of other livelihood sources like alternative employment and remittances. The influences of governance, policies and economy at different levels have far reaching influences on rural livelihood and food security.

The role of agriculture system in reducing the impacts of change, poverty alleviation and food security can be seen from the multiple functions it delivers. As shown in Figure 1.6, agriculture provides seven broad functions that make it extremely important. Besides the basic subsistence and food security, for many countries in the world, agriculture forms the primary source of foreign exchange through exports of agricultural products. With the commercialization of agriculture, it provides employment to larger proportion of population and foster development of agri-business. Agriculture has a direct bearing on the biodiversity, as it helps in conservation and utilization of biodiversity in the agricultural system. Agriculture's dependence of natural resources like water, land and nutrients has a direct bearing on management of natural resources.

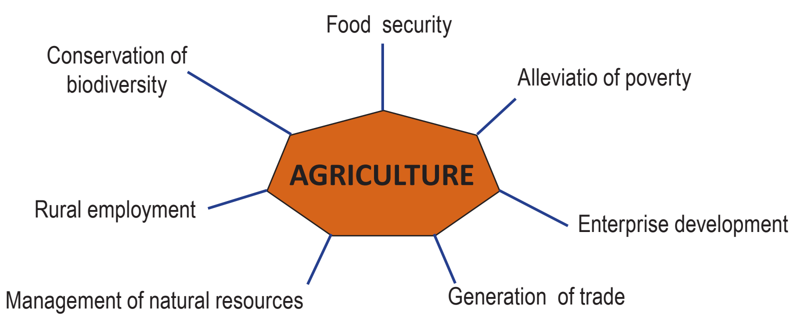

Figure 1.6 Multiple functions of agriculture

These seven functions of agriculture have symbiotic relationship between and among them. For instance, improving agricultural biodiversity through sustainable agricultural practices will help to protect communities from food insecurity associated with both crop loss and decreased yield and alleviate poverty. Similarly, enhanced income and food security will also minimize the exploitation of natural resources including biodiversity. It is apparent from the above illustrations that to ensure vibrant community and food security, agricultural system needs to be well balanced and operate within the principles of sustainable development principles.

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With the understanding of sustainable development, let us analyse GNH and sustainable development and consolidate GNH society's developmental philosophy and practices.

1.7 Gross National Happiness and Sustainable Development

The natural environment and resources have been for centuries the source of culture, wellbeing and livelihood for Bhutanese. While low population density, subsistence use and isolation helped in sustainable use of natural resources, the distinct patterns of change are visible today with increasing economic and development aspirations. Economic development can be generally correlated with decline of natural resources, with a rapid transformation in social values, local institutions and traditional perceptions (FAO, 1999).

"*Throughout the centuries, the Bhutanese have treasured their environment and have looked upon it as the source of life. This traditional reverence for nature has delivered us into twentieth century with our environment still richly intact. We wish to continue living in harmony with nature and pass on this rich heritage to future generations.*"

– His Majesty the Fourth King Jigme Singye Wangchuck.

The above vision is translated into a conscious decision to follow the Middle Path to socioeconomic development by enhancing the wellbeing while maintaining the integrity of the environment and preserving the culture. Coherent to the above wisdom of harmony with nature His Majesty King Jigme Singye Wangchuck articulated the concept of Gross National Happiness (GNH) emphasizing that development has several dimensions other than those associated with the Gross Domestic Product (GDP). It stresses that development needs to be understood as a process which seeks to maximize happiness rather than economic growth alone (Bhutan 2020). GNH places the individual at the centre of development efforts, in recognition of the spiritual and emotional needs of that individual, in addition to the material needs. In the words of Henry van Dyke, "Happiness is inward, and not outward; and so, it does not depend on what we have, but on what we are". GNH asserts that increased consumption of goods and services should not exclusively define development and human aspirations. On the other hand, GDP essentially measures human prosperity and wellbeing in plain economic standards, which are basically gauges of economic activities.

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The main constituents of GNH, from a Bhutanese perspective, are the preservation and promotion of culture, sustainable and equitable development, promotion of good governance and conservation of environment. These elements give a tangible expression to the central tenets of GNH and embody the guiding principles related to the independence, sovereignty and security of the country.

The concept of GNH rejects the notion that there is a direct relationship between wealth and happiness. Instead, it asserts that the key to happiness is in satisfying non-material needs and spiritual growth once the basic material needs are fulfilled. Happiness may be highly subjective, but this subjectiveness is shared by all humans. The concept of GNH also imply that true development takes place when social, economic, spiritual and environmental well-being occur side by side to complement and reinforce each other. These principles affirm coherence of GNH to the theory of sustainable development.

There is considerable common ground between four pillars of GNH - the sustainable and equitable development, culture and heritage, environment and good governance and the principles of sustainable development – economic, social, environmental and institutional. Both concepts emphasize on sustainability and equity issues. Focus on mainstreaming marginalized and disadvantaged groups is another common concern. Cultural plurality and promotion, social freedom and strength of traditional institutions are common features of both the concepts. Both emphasize on nature and biodiversity conservation, and sustainable forest and resource management. People-centred development systems and processes, participation and synergy and collective decision processes are other common characteristics. GNH goes beyond the sustainable development triangle emphasizing the non-material and spiritual needs of human beings.

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1.8 Sustainability concerns in Bhutanese agriculture

Bhutan maintains (approximately) 70.8% of its total land area as forest cover. About half of the country is designated as protected areas that span the length and breadth of the country. Identified as the Bhutan Biological Conservation Complex (B2C2), Bhutan's protected area system includes 9% of the total land area maintained as biological corridors to facilitate the migratory movement of animals and birds between protected areas. With such large area under forest cover, forests play a central role in the farming systems. Its influence in traditional practice and culture is so very strong that over generation forest and natural resources are revered not only as source of livelihood but as a seat for local deities. However, such traditional and customary regulations are weakening, leading to exploitation and over use. In Bhutan, forests are used for varied purposes: for fuel, timber, flag poles, pasture, shifting cultivation, leaf litters, , shingles, medicines, and dyes. The current fuel wood consumption has almost reached the level of annual sustainable harvest. Although Bhutan is forest sufficient at the national level, it is not at the local levels due to over-harvesting and degradation.

Sustainability issues in biodiversity arise from habitat destruction and fragmentation, brown sector (construction, industries) development, over-exploitation, human-wildlife conflicts, replacement of indigenous crops and varieties by exotics, poaching of endangered species, and inadequacy in policy formulation or enforcement. Hydropower plants are based on a run-of-the-river system taking advantage of the natural fall of rivers to generate power. Implementation of proper watershed management plans and inter-ministerial coordination are crucial.

The traditional subsistence oriented mixed farming systems that integrate cropping, livestock rearing, and use of forest products have evolved over a long period of time characterised by diversity and a high degree of self-reliance. The unique mountain agriculture system characterised by diversity and heterogeneity have led to the development of diverse farming systems specific to different localities. Rice based system dominates irrigated terraced land up to an altitude of 2,500 m, while maize and potato based systems are commonly practised on upland slopes. At altitudes between 2500-3000m, buckwheat, wheat, barley are the traditional crops. Rice and maize are the main cereals grown in all zones except the western cool temperate zone where wheat, buckwheat, barley, mustard and potatoes are produced instead. Wetland crops in winter include wheat, mustard and potatoes. Mustard is also

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grown under rainfed dryland conditions. Maize occupies the largest area and is mainly grown in Eastern Bhutan under dryland rain fed conditions. The only new basic food crop is the potato being cultivated in the temperate zone mainly for export purposes

Current production levels account for only 47 and 95% self-sufficiency in rice and maize respectively. The deficit is met through imports. The gap between domestic production and national requirement is widening as consumption rates increase due to increasing preference and changing food habits.

What can be done to address the sustainability concerns of Bhutanese agriculture? It will not be an easy solution but it is also not an impossible task too. The Bhutanese youth need to take up sustainable agriculture entrepreneurship to service the GNH nation.

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Student Activity

Students can be assigned to do different activities to challenge them to use their understanding of 'sustainable development' and 'sustainable agriculture' in day to day life of the Bhutanese – working in the school (teachers, staff and students) and people living in the community around the school. Assign students to practice sustainable agriculture in the school garden. Different students can be assigned to try out different techniques of sustainable gardening in five groups with five different techniques continuing for two years to see results. The second part i.e. integrated pest/biological control is for emergency only.

Activity directions A:

1. Plan to grow vegetables or herbs,
2. Divide students into 5 groups and assign,
   a) Group one: Inter cropping and crop rotation + integrated pest control
   b) Group two: Agro-forestry + integrated pest control
   c) Group three: Green manure + integrated pest/biological control
   d) Group four: Conservation tillage + integrated pest/biological control
   e) Group five: Silvi-pasture + integrated pest/biological control
3. Identify areas and allot them appropriately to practice their sustainable gardening.
4. Prepare ground, add farm yard manure, make nursery beds, following the procedures of growing vegetables and fruits learned earlier.
5. Select seeds /seedlings, saw seeds and plant seedlings, mulch nursery beds and water.
6. Prepare plans to observe, record and care the garden.
7. Monitor, support group work and record observation of work being carried out by different groups.
8. Provide feedback for improvement and
9. Assess students carrying out groups

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Activity B:

1. Write assignment of 450 words based on the following questions:
   a) What do you understand by 'sustainable development'?

   b) How do you think the sustainable practices of 'sustainable agriculture' meets the requirement of sustainable development?

   c) What can you as a farmer do to promote sustainable agriculture?

Or

0. Discuss the sustainability threats of Bhutanese Agriculture and advocate to address the threats through your influencing the political party especially your party member of your constituency.

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2 CHAPTER

Basics of Soil and Water Management

Soil is a natural resource with which the existence of the human beings is closely associated. Soil fertility is the ability of soil to supply essential nutrient elements to plants in adequate amount and in right proportion for their optimum growth. Directly or indirectly, soil is the mother of all food sources. It is one of the key components to determine crop productivity. Water is an abundant natural resource with three-fourth of the earth covered by it. Although in abundance, only 2.7% of water is available as freshwater and 30% of the freshwater is available for human and livestock use, as 70% of the freshwater is in the form of snow and glaciers. For any agricultural activity, soil and water are the most important factors. Therefore, this chapter emphasizes on the concept of soil, soil structure, types of soils which are suitable for different crops. Nutrient management for crops is explained using different sources of plant nutrient such as biological, organic and inorganic sources. Soils and irrigation water management are inter-linked; uptake of many nutrients is possible only when adequate water is available. Different types of irrigation methods such as flooding, drip and sprinkle are described. The concept of crop water requirement is discussed. At the practical level, various soil and water conservation practices are elaborate, including physical, biological and agronomic methods.

2.1 Soil

Soil is defined as loose and crumby part of the outer earth crust. It is a natural dynamic body of mineral and organic constituents, differentiated into horizons, which differs among themselves as well as from the underlying parent material in morphology, physical make-up, chemical composition and biological characteristics. It is made up of small particles of different sizes. Soil is a three-dimensional body, which supports plant establishment and growth, and it is a natural and dynamic medium. For a farmer, soil refers to the cultivated top layer (surface soil) only, up to 15–18 cm of the plough depth. Soils widely vary in their

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characteristics and properties. Soil provides place and anchorage for plant growth and development. It serves as a medium for air and water circulation, acts as a reservoir for water and nutrients and provides space for beneficial microorganisms.

Soil consists of four major components. They are: (i) Mineral matter, (ii) Organic matter, (iii) Water, and (iv) Air. Physically, soil consists of stones, large pebbles, plant debris, sand, silt, clay and humus derived from the decomposition of organic matter. In the organic matter portion of the soil, about half of the organic matter comprises of the dead remains of the soil life in all stages of decomposition. The living part of the organic matter consists of plant roots, bacteria, earthworms, algae, fungi, nematodes and many other living organisms. Soil contains about 50% solid space and 50% pore space. Generally, mineral matter and organic matter occupy the total solid space of the soil by about 45% and 5% respectively. The total pore space of the soil is occupied and shared by air and water on roughly equal basis. The proportion of air and water will vary depending upon the weather and environmental factors.

a) Properties of Soil

i. Soil texture

It is referred to the nature of distribution of particles of various sizes present in the soil. It is the proportion of coarse, medium and fine particles, which are termed as sand, silt and clay respectively. Hence, it can be defined as the proportion of sand, silt and clay particles in soil. The mineral soil particles are classified according to their sizes.

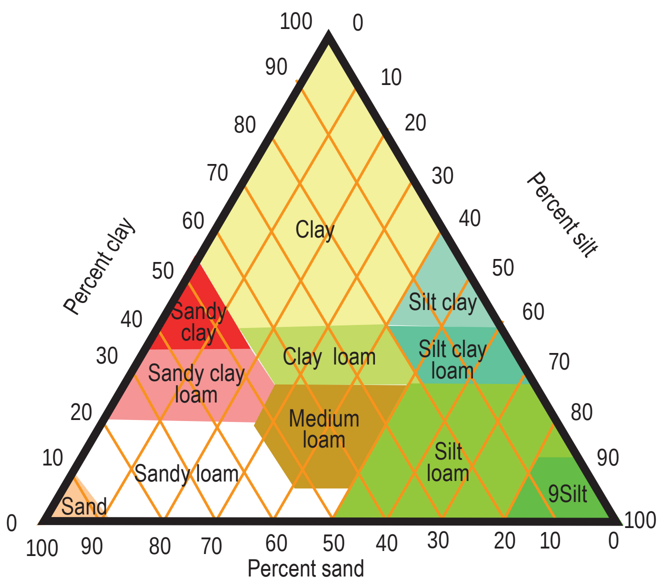

Figure 2.1 Soil texture triangle

Based on the proportion of sand, silt and clay particles, classification is made and standardized into twelve classes as sand, silt, loam sandy, clay silty, clay, clay-loam, loamy sand, sandy loam, silty loam, sandy clay loam and silty clay loam (Figure 2.1).

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ii. Soil Structure

It is defined as the shape and arrangement of soil particles with respect to each other in a soil mass or block. The soil aggregates are not solids but possess a porous or spongy character. Most soils have a mixture of single grain structure or aggregate structure. The number of primary particles (sand, silt and clay) is combined together by the binding effect of organic and inorganic soil colloids. The binding or cementing materials are iron or aluminium hydroxide and decomposing organic matter. The names of soil structures based on their shapes are: platy, prismatic, columnar, blocky, cloddy, granular, crumb, single grain, and massive.

iii. Pore Space

It is a porous material consisting of particles of different sizes touching each other but leaving spaces in between. These spaces, which are not occupied by the soil particles, are known as pore space. It constitutes about 40 to 60% of soil in volume basis. It provides space for water and air circulation and it plays a vital role in irrigation management. There are two types of pore spaces viz., micro pore and macro pore. There is no sharp line of demarcation between the macro and micro pores. The macro pores allow the ready movement of air and permeability of water freely. In contrast, the micro pore air movement is greatly difficult and water movement is restricted to slow capillary movement. The volume of pore spaces varies according to the texture, structure and organic matter content. Soils having big particles contain more pore space than those having small particles. The size of individual pores is highly important for the aeration and infiltration or movement of water in soil.

b) Types of soil

i. Alluvial soils

The alluvial soils are the most important soils from the agricultural point of view. These soils are derived from the deposition laid by rivers. The products of weathering of rocks are brought down and materials transported by water, ice, gravity and wind. In general alluvial soils are low in Nitrogen(N). Examples of alluvial soils are found in Indo-gangetic plains of Uttar Pradesh, West Bengal, Bihar and Brahmaputra valley of Assam. Alluvial soils are fertile and suitable for most of the agricultural crops like lowland rice, pulses, cotton, banana etc.

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ii. Black soils

Black soils are dark grey in colour, which is due to the presence of clay-humus complex. Black soils are mainly formed from basalt trap parent material and occur mostly in monsoon type of climate. Alternate dry and wet periods and calcification favours black soil formation. Black soils are highly clayey (35-60% clay), have high content of exchangeable calcium and are rich in organic matter, N and available Phosphorus (P). Such soils are suitable for crops like cotton, sugarcane, groundnut, millets, maize and pulses.

iii. Red soils

The red colour of soils is due to the coating of ferric oxides on soil particles. Red soils are formed from granites, gneiss and other metamorphic rocks either in-situ or from decomposed rock materials. They mostly occur in semi-arid tropics. They are light textured, friable, with low lime and soluble salts. Such soils are well drained with moderate permeability but are prone to erosion. Soils are suitable for maize, wheat, millets, groundnut and pigeon pea.

iv. Acid soils

Acid soils have low pH with high amounts of exchangeable H+ and A13+. They occur in regions with high rainfall in areas with sub temperate to temperate climate. They have some amount of partly decomposed organic matter. Normally, acid soils are not good for agricultural purposes. Liming and judicious use of fertilizers are required for crop management.

2.2 Nutrient Management

Growth is the development of a plant as a whole or of a specific organ. For growth, plants require nutrients. An essential mineral element is one that is required for normal plant growth and reproduction. With the exception of carbon (C) and oxygen (O), which are supplied from the atmosphere, the essential elements are obtained from the soil. 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. A total of 18 elements are considered essential by many scientists. They are carbon, hydrogen, oxygen, nitrogen phosphorus, potassium, calcium, magnesium, sulphur, iron, manganese, zinc, copper, molybdenum, boron, chlorine, cobalt and nickel. Essential elements can be grouped into four categories

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based on their origin or the relative amount a plant needs in order to develop properly.

Non-mineral essential elements (C, H, O) are derived from the air and water. Primary essential elements (N, P, K) are most often applied in the form of commercial fertilizers or in manures. Secondary elements (Ca, Mg, S) are normally applied as soil amendments or are components of fertilizers that carry primary nutrients. Non-mineral, primary and secondary elements are also referred to as macronutrients since they are required in relatively large amounts by plants. Micronutrients (Fe, Mn, B, Zn, Cu, Mo, Cl, Co, Ni) are required in very small, or trace, amounts by plants. Although micronutrients are required by plants in very small quantities, they are essential for plant growth.

a) Sources of plant nutrients

i. Organic manures

Organic manures include plant and animal by-products such as farmyard manure, compost, oil cakes, bone meal etc. These manures are relatively slow releasing but they supply N for a longer period. Organic manures supply plant nutrients including micronutrients. Organic manures improve physical properties of the soil, such as water holding capacity and infiltration capacity. Organic manures also supply energy (food) for microbes and increase availability of nutrients and improve soil fertility. Farmyard manure (FYM) 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. The bedding material consists of leaf litter, fern, crop residues and so on which absorb urine passed by animals. 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 insitu and incorporated into the soil. Green leaf manuring is incorporation of green matter into the soil transported from elsewhere. In our situation, *Sesbaniaaculeata* (dhaincha)is a very effective green manure especially for rice cultivation. Dhaincha can be grown for about 45 days and incorporated into the soil before transplanting rice. Daincha contains 3.2% N and 34% Ca on dry weight basis which helps to replace plant nutrients in soil.

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ii. Bio-fertilizers

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 which are generally known as legumes. 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 azollae* 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.

iii. Inorganic or chemical fertilizers

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 classified as single or compound fertilizers depending on the number of nutrients they contain. Single fertilizers contain only one of the primary nutrients, either N, P or K. Examples are Urea (contains 46% N), Single Super Phosphate (SSP with 16% P) and Muriate of Potash (MoP with 60% K). Compound fertilizers contain all the three primary 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. Micro-nutrients are added to the soil through some commercial fertilizers usually in liquid formulation.

b) Integrated Nutrient Management (INM) System

INM System is judicious combination of inorganic, organic and bio-fertilizers

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which replenishes soil nutrients removed by crops. The concept of INM 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 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

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. However, chemical fertilizers are easily soluble in soil. That is, why we need to integrate fertilization method so as to reduce loss of nutrients to environment and to maintain soil health.

2.3 Irrigation and Water Management

Plants and any form of living organisms cannot live without water, since water is the most important constituent of about 80-90% of most plant cell. Water is essential not only to meet agricultural needs but also for industrial purposes, power generation, livestock maintenance, rural and domestic needs. But the resource is limited and cannot be created as we require. So we need to use water judiciously. Rainfall is the ultimate source of all kind of water. Based on its sources of availability, water can be classified as surface water and subsurface water. Surface water (including rainfall and dew) is all water available from river, tank, pond, and lake. Besides, snowfall also contributes some quantity of water in heavy snowfall areas. Sub-surface water includes water from underground sources like well.

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a) Irrigation

It is the artificial application of water for supplementing the moisture in the soil that is deficient and does not meet the full requirements of growing crops. Irrigation is essentially a practice of supplementing the natural precipitation for increasing production of agricultural and horticultural crops.

i. Effective irrigation

It is the controlled and uniform application of water to cropland in required amount at the required time to produce optimum yields. The cost of irrigation must be kept minimum and irrigation should be done without any wastage of water, which may cause adverse effect on the soil in the form of water logging problems. Almost all major crops are grown under irrigated condition.

ii. Irrigation management

Management of water based on the soil and crop environment to obtain better yield by efficient use of water without any damage to the environment. Management of water, soil, plants, irrigation structure, irrigation reservoirs, environment, social set up and inter- linked relationship are studied in irrigation management.

b) Crop water requirement

It is defined as the quantity of water required by a crop or a diversified pattern of crops in a given period of time for its normal growth under field conditions.

Water requirement is water required by the plants for its survival, growth, development and to produce economic yield. This requirement is applied either naturally by precipitation or artificially by irrigation. Hence the crop water requirement includes all losses like transpiration loss through leaves (T), evaporation loss through soil surface in cropped area (E) and amount of water used by plants (WP) for its metabolic activities. These three components cannot be separated. Hence, the evapo-transpiration (ET) loss is taken as crop water use or crop water consumptive use. Other application losses are conveyance loss, percolation loss, runoff loss (WL) and water required for special purpose (WSP) like puddling, ploughing and land preparation. Hence, the water requirement (WR) is symbolically represented as $WR = T + E + WP + WL + WSP$.

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c) Methods of Irrigation

It is the application of irrigation water to cropped field by different types of layouts is called irrigation methods. The irrigation methods are broadly classified as a) Surface method or gravity method of irrigation and b) Pressurized or micro irrigation.

i. Surface or gravity irrigation

It is the most common method of irrigation practiced all over the world. In this method, water is applied directly to the surface by providing some checks to the water flow. There are different types of surface irrigation. Common methods include the following.

ii. Basin method of irrigation

It is used in soil submergence method of irrigation in low land rice, bunded rainfed rice and forage grasses, where water is stagnated to the required depth by providing bunds on all the sides to sufficient width and height. The field has to be levelled thoroughly for uniform depth of water. Provision of separate irrigation and drainage channels is more efficient than field-to-field irrigation.

iii. Ring basin

This method is mostly adopted for wide spaced orchard crops. The rings are circular basins formed around the individual trees. The rings between trees are interlinked with main lead channel by sub-channels to get water to the individual rings. As water is allowed in rings only, wastage of water spreading the whole interspaces of trees as in the flooding irrigation method is reduced. This method ensures sufficient moisture in the root zone and saves a lot of irrigation water.

iv. Furrow method

It is the common method adopted for crops planted in rows like maize, sugarcane, potato, onion and vegetable crops. In this method, small evenly spaced shallow furrows or channels are formed in the beds. Another method of furrow irrigation is forming alternate ridges and furrows to regulate water. The water is turned at the high end and conveyed through smaller channels. Water applied in furrows infiltrate slowly into the soil and spread laterally to wet the area between furrows.

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v. Pressurized irrigation method

It includes both sprinkler and drip irrigation methods where water is applied through a network of pipelines by means of pressure devices.

vi. Sprinkler irrigation,

Water is sprayed to the air and allowed to fall on the ground surface more or less resembling rainfall. The sprinkling of water or spray of water is made by pumping water under pressure through a network of pipelines and allowing to eject out by means of small orifices or holes.

vii. Drip or Trickle Irrigation

Water is applied through a network of pipelines and allowed to fall drop by drop at crop root zone by a special device called emitters or drippers. These drippers control the quantity of water to be dropped out. In this system, the main principle is to apply the water at crop root zone based on the daily demand of the crop without any stress. Hence, the root zone is always maintained at field capacity level.

2.4 Soil and Water Conservation Practices

a) Nutrient management

In nutrient management, a proper balance between soil water and soil air is critical since both water and air are required by most processes that release nutrients into the soil. Soil water is particularly important in nutrient management. In addition to sustaining all life on Earth, soil water provides a pool of dissolved nutrients that are readily available for plant uptake. Therefore, it is important to maintain proper levels of soil moisture. Soil water is important for three special reasons:

- The presence of water is essential for the all life on earth, including the lives of plants and organisms in the soil.
- Water is a necessary for the weathering of soil. Areas with high rainfall typically have highly weathered soils. Since soils vary in their degree of weathering, it is expected that soils have been affected by different amounts of water.
- Soil water is the medium from which all plant nutrients are assimilated by plants. Soil water, sometimes referred to as the soil solution, contains

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dissolved organic and inorganic substances and transports dissolved nutrients, such as nitrogen, phosphorus, potassium, and calcium, to the plant roots for absorption.

b) Soil management

Soil management concerns all operations, practices, and treatments used to protect soil and enhance its performance. Soil water management can be defined as active involvement in controlling water content of the soil at an optimal state for all given purposes, including environmental needs. An optimal state is often a compromise between competing uses and needs to account for long term sustainability of the soil water system. Soil and water conservation measures are predominantly applied for the following reasons:

- control runoff and thus prevent loss of soil by soil erosion
- maintain or improve soil fertility
- conserve water or drain excess water
- reduce soil compaction

2.5 Management of Soil and Water Conservation

A variety of soil and water conservation measures are well known. These technologies can be differentiated either by their main purpose or by type. These fulfill several functions simultaneously and are classified by type as:

- physical measures (also termed mechanical or technical measures);
- biological measures (also termed vegetative measures);
- agronomic measures (sometimes called best management practices)

a) Physical soil and water conservation measures

Physical measures are structures built for soil and water conservation. Such measures aim to increase the time of concentration of runoff, thereby allowing more of it to infiltrate into the soil, divide a long slope into several short ones and thereby reducing amount and velocity of surface runoff, and protect against damage due to excessive runoff. Examples of physical measures are given in the box.

In high rainfall areas a common objective is to lead unavoidable surface run-off

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safely off the land using drains and ditches. In semi-arid regions the objective is more likely to be to slow down the run-off and to encourage infiltration or deposition of silt, without diverting the run-off. This requires simple low-cost structures such as stone terraces, check dams, contour terraces etc. There are several well-tested methods for laying out lines either on a level contour or on a predetermined gradient. The A-frame has been widely and successfully used in many countries. Any system of lines, banks, or bunds on the contour can result in a reduction of run-off and soil loss of up to 50 percent. Major physical or mechanical measures to control soil and water conservation are:

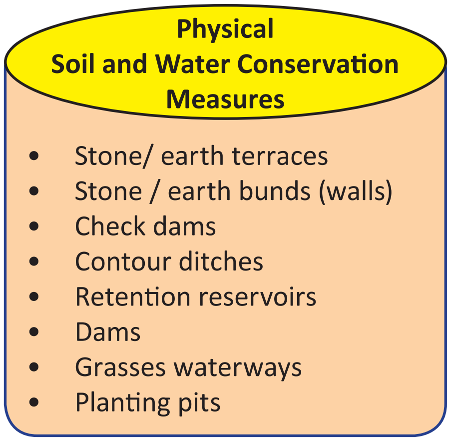

Figure 2.2 Physical soil and water conservation measures

i. Contour bunding

In this practice small bunds are constructed at regular intervals across the slope of the land. This practice is very useful in arid and semi-arid areas with high infiltration and permeability rates.

ii. Subsoiling

It is basically a primary tillage operation, which consists of break opening the soil structure up to a depth of 30 to 60 cm. This practice facilitates greater infiltration rates and moisture holding capacity of the soil.

iii. Basin listing

In this method of soil and water conservation basins are constructed using a special implement called basin-lister. These basins are constructed across the slope. Basin listing provides maximum time to rain water for infiltration into the soil.

iv. Bench terracing

In this practice a series of platforms or terraces are constructed having suitable vertical drops. The range of vertical drop may vary from 2 to 6 feet depending upon prevailing conditions. The capital cost of bench- terracing is more than that of bunding initially but in longer run it proves economical.

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b) Biological soil and water conservation measures

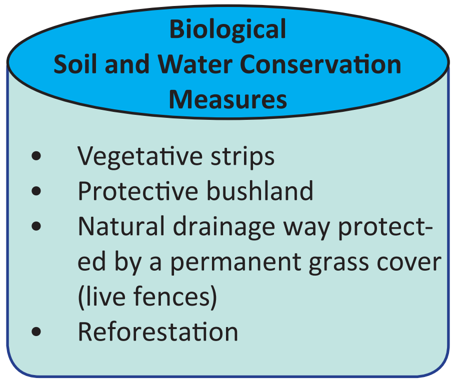

Figure 2.3 Biological soil and water conservation measures

Biological measure for soil and water conservation work by their protective impact on the vegetative cover. A dense vegetative cover prevents erosion, reduces the velocity of surface runoff, facilitates accumulation of soil particles, and increases surface roughness which reduces runoff and increases infiltration. The roots and organic matter stabilize the soil aggregates and increase infiltration. These effects entail a low soil erosion rate compared with an uncovered soil which shows in general a high soil erosion rate. Other positive impacts have been observed, such as improved soil moisture condition and protection against wind erosion. Thus, biological measures are an effective method of soil and water conservation, especially since they are low in cost. There are several types of biological measures.

i. Conservation Tillage

This umbrella term can include reduced tillage, minimum tillage, no-tillage, direct drill or sowing, stubble-mulch farming, strip tillage etc. In countries with advanced soil conservation programs, particularly the USA and Australia, the concept of conservation tillage is the main recommendation for cropland, and it is also being taken up quickly in other areas, for example southern Brazil. The application is mainly in mechanized large scale production system with good rainfall, or for the control of wind erosion where there is large-scale mechanized cereal production. It is less applicable to low input level crop production, or subsistence agriculture. Conservation tillage has the advantage of reducing the need for terraces or other permanent structures. CT reduces the cost of soil preparation and is recommended to reduce emission of carbon dioxide from soil. This is because the soil disturbance by tillage is minimal due to reduced soil microbial activity. However there are several disadvantages which hinder the application of conservation tillage such as: dense plant cover may be incompatible with using low plant populations to suit low moisture availability; crop residues may be of value as feed for livestock; and planting through surface mulches is not easy for ox-drawn planters or manual planting.

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ii. Planting of trees and afforestation

Forests conserve soil and water quite effectively. They not only obstruct the flow of water, but also the falling leaves provide organic matter which increases the water holding capacity of the soil. If tree planting is done in the planned manner in open areas, it will serve as good wind break and if done along the banks of streams and rivers, it will protect the river bank. Farm forestry is an important aspect in soil and water conservation.

iii. Planting of grasses for stabilizing bund

Grasses prevent soil erosion and improve soil structure. The entire soil mass is penetrated by countless roots which are fibrous in nature. Grasses should be grown on bunds which are not suitable for cultivation, both for checking erosion and providing fodder for cattle. Several grasses as well as legumes give maximum root growth and canopy coverage, and stabilize bunds effectively. Legumes do not have many roots but produce better canopy within a short period, while grasses are under the process of establishment. Planting of legumes mixed with grasses is, therefore, in prevents soil erosion in initial stages.

c) Agronomic soil and water conservation measures

Agronomic conservation measures function by reducing the impact of raindrops through interception and thus reducing soil erosion and increasing infiltration rates and thereby reducing surface runoff and soil erosion. Some possible agronomic measures are shown in the box. These measures can be applied together with physical or biological soil and water conservation measures. In some systems they may be more effective than structural measures. Furthermore, it is the cheapest way of soil and water conservation. However, agronomic measures are often more difficult to implement compared with structural ones as they require a change in familiar practices. Following are widely used agronomic measures for soil and water conservation.

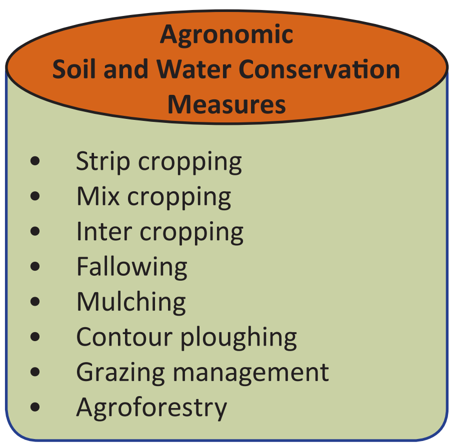

Figure 2.4 Agronomic soil and water conservation measures

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i. Strip cropping

It consists of growing erosion permitting crops and erosion resisting crops in alternate strips. The erosion permitting crops are cotton, jawar, bajara, etc. which allow the runoff water to flow freely within the rows. The erosions resisting crops are mostly legumes like groundnut, beans, soybean which spread and cover the soil and do not allow runoff water to carry much soil with it. In selecting a suitable legume crop it should be seen that the maximum canopy and root development of the crop coincide with the period of high intensity of rainfall.

ii. Mulching

A mulch is a natural or artificially applied layer of plant residues or other material on the surface of the soil with the object of moisture conservation, temperature control, prevention of surface compaction or crust formation, reduction of runoff and erosion, improvement in soil structure and weed control. Artificial mulches of different kinds such as jowar or bajara stubbles, paddy straw or husk, sawdust etc. increase absorption of water and minimize evaporation. They also control runoff and soil losses.

iii. Crop rotation

Rotation of crops means growing a set of crops in a regular succession over the same field within a specified period of time. Continuous growing of jowar or bajra crop causes more erosion, but if followed by a legume crop which covers the soil causes less erosion. Rotation also helps in removal of plant nutrients in a uniform way from future depth of soil and in maintaining the fertility of the soil.

iv. Mixed cropping

It is the practice of two or more crops grown in the same field at a particular time. Some of the benefits of mixed cropping are a better and continuous cover of the land, good protection against the beating action of the rain. The different crops grown in mixed cropping have their roots at different depths holding the soil more firmly thus preventing soil erosion.

v. Contour cultivation

Tillage operations such as ploughing, harrowing, sowing and inter-culture should be done across the slope of land. This will help in creating obstructions to the

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flow of water at every furrow, which acts like a small bund and results in uniform distribution of water. This helps more infiltration of water, less run off and erosion, and gives higher crop yield. Any cultivation done along the slope will accelerate gully formation, more run off and erosion and consequently permanent damage to land.

Student Activity

Design activities for the students though which they can apply their knowledge from the text materials to improve soil and water conservation in their gardening practices. Firstly to study the types of soil that they have, prepare soil appropriately for different crops, add plant nutrients required by different crops, and protect and conserve soil and water, applying physical, biological and agronomic methods for growing crops.

Group work 1: – to identify type of soil, prepare soil and nutrient for growing potatoes using physical soil and water conservation method.

Group work 2: -to identify type of soil, prepare soil and nutrient to grow chili using biological method for soil and water conservation.

Group work 3: - to identify type of soil, prepare soil and nutrient to grow radish using agronomic soil and water conservation method

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3 Chapter

Growing Food Crops

Early humans depended on hunting, fishing and food gathering. However, as people started cultivation and domestication of wild plants and animals, agriculture came into being. Cultivation of crops such as wheat, rice, barley and millets encouraged settlement of communities, which then grew into a town or city. Today, agriculture is highly commercialized. Farmers grow crops and raise animals on a large or commercial scale to make money and maximize profit. This became possible as modern agriculture produced new crop varieties, inorganic fertilizers, pesticides, irrigation, and farm machines.

This chapter begins with the classification of crops based on different criteria such as taxonomical, life cycle, utilization and cultivation range. Concepts such as cropping systems, cropping patterns and seasonal calendars are elaborated in the chapter. The major food crops of Bhutan are highlighted and the package of practice for rice, maize, wheat and oilcrop are provided in the book. It is hoped that the knowledge and skills gained from this chapter will help our students to practise agriculture more efficiently.

Historically, early people depended on hunting, fishing and food gathering. However, as various groups of people undertook deliberate cultivation of wild plants and domestication of wild animals, from which agriculture came into being. Cultivation of crops, notably grains such as wheat, rice, barley and millets, encouraged settlement of farm communities, some of which grew into a town or city in various parts of the world. Excavations, legends and scientific studies show that agriculture is about 10,000 years old. Men concentrated on hunting and gathering during that time, while women were the pioneers for cultivating useful plants from the wild flora. They dug out edible roots and rhizomes and buried small ones for subsequent harvests. People started to work with the crudest of tools, cut down a part of the forest, burnt the underneath growth and started new garden sites. After few years, when these plots lost their fertility or became

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heavily infested with weeds or diseases, they shifted to a new site. This is how shifting agriculture started. It is practiced even to this day. In Bhutan, we call it *Tseri* cultivation. In parts of India, it is called *Jhum* cultivation. Gradually, farming became permanent or sedentary (settled in one place, as opposed to shifting from one plot to another) and people started practicing subsistence farming, where agriculture is considered as a way of life based on the principle of "grow and eat" instead of growing crops for selling.

Today, agriculture is highly commercialized. Farmers grow crops and raise animals on a large or commercial scale to make money and maximize profit. This became possible as scientific or modern agriculture produced new crop varieties, inorganic fertilizers, pesticides, irrigation, introduction of exotic crops and animals and use of farm implements.

During the 19th century, research and development (R&D) in fundamental and basic sciences were brought under applied aspects of agriculture. Laboratories, farms and research stations, and institutes for teaching and extension were developed. New media and audio-visual aids were developed to disseminate new research findings and information to the farmers. These efforts are continued in agricultural development.

There are different branches of agriculture. The main ones include *crop production* which deals with the production of various crops, including food crops, fodder crops, fibre crops, sugar and oil seeds. It includes disciplines such as agronomy, soil science, entomology, pathology and microbiology. The aim is to have better food production and control of diseases. *Horticulture* is a branch of agriculture that deals with the production of flowers, fruits, vegetables, ornamental plants, spices, condiments and beverages. *Agricultural Engineering* is an important component for crop production and horticulture particularly to provide tools and implements. It aims to produce improved tools, implements and machinery to facilitate proper animal husbandry and crop production. *Animal Husbandry* is the science of raising animals, birds and fish for various products such as meat, milk and other dairy products, eggs and fish for human consumption. This chapter focuses on crop production and procedures related science of improving production of some cereals.

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3.1 Crop Classification

From the production point of view, crop is a plant cultivated for economic purpose. Crop classification can be done based on several factors such as the range of cultivation, place of origin, botanical classification, commercial classification, economic classification, life cycle, water availability and according to important uses.

Table 3.1 Classification of crops

Criteria	Types
Place of origin	*Native* -Crops grown within the geographical limits of their origin, for e.g., rice, barely, mustard, wheat, millets and buckwheat are native to Bhutan. *Exotic or Introduced* -Crops introduced from other countries, such as coffee and hazelnut are exotic to Bhutan.
Botanical/ Taxonomical classification	*Graminae:* rice, wheat, maize, *Cruciferae:* mustard, *Solanaceae:* Potato, tomato, chillies, brinjal, *Legumes*: Pea, soybean, beans, *Liliaceae:* Onion, garlic, *Zingiberaceae:* Ginger, turmeric,
Life cycle of crops	*Annual crops* -Crop plants that complete life cycle within a season or year. They produce seed and die within the season. e.g., wheat, rice, maize, mustard. *Biennial crops* -Plants that have life span of two consecutive seasons or years. First year, these plants have purely vegetative growth and during the second year, they produce flower and seed. e.g., sugar beet and beet root.
	Perennial crops -They live for three or more years. They may be seed bearing or non-seed bearing. e.g., sugarcane, napier grass.
Range of cultivation	*Garden crop* -Grown on a small scale in gardens. e.g., onion, brinjal. *Plantation crop* -Grown on a large scale and perennial in nature. e.g., tea, coffee, rubber.

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	Field crop -Grown on a vast scale under field condition. They are mostly seasonal such as rice, wheat, maize.
Commercial classification	*Food crops*: Rice, wheat, maize, millets *Forage crops*: All fodders, oats, sorghum, maize, napier grass, stylo, lucerne. *Industrial/Commercial crops*: Cotton, sugarcane, sugar beet, tobacco, jute. *Spices:* Turmeric, garlic, cumin.
Economic or agronomic classification	*Cereals* -They are cultivated grasses grown for their edible starchy grains. Larger grains used as staple food are cereals– rice, wheat, maize, barley, oats. *Oil seeds* - Crops that yield seeds rich in fatty acids, are used to extract vegetable oils. e.g. groundnut, sunflower, castor, mustard. *Pulses* -Seeds of leguminous plants used as food. They produce dal, rich in protein. e.g. black gram, chickpea, soybean, kidney bean. *Fibre crops* -Plants grown for their fibre yield. Seed fibre– cotton, stem fibre-jute *Spices and condiments* -Crop plants or their products used to season, flavour, taste. e.g., ginger, garlic, fenugreek, cumin, turmeric, onion, coriander *Beverages* -Products of crops used for preparation of mild, agreeable and stimulating drinks.e.g.,tea, coffee, cocoa.
According to source of water	*Irrigated crops* -The crop cultivation primarily depends upon the irrigation water for a part or entire growth period of the crop. Example: rice.
	Rainfed crops -The crop cultivation entirely depends upon the rainfall received. Crop varieties depend upon the season and the rainfall pattern. Example: wheat, maize. *Upland crops* – crop cultivation takes place on dryland (not terraced) and depends entirely on rainfall. Example: upland rice.

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According to important uses	*Catch crops* are those crops cultivated to catch the forthcoming season. It replaces the main crop that may have failed. Generally, they are of very short duration, quick growing, harvestable or usable at any time of their field duration and adaptable to the season, soil and management practices. e.g., green gram, black gram, cowpea, onion, coriander. *Restorative crops* are those crops which provide a good yield along with enrichment or restoration of soil fertility. They fix atmospheric nitrogen in root nodules, shed their leaves during ripening and thus restore soil conditions. e.g., legumes. *Cover crops* are those crop plants which are able to protect the soil surface from erosion (wind, water or both) through their ground covering foliage and or root system. e.g., groundnut, black gram, sweet potato. *Alley crops* are those arable crops, which are grown in 'alleys' formed by trees or shrubs, established mainly to hasten soil fertility restoration, enhance soil productivity and reduce soil erosion. They are generally of non-trailing with shade tolerance capacity. For example, growing pulses in between the rows of Casuarinas trees.

3.2 Cropping Systems

All crops have specific planting season and requirement where they grow and complete their life cycle. To take benefit of the seasonal variations of each crop and to ensure continuous supply of food, different crops can be cultivated in different combinations. For instance, they can be relay cropped, intercropped or sequentially cropped (see definitions below). All these different combinations of crops are part of the cropping systems shown in Figure 3.1 below is an example of cropping pattern 12 month cycle mapped against rainfall.

a) Cropping system

It means the pattern of crops taken up for a given piece of land, or sequence in which the crops are cultivated on a piece of land over a fixed period and their interaction with farm resources and other farm enterprises. Examples: wetland

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cropping system in which rice is grown with other crops like wheat and vegetables; dryland cropping system in which potato maize is grown with other crops.

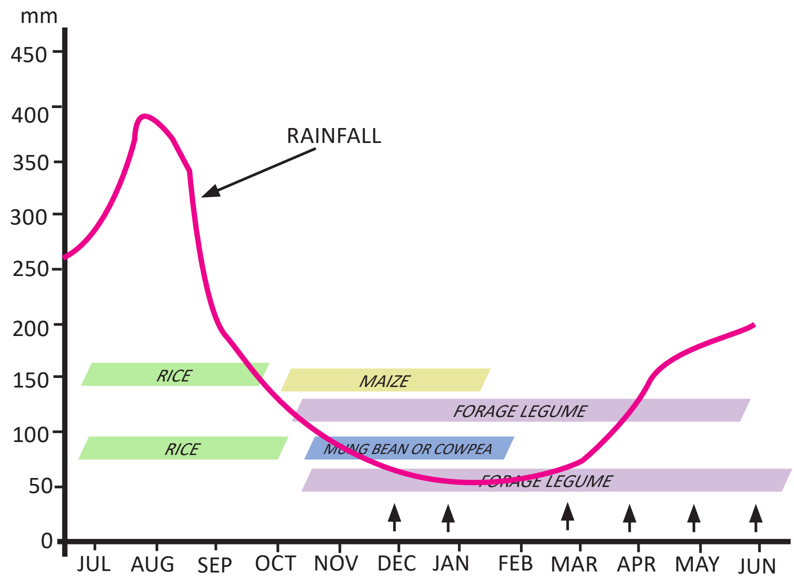

Figure 3.1 cropping pattern of 12 months cycle of rainfall

b) Cropping Pattern

It means the proportion of area under various crops at a point of time in a unit area. Cropping pattern indicates the yearly sequence and spatial arrangement of crops and fallow on a given area of land. Example: rice-wheat, rice mustard and rice-vegetables are common cropping pattern in Wangdue-Punakha valley. Even rice-fallow is a cropping pattern.

c) Crop rotation

It may be defined as a process of growing different crops in succession on a piece of land in a specific period of time with an object to get maximum profit from minimum investment without impairing soil fertility. It is the repetitive cultivation of an orderly succession of different crops and fallow on the same land. One cycle may take several years (one year or more than one year) to complete e.g., rice-rice-pulse (one year), sugarcane–ratoon sugarcane–rice (2 or 3 years), banana–ratoon banana–rice (3 years). Some of the principles of crop rotation are:

- The crops with tap roots (deep rooted) should be followed by those, which have fibrous (shallow) root system. This helps in proper and uniform use of nutrients from the soil.

- Leguminous crops should be grown before non-leguminous crops because legumes fix atmospheric N into soil and add more organic matter to the soil.
- More exhaustive crops like potato and maize needing more fertilizers should be followed by less exhaustive crops like legumes.
- The crop of the same family should not be grown in succession because they act as alternate hosts for insect pests and diseases
- An ideal crop rotation is one which provides maximum employment to the farm family, labour and permits efficient use of machines and equipment and simultaneously maintains soil productivity.

There are many advantages of crop rotation. It helps in maintaining of soil fertility, organic matter content and recycling of plant nutrients. All crops do not require plant nutrients in the same proportion. If different crops are grown in rotation, the fertility of land is utilized more evenly and effectively. Restorative crops like heavy foliage crops and green manure crops included in rotation increase nitrogen and organic matter content of the soil. It avoids accumulation of toxins and maintains physical properties of soil. It also controls certain soil borne pests and diseases. Cropping can be categorized in the following ways.

d) Mono-cropping

It refers to growing of the same crop repeatedly on the same land every season. This is in contrast to crop rotation wherein different crops are grown according to season. Mono-cropping or monoculture is not favoured as this practice encourages pest and disease build-up.

e) Multiple cropping

It is growing of two or more crops on the same field in one year. It can be further classified as:

i. Sequential cropping

Growing two or more crops in sequence (in succession) on the same field in a year. The succeeding crop is planted after the proceeding crop has been harvested. e.g. Rice-rice, rice-wheat.

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ii. Relay cropping

It refers to planting of the succeeding crop before harvesting the preceding crop. Seeding of the second crop is usually done on the standing first crop. Thus the field is never left fallow or there is no gap at all between two successive crops. e.g, Rice–lentil.

iii. Ratoon cropping or ratooning

It refers to raising a crop with regrowth coming out of roots or stalks after harvest of the crop although not necessarily for grain. e.g., Sugarcane, Sorghum.

f) Intercropping

It is growing of two or more crops simultaneously on the same field. As opposed to intercropping, *sole cropping*, same as *mono-cropping* is growing one crop alone in pure stand at normal planting density. Maize grown together with soybean in eastern parts of Bhutan is a good example of intercropping.

g) Multi-storied cropping

It is growing crops of different heights in the same field at the same time. It is practiced in orchards and plantation crops for maximum use of solar energy even under normal planting density. e.g. coconut/arecanut, banana and turmeric or pineapple.

Figure 3.2 Multi-storied cropping

3.3 Food Crops of Bhutan

Bhutan has considerable diversity of agricultural crops, varieties and agro-ecosystems. Such a diversity is partly a result of altitudinal and temperature variations from north to south of the country. The major food cereals of Bhutan are rice and maize, based on the area grown, production and per capita consumption.

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Grown to a lesser extent, wheat, buckwheat, millets and barley are other crops that fill up the food basket of the Bhutanese people. Among oilcrops, rapeseed mustard is the most commonly grown crop in the country. There are many grain legumes such as common beans, soybean, kidney beans and urd and mung beans that are cultivated and consumed as food. Bhutan is also rich in the diversity of fruits and vegetables. Genetic variation is the key to agricultural development and food security and the value of conserving agro-biodiversity lies in its potential to supply raw materials for future development needs. Below is a brief description of the major agricultural crops in Bhutan.

a) Rice

Rice is the staple food for the largest number of people on earth. It is eaten by nearly half the world's population. Rice farming is about 10,000 years old, and the single largest use of land for producing food in the world. There are about 25 species of rice, of which two species called *Oryzasativa* and *Oryzaglaberrima* are important for human consumption. There are thousands of rice varieties. The International Rice Research Institute (IRRI) based in the Philippines has a collection of over 100,000 varieties in their gene bank. Rice is grown in many different ecosystems such as irrigated system (water provided through canals or wells, grown in bunded or terraced fields), rainfed system (water from rainfall only, grown in bunded fields or terraces) or upland system (water from rainfall only, grown in dry lands without terraces).

Rice is an excellent source of energy for our body. It is easily digested and so the energy it supplies becomes quickly available to us.

Rice contains mostly carbohydrates (85%), protein (8%) and fats (7%). Carbohydrate powers the body and helps to keep us moving. It is stored in our muscles and liver and released when we need it.

In Bhutan, rice is grown from tropical lowlands (200 m) in the south (Sarpang, Samtse) up to elevations as high as 2700 m in the north (Bumthang, Paro). Because of Bhutan's rugged topography, rice fields are generally terraced. Rice environments are broadly grouped into three altitude zones which also reflect temperature regimes. The high altitude zone, also referred to as warm temperate zone, covers rice areas from 1,600 m and above. Low temperature at early vegetative stage of the rice crop characterizes this environment. Around 20% of the rice areas fall under this zone. The mid altitude zone which accounts for 45% of the rice areas

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has an elevation of 700 m to 1600 m. Its sub-ecologies are the dry and humid sub-tropical environments, the latter receiving more rainfall than the former. The remaining 35% is the low altitude zone (200 m – 700 m) concentrated in the southern part of Bhutan and also referred to as the wet sub-tropical zone. Rice agro-ecological zones are described briefly below.

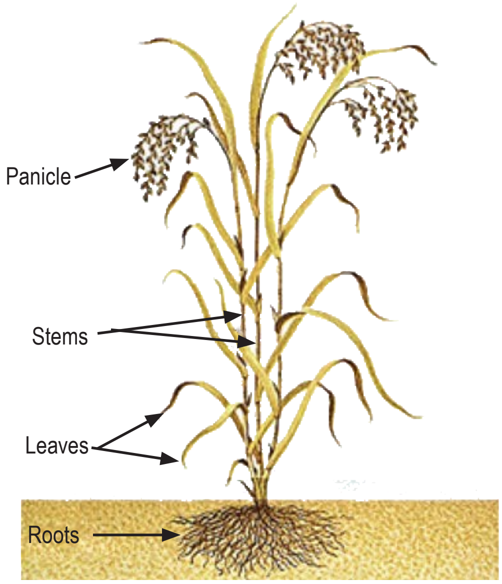

Figure 3.3 Rice plant

The *warm temperate high altitude zone* includes mainly the valleys of Paro and Thimphu, higher altitude areas of Punakha and Wangdue valley, and parts of other districts. Approximately 20% of the total rice area falls in this zone. The highest altitude where rice is grown is about 2700 m in Bumthang. The climatic conditions allow only one crop of rice in a year. Rice is sown in March-April, transplanted in May-June and harvested in October-November. Rainfall in this zone is rather low (650-850 mm per year) and hence rice is grown as irrigated crop. Small springs and the main rivers are the sources of irrigation. Rice blast is a major problem.

The *dry sub-tropical zone* includes broad valleys of Wangduephodrang and Punakha, hill slopes and narrow valleys of Trongsa, Trashigang, Monggar and Lhuentse. This is a mid-altitude zone with a lower rainfall (850-1200 mm). Rice is sown in March-April, transplanted in June and harvested in October-November. Two crops of rice could also be grown. The first crop, transplanted in March by using seedlings raised in a poly-tunnel nursery, can be harvested in July followed by an early maturing second crop can be planted which is harvested in October.

The *humid sub-tropical (mid altitude) zone* includes hills of Tsirang, Dagana, Trashigang, Zhemgang, Pemagatshel and Chukha. This is a distinct humid hilly environment with substantially high rainfall (1200-1500 mm). Almost all rice is grown under irrigated condition. The rice terraces are carved in hill slopes. The dry and humid subtropical zones account for about 45% of the total rice area. Low temperature is not a major problem during early crop growth stage. However humid conditions favour disease development.

The *wet sub-tropical low altitude zone* includes mainly the districts of Samtse, Sarpang, and Samdrupjongkhar and account for about 35% of the national rice acreage. It is a high rainfall environment with higher temperatures. Diseases and insect-pests are more common. Soil conditions are poor (low N and K) compared to other zones. Rice is grown mainly as a rainfed crop due to lack of assured irrigation. Rice cultivation is dependent on monsoon rains and yields are generally low compared to other zones. Moisture stress at flowering and post flowering stages considerably reduces yield.

The traditional Bhutanese rice varieties can be broadly classified as "BjaMaap" (red grain varieties) and "BjaKaap" (white grain varieties). BjaMaap are predominant in higher elevations usually above 1500 m, while BjaKaap are more commonly grown in lower elevations. Bhutanese farmers cultivate and maintain a range of varieties in their fields. A farmer may cultivate 2-5 rice varieties in small parcels of land to fulfill varied needs such as for toe (cooked rice), *zaw* or *siroula* (puffed rice), *seep* or *chiura* (flattened rice), *selroti* and *mekhu* (roti-like cooked in oil), *torm* (ritualistic divine figures), *khir* (rice cooked with milk) and *chankey* and *ara* (local brew).

b) Maize

Scientifically known as *Zea* mays, is one of the most extensively cultivated cereal crops in the world. Globally, maize is a staple crop, and many people rely on it as a primary source of nutrition. In addition to playing a major role in the human diet, maize is also used as livestock fodder and feed. The exact domestication point for maize is unknown, but it is estimated that the crop is at least 5,000 years old. The plant was originally domesticated in Mesoamerica, and appears to be related to species of wild grass which still exist in Central American today. People in many English speaking nations know maize as corn. The major chemical component of the maize kernel (grain) is starch, which provides up to 73% of the kernel weight. Other carbohydrates are simple sugars present as glucose, sucrose and fructose in amounts that vary from 1 to 3 percent of the kernel. After starch, the next largest chemical component of the kernel is protein. Protein content varies in common varieties from about 8 to 11 percent of the kernel weight. Most of it is found in the endosperm. The oil content of the maize kernel ranges from 3 to 18 percent. Maize is widely cultivated throughout the world, with the United States

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producing 40% of the world's harvest. Other top maize producing countries include China, Indonesia, Mexico, Brazil, India, France and Argentina.

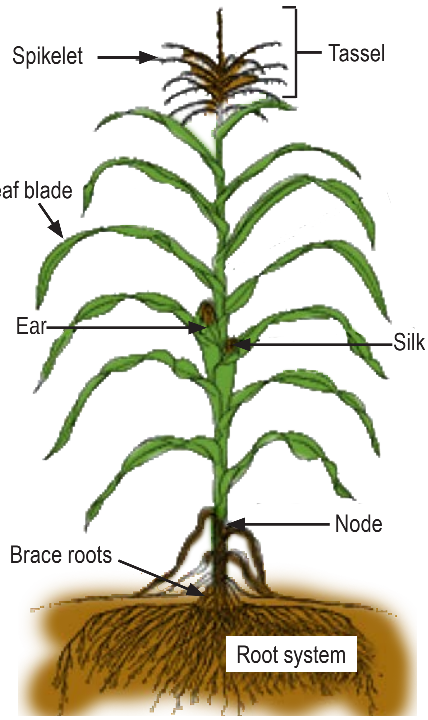

Figure 3.4 Maize Plant

In Bhutan, maize ranks first in terms of area cultivated among the food crops. Maize is grown in all the 20 districts from an elevation of 150 m to nearly upto 2800 m, although the extent of cultivation varies. The maize production environment in the country is broadly categorized into three zones based on the altitude. The three production zones are, Sub-tropical maize production zone I (<1200 m) or low altitudes, Sub-tropical maize production zone II (1200-1800 m) or mid altitudes and the Highland maize production zone (>1800 m). Maize is predominantly grown as a rainfed crop on sloping dryland fields. A small portion however is also grown in the terraced wetlands prior to rice. It is predominantly cultivated in six the eastern districts where it is consumed as a staple food and to a slightly lesser extent in the southern and central parts of Bhutan. Due to its versatility to adapt to a wide range of agro-ecology and cropping systems the cultivation of maize is expanding to new maize growing districts like Bumthang, Thimphu, Paro and Haa.

Different types of maize are cultivated in the country with a variety of colored kernels that are white or yellow and may be either dent (small depression in the grain), semi-dent or flint (rounded full grains). Popcorn is very popular and is mainly cultivated for its popping quality. Most of the varieties cultivated can be categorized as full season varieties with long maturity period with the exception of a very few short duration varieties that are used for double cropping and those used in the rice-maize rotation. The local varieties are recognizable by their distinctive morphological traits especially the tall height, cobs fully covered by husk, usually slender stalk and small and slender size of cobs. Some of the popular land races of maize are BaipoAshom, Kanglungpa, Bartshampa and Udzorongpa whose names indicate the area where they are popularly cultivated.

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Theksumpa is the most popular traditional extra early variety that matures in 90 days and is popularly grown as the second crop of maize in the maize-maize rotation. The most popular traditional popcorn variety is known as the SharpaAshom and is widely used by farmers for popping. Farmers give different names to varieties that show adaptation to micro-niches, soil types, sowing time, nutritive value and other properties.

(a) dent grain

(b) flint grain

Figure 3.5 Maize grain

Maize is eaten as a staple in the eastern and some southern parts of Bhutan. It is mainly consumed as maize grits (*kharang*) or as flour (*bokpi*). Kharang is a coarse milled granules cooked similar to rice or often mixed with rice. Maize bokpi is a finely milled flour and eaten as dough. A large percentage of maize is also used to make alcoholic beverages.

c) Wheat

Wheat (*Triticum aestivum*) is a cereal grain, originally from the Levant region of the near East and Highlands but now cultivated worldwide. Globally, wheat is the leading source of vegetable protein in human food with higher protein content that major cereals maize or rice. Wheat grain is a staple food used in making flour for bread, biscuits, cookies, cakes breakfast cereal, pasta, noodles, for fermentation to make beer, and other alcoholic beverages. Wheat is planted to a limited extent as a forage crop for livestock, and its straw can be used as a construction material for roofing thatch. The whole grain can be milled to leave just the endosperm for white flour. The by-products of this are bran and germ. The whole grain is a concentrated source of vitamins, minerals and protein, while the refined grain is mostly starch.

In Bhutan, wheat is cultivated in different agro-ecological regions from about 200 m to above 3000 m. It is grown as a main or secondary crop after maize, rice and potato and in rotation with buckwheat at higher altitudes. Apart from grain, wheat is also grown as winter fodder and for hay making in high altitudes. Wheat grown in Bhutan can be classified into two major groups: winter wheat and spring wheat.

Winter wheat is cold hardy, requiring vernalization (*cold temperature during*

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vegetative growth so that flowering occurs later) and is confined to higher elevation drylands. Spring wheat fits well in the rice-based cropping system in lower elevations. Wheat is used both for human consumption and for animal feed. Wheat is consumed traditionally as *kapchi* which is a flour product after roasting and grinding, apart from brewing into *banchang* and *ara*. Wheat flour is also used to make *torm* where rice and other crops are not easily available.

d) Oil crops

There are many types of oilcrops but the predominant oilseed crops in our country are rapeseed (*Brassica campestris*) and mustard (*Brassica juncea*) grown at altitudes from about 200 m to 3000 m. The acreage under oilseed crop is slowly diminishing because it is not economically viable. This is due to limited choice of cultivars and the high cost of production, thus cheaper imports depress domestic production. In the wetlands there are other competing crops such as wheat and vegetables.

In the dryland, mustard is grown as a secondary crop under rainfed conditions. In addition to Brassica species, there are other oil-bearing crops grown traditionally. Niger seed (*Guizotiaabyssinica*) is grown in small areas during summer in the lower hills. Niger is known to do well even under poor fertility and management conditions and competes well with weeds. Sesame (*Sesamumindica*) grows in the southern parts of the country. Two types of sesamum are grown, one with white seed and the other with black seed. Another minor source of vegetable oil is sunflower (*Helianthus annuus*) grown mainly in the cool temperate zone above 2000 m.

In addition, there are a number of perennial oil-bearing trees from which seeds are harvested to extract oil. Locally called Pangtsi (*Symplocuspaniculata*), it is found in abundance in the mid-altitude valleys of Punakha and Wangdue. It contains about 20% edible oil. Yika (*Maducabutyretica*) is found in Eastern Bhutan, and the oil is mostly used for lamp oil, although the oil and fruits are edible. Karshing or Kadam (*Jatropacurcas*) is widespread in the country and its oil can be used for soap making. The plants are used as live fence and for erosion control. Shingshe (*Neolitseasp*) is found in eastern parts and its oil is used for consumption and for lighting lamps.

Grain legumes are an important component of the Bhutanese farming systems. They are grown in diverse land use systems such as dryland, wetland and kitchen

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gardens in different cropping systems and seasons depending on altitudes and species. However, most grain legumes are grown on drylands. More than 16 species of grain legumes are grown in the country, the most widely grown species being soybean (*Glycine max*), common bean or rajma bean (Phaseolus vulgaris), pea (*Pisumsativum*) and urd/mung bean (*Vigna species*). The grain legumes are known by various names in different languages and dialects in the country. Most farmers grow traditional varieties and maintain their own seeds. Reasons for growing legumes by the farmers include: food source, income source, availability of land and seeds, fodder for livestock, easy management, improvement in soil fertility and used for religious ceremonies and less damage by wild animals. By region, the eastern and west-central regions have the greatest percent of land under legumes.

3.4 Production Practices of Rice

a) Growing conditions

Rice can be grown under widely varying conditions of altitude and climate. It is grown from sea level to as high as 3000 m. Rice is best suited to regions which have high humidity, prolonged sunshine and an assured supply of water. The average temperature required throughout the life period of rice ranges from 21-37^{o}C. Rice can be grown under diverse soil conditions. However, soils having good water retention capacity with good amount of clay and organic matter are ideal for rice cultivation. It grows well in soils having a pH range between 5.5 and 6.5. Rice can be established either by direct seeding or transplanting. In our country, transplanting is the most common method of rice cultivation. The table below describes the rice growing conditions in Bhutan.

Table 3.2 Conditions for growing rice

Criteria	Description
Elevation	• Between 250 m such as in the southern foothills of Sarpang, Samtse, and Samdrup Jongkhar to above 2,700 m like in Bumthang • At higher elevations (>2,700 m), rice takes considerably longer to grow and mature due to low temperatures.

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Ecosystems	• Irrigated ecosystem where rice is grown in terraced fields with assured irrigation water such as those in Paro, Thimphu, Wangdue, and Punakha. • Rainfed ecosystem where rice cultivation depends on rainfall – in terraced fields – such as those prevalent in the southern foothills. • Upland ecosystem where rice cultivation also depends on rainfall – but in sloping drylands without terraces. Rice is usually direct-seeded, either dibbled or broadcast.
Soil pH	• Slightly acidic soils with a pH range of 5.5 to 6.5.
Soil texture	• Grow ideally in clay and clay-loam soils which have good water-holding and retention capacity. • Sandy soils quickly lose water and lead to moisture stress. Addition of organic matter helps.
Temperature	• Seeds germinate and grow at mean temperatures above 14°C. At lower temperatures, growth will be slow. • Critical temperature for rice flowering and fertilization ranges from 16°-20°C. • At grain filling and ripening stage, 18°-32°C. • Temperatures higher than 35°C may affect pollen shedding and thereby grain filling.

b) Choice of variety

The choice of a variety depends on altitude, cropping pattern, ecosystem, and growers' preference. The recommended varieties for different altitudes and growing conditions in Bhutan are given on page 58. The variety names are given based on the place of origin and also where they are grown abundantly. The potential of yield is approximately calculated a tone per acres of land and the yield can vary depending on the fertility of soil and the care that the farmers are able to provide.

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Table 3.3 Variety of rice released under different growing conditions

Variety	Year of release	Yield Potential (t/acre)	Altitude range (m)
IR 64	1988	2.0-3.2	600-1500
IR 20913	1989	1.6-2.4	600-1500
No 11	1989	1.6.2.4	>1500
BR 153	1989	1.2-1.6	Up to 600
KhangmaMaap	1999	1.6-2.4	>1500
BajoMaap 1	1999	2.0-3.2	600-1500
BajoMaap 2	1999	2.0-3.0	600-1500
BajoKaap 1	1999	2.0-3.4	600-1500
BajoKaap 2	1999	2.0-3.4	600-1500
Yusi Ray Maap 1	2002	2.5-3.5	>1800
Yusi Ray Kaap 1	2002	2.5-3.5	>1800
Wengkhar Rey Kaap 2	2002	2-3	600-1500
Wengkhar Rey Kaap 6	2006	2-3	600-1500
Jakar Rey Naab	2006	1.5-2.0	>2000
YusiRaykaap 2	2010	2-3	>1800
YusiRaymaap 2	2010	2-3	>1800
WengkharRaykaap 10	2010	1-2	<700
Bhur Raykaap-1	2010	2-3	<700
BhurRaykaap 2	2010	1-2	<700
BhurKambja 1	2010	1-1.5	<700
BhurKambja 2	2010	1-1.5	<700

c) Nursery preparation

There are three methods of raising rice seedlings in Bhutan as described below, including the conditions as to which method to adopt:

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Table 3.4 Methods of raising rice seedlings

Method	Conditions for Adoption			
	Irrigation	Weeds	Temperature	Altitude
Semi-dry bed	Not assured	Shochum areas	Low (<18°C) at seedling stage	High and mid (>1000 m)
Wet bed	Assured	No shochum	High (>18°C)	Mid and low (<1000 m)
Polytunnel	Not assured	Shochum areas	Low (<15°C)	High and mid (>1000 m)

i. Semi-Dry Bed Method

1. Prepare a well-levelled field with fine, pulverized soil.
2. Apply 3 kg of well-rotten Farm Yard Manure (FYM) for a 1 m x 3 m seedbed. Mix them thoroughly with the soil.
3. Make raised seedbeds 10-13 cm high, 1 m wide, and any convenient length (5-10 m)
4. Broadcast dry seeds uniformly on the seedbeds. One "Drey" or 1.2 kg seed is sufficient for a 1 m x 6 m area.
5. Cover the seeds using a thin layer of fine soil mixed with well-decomposed FYM.
6. Irrigate the seedbeds immediately after sowing. The seedbeds should be slightly soaked. Never flood.
7. Regularly check the moisture of the seedbeds and irrigate when necessary.
8. Seedlings are ready for transplant 30-50 days after sowing, depending on the altitude and temperature.

ii. Wet Bed Method

1. Plough, puddle, and level a conveniently-located plot. Apply enough FYM before puddling.
2. Make slightly raised seedbeds, 10-13 cm high, 1 m wide, and any convenient length.
3. Soak the seeds in clean water for 24-36 hours. Then rinse the seeds, drain, and incubate them for 36-48 hours. During incubation, keep them moist and warm in half-filled, loosely-tied sacks. Every 12 hours, drench the sacks and

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turn them upside down to even out the temperature.

4. Broadcast the pre-germinated seeds uniformly on the seedbeds. One Drey of seeds is enough for a 1 m x 6 m seedbed.
5. Maintain just enough water to continuously saturate the seedbeds for the first week. Thereafter, gradually increase the water level as the seedlings grow. Never let the seedbeds dry out.
6. The seedlings are ready for transplant 20-25 days after sowing depending on the temperature.

iii. Polytunnel Method

A polytunnel cover is used over the seedbed to protect seedlings – raised as first crop in rice double cropping – from cold and provide higher seedbed temperatures for seed germination and growth. Minimum temperature required for the germination of rice seed ranges from 9°-13°C. (Note: the normal air temperature during the first week of February in Wangdue and Punakha Valley averages only 4o-8°C). A polytunnel cover increases the temperature to 10°-12°C making seed germination and growth possible.

Procedures

1. Prepare a well-levelled field with fine, pulverized soil.
2. Make raised beds 4 to 5 inches (10-13 cm) high, 1 m wide, and of any convenient length.
3. Sow seeds evenly on the seedbed as in a semi-dry bed nursery.
4. Cover the seeds with fine soil mixed with FYM (1:1 mixture).
5. Sprinkle water or irrigate lightly through the channels to soak the beds. Never flood.
6. Put bamboo or "Kempah" 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. Cover the edges of the polythene with soil to hold them down to the ground.
8. Check the moisture frequently to ensure that there is enough supply and, whenever necessary, irrigate by raising the polythene sheet.

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9. After seedling emergence, open the plastic tunnel every 9 to 10 a.m. and close it at 3 to 4 p.m.
10. Irrigate the nursery, as and when required, preferably during the day.
11. Seedling vigour will depend upon the soil temperatures and growing conditions. Normally, seedlings attain 3-4 leaf stage after 40-45 days of sowing, which are ready for transplanting.

Field Preparation

1. Pre-irrigate the field, if it is dry, before ploughing.
2. Plough 2-3 times thoroughly and flood it thereafter.
3. Drain the water slightly and plough/rotovate/harrow as needed.
4. Repair and maintain bunds and incorporate chemical fertilizers, if any.
5. Do final puddling and levelling just before transplanting.

*Manure and Fertilizer Applicatio*n

1. Apply about 3-4 t/acre FYM basally (for medium altitude areas, about 3-6 t/acre), and topdress with 14 kg N/acre (30 kg Urea/acre 35-40 days after transplanting.
2. If adequate manures are not available, apply chemical fertilizer at the rate of 30:12:8 kg NPK/acre. Apply half dose of Nitrogen and full dose of Phosphorus and Potash as basal application.
3. Topdress the remaining N two times at tillering and at panicle initiation equally.
4. Wherever possible, carry out soil tests by sending soil samples to the National Soil Service Center (NSSC) to determine the exact nutrient requirement.
5. When using green manure preferably in the mid and low altitudes, incorporate 6 8 weeks old Sesbaniaaculeata (Dhaincha) before transplanting of rice. Topdress with N at the rate of 35 kg/ha for higher yields.

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d) Rice establishment

Establishing the rice crop in Bhutan is either by direct seeding or transplanting, although the latter is commonly practised by Bhutanese farmers.

Table 3.5 Methods of growing rice in Bhutan

Method	Advantages	Disadvantages	Altitude zone
Direct seeding	• Less labour required • Matures earlier • Similar yield as in transplanted crop	• Difficult to get a good crop stand • More weeds problem	Mid and low
Trans-planting	• Good, optimum crop stand • Easier weed control	• Requires more labour in seedling uprooting and transplanting	All zones

i. Transplanting

- For mid-altitudes, do transplanting in May – June. Use the traditional or random method of transplanting if the weed pressure is expected to be low, if weedicide (Butachlor) is intended to be used for weed control, and if the terraces are narrow and small.
- Do line planting when controlling weeds using a rotary weeder. Use planting rope to maintain row spacing of 20 cm and plant-to-plant spacing of 15-20 cm within the rows. Avoid wide spacing particularly in random transplanting.
- A plant density of 25-35 hills per square meter is optimum. Plant 2-3 seedlings per hill at 20 cm x 20 cm distance.

ii. Weed Management

1. Where weed pressure is expected to be low or moderate, do hand weeding at least two times, that is, at 20 and 40 days after transplanting. If hand weeding is to be done, keep in mind to closely space the plants and perform the first weeding not later than 30 days after transplanting.
2. If weed pressure is expected to be high, use line planting and rotary weeding. If line planted, do two rotary weedings, that is, at 20 and 40 days after transplanting.

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3. If there is no or little shochum weed but weed pressure is expected to be high, use Butachlor at 12-16 kg per acre and apply 3-6 days after transplanting. Do not use Butachlor in areas heavily infested with shochum.
4. Since weeding is laborious and the use of herbicides is not environment-friendly, use indirect complementary weed control methods like good land preparation, proper water management, and use of weed-free seedbeds and seeds.

e) *Irrigation management*

1. Avoid letting the soil crack and keep the fields saturated or moist. About 800-1200 mm water is needed for a rice cropping season.
2. After transplanting, keep the water level as minimum as possible for about 4 7 days until the plants recover.
3. Thereafter, gradually increase the water level up to 5 7 cm and ensure enough water from tillering to flowering.
4. Irrigate at short intervals (3-5 days) but do not allow the field to dry-up and crack.
5. Do not subject the rice plant to water stress during the flowering stage as this is its most critical stage of growth.
6. Drain the water from the field 10 15 days before harvest.

g) *Harvesting*

1. Under normal conditions, begin harvesting from first week of October in the Wangdue-Punakha valley.
2. Harvest the crop as soon as it matures, when at least 85% of the upper portion of panicles turns straw coloured.
3. For some varieties like No. 11 wherein some leaves and stems may still be green at grain maturity, use days to maturity of a particular variety as basis for harvesting schedule.
4. Use serrated sickles to harvest the crop manually. Where available, powered machines or reapers can be used to harvest rice.

3.4 Production Practices of Maize

Maizeis the staple food crop in the Eastern Bhutan. It is mostly grown on dryland and *tseri*. It can be successfully grown up to an elevation 2500 m. In the east, maize is also intercropped with potato, legumes and millet. The seasons for growing maize are:

Table 3.6 Conditions of growing maize

Altitude	Season
Low altitude area (600 m)	Feb.-April to Sept.-Oct. (Single cropping)
Low altitude area	Feb.-May and June-Oct. (double cropping)
Medium altitude area (1200-1800 m)	March-April to Sept.-Oct.
High altitude area (>1800 m)	April-May to Oct.-Nov.

a) Varieties

There are three improved and recommended varieties of maize. These are Yangtsipa, KhangmaAsom 1 and KhangmaAsom 2. For areas up to an altitude of 1800 m, the three varieties are recommended. For areas above 1800 m local varieties can be used.

i. Yangtsipa

Medium tall with 2.36 to 2. 50 m plant height, matures in 120 130 days, average yield of 1.30 to 1.70 t/acre at moderate management, has yellow flint grain texture, resistant to lodging, tolerant to low fertility and highly responsive to applied fertilizers, moderately resistant to Northern Leaf Blight disease and moderately tolerant to drought.

ii. Khangma Asom1

Medium tall with 2.10 to 2.40 m plant height, maturity of 140-160 days, average yield of 1.30 to 1.70 t/acre at moderate management, yellow semi-dent grain texture, resistant to lodging, tolerant to low fertility, highly responsive to applied fertilizers, moderately resistant to Northern Leaf Blight and Downey mildew.

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iii. KhangmaAsom 2

Medium tall with 2.10 to 2.38 m height, maturity of 110 120 days, average yield of 1.30 to 1.70 t/acre, white semi-dent grain texture, resistant to lodging, tolerates low fertility and responsive to applied fertilizers, moderately resistant to Northern Leaf Blight and drought tolerant.

b) Land Preparation

Plough the field at least 2-4 weeks before sowing and leave the soil in rough condition to kill potential soil borne pests and diseases by way of predators and solarisation (exposure to sun and heat). At final land preparation break the clods, remove weed and incorporate well decomposed FYM or compost.

c) Manure and Fertilizers

Apply well-decomposed FYM or compost whichever available. The use of un-decomposed organic matter enhances cutworm population. The quantity of chemical fertilizers required depends upon the previous crop grown and the inherent fertility status of soil. As a general recommendation apply 16 kgN /acre and 8 kgP2O5/acre. In Potash deficient areas, apply 13 kg Muriate of Potash (MoP) per acre. Wherever maize is relayed with potato, maize crop normally establishes on the residual nutrients applied to potato crop. However, for good maize crop establishment apply additional 10-12 kg Urea per langdo as top dress at the time of earthing up of potato.

d) Method and time of application

Broadcast half the quantity of Urea and full dose of single super phosphate (SSP) and MoP at the time of final land preparation and incorporate well into the soil. Apply remaining half of Urea approximately at "knee high" stage or at "pre-tasseling stage of the crop whichever is convenient, and mix it well with the soil.

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e) *Crop Establishment:*

i. *Sowing time*

Maize should be sown when adequate moisture is available in the soil. Maize is very susceptible to water logging, so, proper drainage has to be ensured.

Sowing: Sow the seeds behind the plough or dibble the seeds using a long pointed stick. Maintain a distance of about 60 cm between the rows and about 30 cm within the row.

ii. *Seed rate*

If proper land preparation and management practices are followed, a seed rate of 10-12 kg/acre will be sufficient to get an optimum population of 20,000 plants per acre.

iii. *Plant density*

In poor soil and places where farmers have minimum available FYM or compost or fertilizers the density of 10,000 plants per acre is recommended. In good soils and in places where farmers have sufficient FYM or compost or fertilizers, a density of 20,000 plants per acre is recommended. Optimum population can be maintained by thinning at “knee high” stage of the crop.

iv. *Weed control*

Since the initial growth of maize is slow, it is recommended to keep the field weed free during the early stages of crop growth. The interval between 25 and 45 days after crop emergence is crucial as far as competition between crop and weed is concerned. First weeding should be done at least at 25-30 days after crop emergence. Second should be carried out at 20-25 days after the first weeding. If only one weeding is possible then, it should be done at 25-30 days after the crop emergence since maize is very susceptible to weed damages at early growth stages.

v. *Harvesting and Threshing*

Maize should be harvested when the ears are dry. The development of black layer at the base of the grain (point of attachment to cob) indicates the crop’s physiological maturity. After physiological maturity no further development of the grain takes place and needs drying. After harvest, the ears should be dried well in the sun

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before storing.

vi. Storing

Maize ears or grains should be thoroughly dried before storage. Remove the few outer husk of ear for faster drying. High grain moisture predisposes infestation and infection by storage pests and diseases. Similarly, before storing the produce, the store and the containers should be thoroughly cleaned to ensure safe storing. Lime at rate of 10 g/kg seeds can be used to prevent insect-pest attack.

g) Plant protection against insect-pests

Cutworms: Larvae are active during the night and cut and feed on the young seedlings. During daytime they hide in the soil.

Control: Plough the fields 10-15 days before sowing and expose the soil to the sun to kill egg masses and larvae by heat and predators. Increase the seed rate by 10-15% to compensate the anticipated losses in plant population.

Stem borer: The initial symptom of infestation on young plants is rows of oval perforations in leaves of the unfolding whorl (leaf). Feeding of the young larvae causes this damage. As they develop, the larvae tunnel into midribs, damage the growing point (causing a condition referred to as "dead heart").

Control: Plough the field well and the expose soil to sun and predators. Inspect and destroy the egg masses if noticed on leaves during growing season. Collect the infested plants and destroy them by burning or feed to cattle. Chemical control is useful to prevent infestation. Spray Fenitrothion at the rate of 1.5-2.0 mL/litre of water.

Corn earworm: Although they may occasionally feed in the leaf whorl or on the tender tassel, the larvae principally damage maize ear. They begin feeding soon after emergence, concentrating on the silk channels. In addition to causing direct injury to the kernels, they open avenues for infection by ear rot pathogens.

Control: Spray Fenvalerate (20% EC) at the rate of 1.5 - 2.0 mL/ litre of water.

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h) Diseases

Northern Corn Leaf Blight: It is a fungal disease prevalent in cold humid conditions. Initially spindle shaped yellowish brown necrotic spots appear on leaves and later coalesce and the entire leaf becomes yellow and dry. In early stage of the crop it may cause the death of seedlings.

Control: Burn all crop debris to destroy the fungal spores or plough them in. Spray a fungicide like Mancozeb at the rate of 2 g/litre of water.

To conclude, what has been discussed so far is to be understood as the 'agriculture' the art and science of cultivating the land for food in this case. Growing food is not easy job but at the same time someone has to do it is an honourable job, growing food for humanity sustainably. No matter what you study and how much you study, at the end you work for your food. Why not join farming community and grow your own healthy food, rather than roaming around for job, which may not give you peace of mind to eat your food at ease.

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Student Activity

Students can be assigned variety of tasks on growing of food crop in smaller groups to learn the practices of different crops in the school campus if feasible or participate in the community growing food crops from time to time, which can be beneficial for the community as well as for the students and writing assignment analytically on growing of food crops comparing the ideas of the text verses the practices in the community.

Task one: Growing of food crop in the school campus(for schools with space for gardening)

a) Group students in three to four groups and assign them to grow food crops i.e. locally available and grown.

b) Prepare plans of growing crops on small plots right from the beginning of the academic session, following the procedures discussed in the text.

c) Record work involve, time of development and care required, production, etc.

d) Arrange a presentation of their records of growing food crops – challenges and benefits, assess their tasks

Task two: Invite an experienced farmer to the class and ask how food crops are grown in their community or Field trip to Learn growing food crop from the community:

a) Invite a farmer with prior information of what he/she needs to talk to the students or brief students to ask question on the growing of crops

b) Arrange field trips cum helping farmers at different stages of work on growing of food crops.

Task three: Assignment on growing practices of (one only) Rice/Maize/wheat/Oil seed.

a) What do understand by cropping system and cropping pattern of Bhutanese society?

b) Why do Bhutanese farmers adopt cropping pattern in the manner they do?

c) Write cultivation procedures of any one of the food crops analytically – rice / maize/wheat/oil seeds and suggest how the farmers could do better farming.

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Chapter 4

Food processing, value addition and preservation

Agriculture is the mainstay of economy in many developing countries including Bhutan. With the invention of modern technologies, agriculture farming has become much easier. Agriculture is not only about growing food but also includes post production handling and management, processing, value addition and preservation. Being perishable in nature a major portion of the harvested fruits and vegetables are lost during the post-harvest stages. Therefore, post-harvest food processing, value addition and preservation of food should be given an utmost importance. The chapter on post-harvest technology in class ix guides you through proper post-harvest handling operation and management of food crops. This will not only help in providing quality raw materials for processing and value addition but also reduce losses from post-harvest handling. It is important to remember that quality products can be developed only from quality produce. Therefore, it is vital to learn how to handle agriculture produce before actually taking up food processing, value addition and preservation.

This chapter guides the students on processing, value addition and preservation of agriculture produce. The processing methods, principles of preservation and use of additives for value addition are as per the international standards. It is essential to know; how to produce, what to produce, when to produce and for whom to produce. Critically one should have a clear understanding of how safe is the processed food and what does it contain. Thus having the concepts and technical knowhow one could easily start an agriculture based enterprise on food processing and value addition. There are some examples of processed products detailed in the subsequent topics. This would not only generate employment opportunities but also substitute import, and enhance income besides improving the produce value chain.

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4.1 Food preservation

The main objective of fruits and vegetables processing is to supply wholesome, safe, nutritious and acceptable food to consumers throughout the year. It also aims to reduce food loss during the season when there is glut, reduce food imports and meeting the internal demand, to diversify the economy, generate employment and additional income for the people venturing into the business. Benefits of food processing, value addition and preservation are;

1. Converts raw food and farm produce into edible, usable and palatable form.
2. Helps to store perishable and semi-perishable agricultural commodities for longer duration.
3. Avoid and reduce glut in the market during the season.
4. Reduce post-harvest losses and make the produce available during off-season.
5. Employment generation.
6. Development of ready-to-serve (RTS) products.
7. Helps in preservation of locally grown fruits and vegetables.
8. Helps in improving palatability and organoleptic quality of the produce by value addition.
9. Helps to ease marketing and distribution tasks.
10. Increases seasonal availability of many foods.
11. Enables transportation of delicate perishable food across long distances.
12. Make safer food for consumption through microorganism checks.
13. Development of healthy foods.
14. It brings about food and nutritional security.
15. Provides potential for export to fetch foreign exchange.

a) Factors affecting food deterioration

There are several factors that cause deterioration and spoil food during the post-harvest stages. Some of the major factors causing food deterioration are;

i. Enzymatic changes

Natural enzymes present in the plant cells can lead to desirable or undesirable changes in food. The post-harvest senescence and spoilage of fruit and vegetables, oxidation of phenolic substances in plant tissues by phenolase leading to browning, sugar-starch conversion in plant tissues by amylases, post-harvest demethylation of pectic substances in plant tissues leading to softening of plant tissues during ripening, and firming of plant tissues during processing are some of the changes that are caused by enzymes in the harvested produce.

ii. Chemical changes

Deterioration of food is also caused due to chemical changes occurring in the foods. A chemical change in food mainly leads to change in sensory quality, nutritional content, color and flavor of food. Lipid oxidation and non-enzymatic browning are the main chemical changes that occur within the food.

iii. Physical changes

Physical factors such as moisture, temperature, air (oxygen) light and time are the major causes of food deterioration. All of these physical factors should be maintained within the safe and recommended limit for storage of foods.

iv. Biological changes

Micro-organisms are one of the major factors leading to spoilage of food. The two major groups of micro-organisms found in food are bacteria and fungi followed by yeasts and moulds. Insect pests and rodents are some of the other major biological factors that cause food loss.

b) Principles of Food Preservation

A good method of food preservation is one that slows down or prevents altogether the action of the agents of spoilage. Also, during the process of food preservation, the food should not be damaged. In order to achieve this, certain basic methods can be applied on different types of food. The following are the list of principles of food preservation.

i. Removal of micro-organisms or inactivating them

This is done by removing air, water (moisture), lowering or increasing temperature,

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increasing the concentration of salt or sugar or acid in foods.

ii. Inactivating enzymes

Enzymes found in food can be inactivated by changing their conditions such as temperature and moisture.

iii. Removal of insects, worms and rodents

By storing food in dry, air tight containers the insects, worms or rodents are prevented from destroying it.

c) Control of microorganisms

The micro-organisms that cause spoilage of food can be controlled using following methods.

1. ***Heat:*** pasteurization of food which are sensitive to heat at 72°C for 15 minutes can control microorganisms. However, those food products insensitive to heat can be sterilized at 121°C for 5 minutes.
2. ***Cold:*** reducing the temperature of produce to the level not suitable for growth and development also helps to control the microorganisms. Freezing of meat and vegetables like pea, mushroom and beans are common. Food products are frozen at temperature lower than -30°C to -60 °C and stored at -20 °C.
3. ***Drying:*** drying or dehydration is the removal of moisture from the produce which hampers the growth, reproduction and development of microorganisms. Almost all the microorganisms need moisture to sustain.
4. ***Acids:*** food high in acid are not preferred by the microorganisms especially bacteria. In most cases you will see that bacteria attacks vegetables and very few cases in fruits. Fruit like apple contains malic acid, citrus contains citric acid and grapes contain tartaric acid etc.
5. ***Sugar and salt:*** adding sugar and salt to food is a traditional method of preservation. High concentration of sugar and salt will draw more water from the cell by a process called osmoses. Thereby the microorganisms will lose water and die.
6. ***Oxygen concentration:*** optimal concentration of oxygen (21%) in the air favours all living entities. Increase or decrease in the level of oxygen would hamper the normal activity. Thus by increasing or decreasing the concentration of oxygen

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can keep the microorganisms under control.

7. ***Smoke:*** smoking of fish and meat helps to reduce microbial load on the products and thereby subsiding the harmful effects. In Bhutan drying of pork (si-kham), beef (sha-kham) and fish (nga-dotshem) above the hearth is very common in the olden days.

8. ***Radiation:*** Radiation in various forms, from high-energy radiation to sunlight, can be used to kill microbes or inhibit their growth. Ionizing radiation includes X-rays, gamma rays, and high-energy electron beams.

9. ***Chemicals (Preservatives):*** There are so many chemical preservatives available commercially to control the spoilage of food by microorganisms. Chemicals like sodium nitrite and potassium nitrate are used to preserve meat products and potassium metabisulfite is used to preserve fruit and vegetable juice. These chemicals in aqueous solution forms acids such as nitric and sulphuric which kills the microbes and control them.

d) Control of enzymes

1. ***Heat:*** heating of food products containing enzymes is critical to reduce the ill effects of enzyme on the quality of food. Heat can be applied to a food product through mediums like air and water. Heating of food in water at 100°C for 3 to 5 minutes to inactivate enzyme is referred as blanching.

2. ***Oxygen control:*** the cut surface of fruits and vegetables should be protected from air to control browning. This you might have observed while eating apple, cutting potato, guava, pear etc. Minimal processing of fruits and vegetables employ chemicals like antioxidants and acids to reduce browning.

3. ***Acids:*** organic acids like citric, malic, acetic acid are applied to manage the effect of enzymes on food precuts.

4. ***Chemicals (antioxidants):*** Sulfites were used to inhibit enzymes in food however as sulfites are harmful to human health ascorbic acid is used as substitute. Ascorbic acid formulations are readily available in the market.

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4.2 Methods of food preservation

There are many techniques developed and practiced around the world in preservation of food. Some of the most common techniques are discussed below.

a) Physical methods

i. Asepsis

Asepsis means preventing the entry of microorganisms by maintaining the general cleanliness while harvesting, grading, and packing and transportation of horticultural produce to increase their keeping quality. Washing and wiping of the fruits and vegetables before processing should be strictly followed to reduce the soil particles, pesticide residues and initial contamination by microorganisms.

ii. Heating (Thermal processing)

Food preservation by thermal processing is achieved by the use of elevated temperatures to increase the rate of reduction in the microbial population present in the raw food material and transfer of thermal energy into the food products as required for achieving the desired elevated temperatures. Some of the commonly practiced thermal processing methods are discussed below;

iii. Blanching

Figure 4.1 Blanching of leafy vegetable

Blanching is applied as a pretreatment which is normally carried out between the preparation of raw material and later operations in which fruit and vegetables are dipped in hot water for short time. It is used to destroy enzyme activity in fruits and vegetables, prior to processing. The factors that influence blanching time include type of fruit or vegetable, the size of the cut pieces, temperature and the medium of heating such as boiling water, steam, microwaves etc. Blanching helps in several ways as it inactivate enzymes, which prevents undesirable changes in sensory characteristics and nutritional properties that take place during storage, reduces the number of contaminating microorganisms on the surface of food and leads to softening of vegetable tissues.

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iv. Pasteurization

Pasteurization is a process of heat treatment used to inactivate enzymes and to kill relatively heat sensitive pathogenic microorganisms that cause spoilage, with minimal changes in food properties (e.g. sensory and nutritional). It is also defined as mild heat treatment for avoiding microbial and enzymatic spoilage. It is a relatively mild heat treatment, usually performed below 100 °C. It greatly improves the product's keeping quality by effectively destroying disease producing and other microorganisms.

There primary purposes of pasteurization in different food are;

1. Enzyme inactivation (eg: fruit juice)
2. Destruction of spoilage microorganisms (eg; beer, ice cream)
3. Destruction of pathogens (eg; milk, liquid egg)

There are two broad categories of pasteurization; one involving heating of food in their final containers while heat is applied prior to packaging for the other. The latter category includes methods that are inherently less damaging to food quality and then require packaging under aseptic or nearly aseptic conditions to prevent or at least minimize recontamination. On the other hand, heating within the package is less costly and produces quite acceptable quality with the majority of foods. In practice, therefore, most of the canned food produced locally in developing countries such as canned peas and tomatoes, canned pineapple slices etc. are heated within the package.

Pasteurization can be achieved by combination of temperature and time; (i) heating of food for a longer time by maintaining a relatively lower temperature and (ii) heating food for a short time at high temperatures. Pasteurization can be done in several methods or equipment, such as water bath, continuous spray or water spray, tunnel pasteurization, heat exchanger pasteurization, flash pasteurization, ultra-high temperature pasteurization, etc.

Food products can be pasteurized in different kinds of packages such as traditional and returnable glass bottles, Polyethylene terephthalate (PET) and other plastic containers, cans and cartons with polyethylene coating or in plastic containers.

Pasteurization being a relatively mild heat treatment, there are only minor changes in the nutritional and sensory characteristics of food products. However, the shelf

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life of food is usually extended by only few days or few weeks compared to severe heat sterilization method. Minor changes or loss of nutritional and physical characteristics can still be observed in pasteurized foods.

v. Sterilization (Canning)

Sterilization is the complete destruction or elimination of all viable microorganisms on food product. It destroys microorganisms such as yeasts, bacteria, molds, and spore formers. It involves heating of processed food at a sufficiently high temperature (121°C) and for a sufficiently long time (10-15 minutes) to destroy microbial and enzyme activity. As a result, sterilized food has a shelf life of more than six months. Higher temperature for a short time (140°C/3-4 seconds) is possible if the product is sterilized before it is filled into pre-sterilized containers in a sterile atmosphere.

The basic principles of sterilization in food processing are; processed products must be free of toxin producing microorganisms and microorganisms that cause food spoilage until it is consumed, food must be heat treated to the equivalent of 121.1°C for three minutes to achieve a 12-decimal reduction since Clostridium botulinum spores are capable of growing in low acid products during storage and the processing conditions should be applied to the slowest-heating point by maintaining time-temperature profile, so that all the products will be sterilized.

Figure 4.2 Canned fruits and vegetables

The food sterilization methods are divided into two categories namely, sterilization by heating (thermal processing) and sterilization without heating (non-thermal processing). Thermal processing is widely practiced in spite of some problems such as nutrient or quality loss and its ineffectiveness against certain microorganisms. Thermal processing is further subdivided into bulk canning (in-container sterilization) and aseptic sterilization (processing).

Bulk canning thermal processing requires heating of food in the temperature range of 115°C-130°C for a time sufficient to achieve a 12-log reduction of the spores of Clostridium botulinum. In the current practices, it is moved to even higher temperatures and consequently s shorter process time to retain and maximize the organoleptic and nutrient retention within the product. An established procedure must be determined and followed to render a product commercially sterile through appropriate time-temperature combination. The methods of heating medium in sterilization include saturated steam, hot water and flames. Packaging of food can be done in tin-plate cans, glass containers, metal closures, retort pouches, etc.

Aseptic processing involves sterilization of the product, sterilization of the packaging material and maintenance of the sterility during the filling and sealing operations. Aseptic processing and packaging provides higher quality product but it needs large capital investment and require sophisticated instrumentation. Aseptic processing can be achieved through use of equipment such as steam injection sterilizer, liquid infusion into system, tubular aseptic sterilizer and plate sterilizer. The sterilization of packaging materials can be achieved through methods such as superheated steam systems, dry hot air systems, and hydrogen peroxide and radiation methods.

vi. Drying/Dehydration

Figure 4.3 Dried/dehydrated fruits and vegetables

Preservation of food by drying is one of the oldest methods of food preservation known to man. Its principles are governed by heat and mass transfer laws inside and outside the product and the weight of the product is reduced to the extent of 1/4th to 1/9th of its original fresh weight. Drying of food and biological products serves several purposes such as increased shelf life, reduced packaging costs, minimize shipping wastes, encapsulating flavors, making food available during off-season, and add value to food by changing the phase structure of the native material and maintaining nutritional value. Preservation of food by drying is due to the reduced water activity thus avoiding microbial growth

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and deteriorative chemical reactions. Water activity of food in simple language is the amount of free water available for microorganisms to grow. The end point of drying can be determined in terms of moisture content and water activity in the dried foods.

Drying process involves the application of heat to vaporize water from food after its separation from attached plants. It is a combined/simultaneous heat and mass transfer operation for which energy must be supplied. The most common medium for transferring heat to a drying tissue is a current of air that involves convection. In general, drying processes are broadly classified into thermal drying, osmotic dehydration and mechanical dewatering. A gaseous or void medium is applied to remove water from the food material in thermal drying which can be further sub divided into air drying, low air environment drying and modified atmosphere drying. A solvent or solution is applied to remove water in osmotic dehydration, while physical force is used in mechanical dewatering.

Several factors should be taken into consideration before drying of foods. There are four main factors that affect the rate and total drying time, namely the properties of the products such as particle size and geometry, the geometrical arrangement of the products in relation to heat transfer medium (drying air), the physical properties of drying medium/environment and the characteristics of the drying equipment. Other important factors to be considered are desired properties of the dried product, temperature tolerance of each product, products susceptibility to heat, pretreatments required, capital and processing costs and environmental factors. There is no one best drying technique that is applicable to all products.

Thermal drying is the most commonly used drying methods for food. Thermal air drying methods include sun drying, solar drying, in-store drying, convection air drying, explosive puff drying, and spray drying fluidized bed drying, spouted bed drying, and rotary drum drying and drum drying. Food are directly exposed to the sun in sun drying while solar drying is an extension of sun drying that uses radiation energy from the sun through fabricated solar drying structures.

Drying through low air environment includes vacuum drying, freeze drying, heat pump drying, superheated steam drying and smoking. Vacuum drying of food involves application of low pressure and a heating source to the food which results in drying of food without exposing to high temperature and also low oxygen level reduces oxidation reactions during drying. In freeze drying, the food material is

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initially frozen and the drying happens due to the removal of water from the food directly in the form of vapor (sublimation). Freeze drying is usually applied in high value products which contain heat sensitive components such as vitamins, minerals and antibiotics.

There are several pretreatments to be done before drying of foods. Pretreatments are carried out in order to improve product quality, storage stability and process efficiency.

- ***Blanching*** is one of the most common pretreatment methods. Blanching is a process in which a food product is immersed in hot water or steam for a short duration prior to drying. It inactivates the naturally occurring enzymes present in foods, since enzymes are responsible for off flavor development, browning, discoloration, and nutritional and textural changes in food. Blanching also reduces initial microbial load and improve color, texture and flavor under optimal conditions. However, it can also lead to loss of vitamins and nutrients, change in texture, color and flavor and other physical and chemical properties.

- ***Sulphur dioxide pretreatments*** are used to preserve the texture, flavor, color and vitamin content. It is believed to reduce the darkening of food during the process of drying and it also has insecticidal and fungicidal properties. Some of the chemicals used as a dipping treatment are esters, salts, organic acids, and oils. Freezing pretreatments are done for freeze dried food products while mild cooking can be done in some foods. There is a change in microbial, chemical, physical and nutritional characteristics during the drying process. Chemical changes such as browning, oxidation, color loss, and aroma development, and physical quality changes such as porosity, shrinkage, crust formation and changes in nutritional qualities such as vitamin and mineral loss take place during the course of drying and to the dried products.

- ***Osmotic dehydratio***n is the process of water removal by immersion of water-containing cellular solid in a concentrated aqueous solution. The concentration gradient between the solution and the intracellular fluid is the driving force for water removal from foods. Osmotic dehydration may be mostly used as a pretreatment for freezing, canning and minimal processing since it does not remove the moisture completely to be shelf stable. Curing salts such as sodium chloride, sodium and potassium nitrite or nitrate are used to achieve preservation through osmotic dehydration process. Application through this

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process is mostly applied to certain meat, fish and cheese products. Osmotic dehydration process can be affected by several factors such as osmotic agents' type, concentration and temperature of osmotic solution, physicochemical properties of solute used in osmosis, material geometry, food mass ratio, physicochemical properties of food materials and operating pressure.

vii. Low temperature storage and freezing

Low temperature storage can be achieved using several methods such as refrigeration (chilling) storage at 0-5°C, cellar storage in underground rooms and freezing storage at -18°C to -40°C. Cellar storage in underground room is not very effective in reducing the temperature but it is used in villages where improved cold storage facilities are not available. Commercial cold storages with proper ventilation and automatic control of temperatures are a mechanical refrigeration system where fruits and vegetables can be stored safely up to a period of a few days to many weeks depending on the produce. Currently in Bhutan, cold storage structures are used for storage of fresh apples to be marketed during the off-season.

Figure 4.4 Frozen fruits and vegetables

Freezing is one of the best methods for preservation and storage of food but care should be taken in freezing of certain fruits and vegetables which are sensitive to low temperatures and cause chilling and freezing injuries. The extreme cold retards growth of microorganisms and slows down changes that affect quality or cause spoilage in food. Most food retains their natural color, flavor and texture better than when other methods of food preservation are used. Some of the major advantages of freezing are maximum retention of taste, flavor and color of horticultural commodities, better retention of nutrients and pigments, maintaining of food resembling its fresh counterparts and more hygienic.

Freezing changes the physical state of food by changing the water into ice when energy is removed in the form of cooling below freezing temperature. It does not stop but slows down the physicochemical and biochemical reactions that govern

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the deterioration of foods. Freezing can lead to change in its physical, structural, and chemical properties of food.

Freezing of food can be done using several methods such as freezing by contact with a cooled solid (plate freezing), freezing by contact with a cooled liquid (immersion freezing), freezing by contact with a cooled gas and cryogenic freezing. In cryogenic freezing, food is directly exposed to liquefied gases such as liquid nitrogen or liquid carbon dioxide at an atmosphere below -60°C. Cryogenic freezing is a fast method of freezing, compatible with various types of food products and have low capital cost. The rapid formation of small ice crystals in cryogenic freezing also reduces the damage caused by rupture of cell and preserves, color, flavor, texture and nutritional value. Liquid nitrogen is a most commonly used cryogenic gases in freezing. Liquid nitrogen is colorless, odorless and chemically inert which makes it safe for use in freezing of food products.

viii. Ionizing radiations

Preservation of food by irradiation consists of exposing the food to predetermined level of ionizing radiations that destroy the microorganism and inactivate the enzymes. Food is preserved without marked change in their natural qualities but the method can be quite costly. Ionizing radiations are produced from sources such as radioactive isotopes, electron generating electrical machines and X-rays.

The potential applications of irradiations are disinfection, shelf-life extension, decontamination and product quality improvement. These can have advantages such as minimizing food losses, improving public health, increased international trade, etc. Depending upon the type of foods, the purpose of irradiation can sprout inhibition, delayed ripening, insect and parasitic disinfection, reduction of spoilage microbial organisms and pathogens, sterilization and reduction or elimination of virus contamination.

The other advanced methods of food preservation are high-pressure treatment of food where a high pressure is applied uniformly throughout the product, and applications of magnetic field to preserve foods.

b) Chemical preservation methods

Use of chemical additives such as sugars, salts, acids, spices, alcohol, etc., is a common method for preservation of foods.

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i. High sugar preservation

The principle of this technology is to add sugar in a quantity that is necessary to augment the osmotic pressure of the product's liquid phase at a level which will prevent microorganism development. Sugar concentration of 68 to 70% generally assures safe preservation of food from bacteria, yeasts and molds. To have a synergistic effect on preservation, other chemical additives could be used and acids added to lower the pH to prevent the microorganism growth. Additionally, packaged processed products such as jam and jelly could be pasteurized for further protection from microorganisms which can still grow in high sugar concentrations.

ii. Preservation by salt, acid and spices

Pickling is a perfect example of food that are preserved using salts and spices. Vinegar (acetic acid) is also commonly used in preservation of fruits and vegetables. Spices and oils can be added to the food products as an additional preservative besides its flavor and taste. The food is preserved based on the underlying principle of fermentation.

iii. Preservation by chemical additives

According to FDA, 'chemical preservative is any substance which is capable of inhibiting, retarding or arresting the process of fermentation, acidification or other decomposition of food or masking any of the evidence of any such process or of neutralizing the acid generated by any such process but does not include salt, sugars, vinegar, spices or oils extracted from spices'. Chemical additives are added in a very small quantity to the food and they do not change the organoleptic and physico-chemical properties of the foods. It can be applied as direct additives during processing of food. The effectiveness of chemical preservatives depends on several factors such as chemical composition, pH, concentration, microorganism species and the initial number of microorganisms in the treated food product.

Chemical preservatives for food can be classified into class I and class II preservatives. Class I preservatives are mainly natural products which is used in higher concentrations than class II preservatives. They include salts, sugar, dextrose, vinegar, honey and spices. Class II preservatives on the other hand are synthetic products and used in small quantities. Some of the commonly used class II preservatives are benzoic acid and its salts, sulphur dioxide and salts of sulphurous acid, nitrites and nitrates, sorbic acid and its salts, propionic acid and

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its salts, lactic acid and its salts. Sulphur dioxide (as potassium metabisulphite) and its derivatives can be considered as universal preservatives for food. Chemical additive's mode of action involves alteration of cell wall permeability, damage of the cell wall, damage of proteins, alteration of colloidal nature of protoplasm, inhibition of enzyme activity, disruption of cytoplasmic membrane, bactericidal action (toxicity of the antimicrobial agent towards microorganisms) and interference with synthetic processes.

General rules for use of chemical preservatives on food should be used. It should be used only at a dosage level that is needed for a normal preservation and not more than that prescribed in international standards. The use of chemical preservatives must be strictly limited to those substances which are recognized non-harmful on human health and are accepted by national and international standards and legislations.

c) *Biochemical methods (Fermentation)*

Figure 4.5 Fermented Chinese cabbage called kimchi

Fermentation is a process in which microorganisms change the sensory and functional properties of the food to produce end result that is desirable to the consumer. In contrast to physical and chemical methods of preservation which aims to decrease the number of spoilage microorganisms in food or control against further multiplication the biochemical method encourages the development of lactic acid forming bacteria and their metabolic activities in food preservation. Only microorganisms of choice are encouraged to grow for their desirable effects on food.

In the past, fermented products were developed mainly to preserve harvested products and to improve the sensory properties of an abundant and unappealing produce. The potential benefits of fermented food are increased food safety, health benefits, retail and nutritional value, sensory properties, digestibility, ease of storage and transportation and increased shelf life.

The principal group of microorganisms used for food fermentations include lactic acid bacteria, acetic acid bacteria, yeast and molds. Acidic fermentation can be achieved by natural acidification and artificial acidification. Natural acidification is achieved by lactic acid fermentation. In absence of oxygen and due to effect of additives such as salt, tissues of fruits and vegetables gradually die and lead to loss of cell membrane permeability. This leads to diffusion of soluble cell components into the solution, brine for instance and serves as substrates for microorganisms. Lactic acid as the main metabolic product is formed since the lactic acid bacteria overcomes other undesirable microorganisms in such specific conditions. Artificial acidification is achieved by addition of acetic acid in to the food. Preservation of food can be achieved by combined acidification which involves weak lactic acid fermentation followed by addition of vinegar (acetic acid).

Some of the food products developed through fermentation include alcoholic beverages such as beer and wine, and dairy products such as yogurt and cheese and fermented vegetables such as Korean kimchi, sauerkraut, pickles and olives. Animal products such as sausages and fish are produced as fermented foods.

d) Hurdle technology

A combination of one or more of the methods described above for synergistic preservation on food is referred to as hurdle technology. Hurdle in food is defined as the substance or the processing step or various preservation factors, inhibiting the growth of various microorganisms resulting in the death of microorganisms. Hurdle technology advocates the deliberate combination of existing and novel preservation techniques for establishing a series of preservative factors (hurdles) that any microorganisms present should not be able to overcome. The effect will be greater with increased hurdle. The microorganisms will not multiply or either dies when successful level of combination of hurdles such as pH, redox-potential, water activity, temperature, preservatives etc. is applied.

Physical hurdles include high temperature (blanching, pasteurization and sterilization) low temperature (chilling and freezing), electromagnetic radiation, packaging film, modified atmosphere packaging (gas, vacuum, moderate vacuum and active packaging), aseptic packaging, etc. Physico-chemical hurdles is a combination of physical and chemical preservation methods such as low water activity, low pH, low redox-potential, common salt (NaCl), nitrate, Carbon dioxide, oxygen, ozone, organic acids, lactic acid, lactate, acetic acid, acetate, ascorbic acid, smoking, phosphates, sulphites, phenols, ethanol, spices, herbs, etc. additionally, there is microbial derived hurdles such as competitive flora, protective cultures, bacteriocins and antibiotics. The main advantage of hurdle technology is development of high quality food that is shelf stable and having superior quality with minimum changes in its qualities.

4.3 Enhancing food preservation by indirect approach

a) Packaging

Direct approach to food preservation such as drying and freezing might lead to recontamination of the product. Therefore, indirect approach of food preservation like packaging can play an important role in producing high quality food. Food preservation through packaging is one of the oldest methods practiced by humans. Packaging performs five main functions (5Ps) namely, product containment, preservation and quality, presentation and convenience, protection, and provide storage history.

An ideal packaging should fulfill some important criteria listed below;

- Zero toxicity,
- High product visibility,
- Strong marketing appeal,
- Ability of moisture and gas control
- Stable performance over a larger temperature range
- Low cost and availability
- Suitable mechanical strength
- Ability to include proper labeling
- Resistance to migration or leaching of chemicals from package into the food product
- Protection from loss of flavor
- Controlled transmission of required or unwanted gases
- Closure characteristics such as sealing, resealing and pouring

There are several types of packaging materials used in food packaging. Plastics (polymers) are the fastest growing group of packaging materials due to its wide diversity and extremely broad spectrum of properties, plastics are also relatively cheap, light, easily processed and shaped, and easy to seal. The other widely

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used packaging materials are metals such as steel, tin and aluminum. The main advantages of metal cans in packaging are their strength providing mechanical protection, effective barrier properties, and resistance to high temperatures that provides stability during processing, protect light sensitive products. Some of the disadvantages of metal cans are invisible content, heavy mass, high cost, and tendency to interact with contents and environment. Glass containers are used as a prestigious means of packaging for products such as wines, liquors, and pickles. Glasses are highly inert, impermeable to gases and vapors, and amenable to the most diverse shaping, and product visibility. The main disadvantages are its fragility, heavy mass and high cost and high energy requirement during manufacturing.

Figure 4.6 Aseptic packaging in tetra packs to preserve food products

Pulp products in the form of paper, paperboard, and corrugated board are widely used in food packaging. The main disadvantages of paper packing are its low cost, low mass, high stiffness and excellent printability while its disadvantage is its sensitivity to moisture. Cardboard boxes are mainly used as a protective package or a presentation package. Some other material such as ceramics and metalized films are also used in food packaging.

b) Production of Value added products

There are diverse value added products from fruits, vegetables, cereals, dairies, meats and other sources. Some of the commonly processed value added products are described below.

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i. Jam, jelly, marmalade and preserve

Jam, jelly and marmalade preparation is based on concentrating fruits to nearly 70 per cent solids (TSS) by addition of sugar and heat treatment. An unfavorable condition is created for the growth and reproduction of most species of microorganisms i.e., bacteria, yeasts, molds responsible for the spoilage of food due to the high osmotic pressure of sugar. The water activity of the product is reduced which ultimately decreases the chances for microbial spoilage at this concentration of solids.

In the preparation of jam, the fruit pulp is boiled with sufficient quantity of sugar to a reasonably thick consistency which is firm enough to hold fruit tissues in position. Jam should not contain less than 68.5% soluble solids as determined by a refractometer (Instrument for checking total soluble solids). The major steps involved in preparation of jam are; selection of good quality fruit, preparation of fruit, addition of sugar and acid, mixing, cooking, filling, closing, cooling and storage. Jam may be made from a single fruit such as apple, mango, strawberry, banana, pineapple etc. a two or more fruits can also be combined to make a mixed jam.

Figure 4.7 Fruit jam, jelly and marmalad

Jelly is prepared by boiling a clear, strained solution of pectin containing fruit extract along with sufficient quantity of sugar and acid. Jelly is a semi solid product and a perfect jelly should be transparent and well set with original flavor of the fruit, firm enough to retain a sharp edge and should be tender enough to resist the applied pressure. It should not be too stiff, gummy, sticky, and syrupy or have crystallized sugar. Fruits like guava, papaya, plum, gooseberry etc. are used for preparation of jellies. Fruits such as pineapple, apricot, raspberry etc which

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contain low amount of pectin can be used after adding small amount of pectin powder. Pectin, water, acid and sugar are essential substances for processing of jelly. A good quality jelly is formed only when the concentrations of mixture of water-sugar-acid-pectin attain a certain minimum value.

Marmalades are generally made from citrus fruits such as orange. A shred of citrus fruits or peels are suspended in the marmalade. Preserves on the other hand are prepared from by addition of sugar to whole fruits and vegetables followed by evaporation to a point where microbial spoilage cannot occur. The soluble solids concentration of about 70 per cent is to be reached at the end and it can be stored without hermetic sealing and refrigeration.

ii. Sauces and chutneys

A mixture of fruit or vegetable with spices, salt and/or sugar, vinegar, etc is known as chutney. It should be smooth, palatable and appetizing with flavor of the fruit or the vegetable used. Chutneys can be processed from fruits and vegetables such as tomato, mango, gooseberry, etc. Sauce on the other hand differs from chutney in that it does not contain skin, seeds and stalks of fruits and vegetables and it is thinner and smoother consistency. The common preservatives used in these products are vinegar, salt, sugar and spices while chemical preservatives such as sodium benzoate and potassium metabisulphite are used for long-term storage help to help retard the growth of microorganisms.

iii. Pickles

Pickling is the process of preserving food in common salt or in vinegar, spices and edible oil. Pickles may be sour, sweet or mixed and can be grouped as unfermented and fermented pickles. Fermented pickles undergo lactic fermentation while unfermented pickles are preserved by use of various spices and oil. Pickles can be processed from chilli, mango, bamboo shoot, radish, etc.

Figure 4.8 Pickles

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iv. Fermented products

Fermented products are produced through lactic acid, acetic acid and alcoholic fermentation process. Alcoholic fermentation occurs due to yeasts and lactic fermentation by bacteria. Lactic fermentation involves fermentation of carbohydrates into lactic acid by lactic acid bacteria to prepare fermented pickles such as sauerkraut, fermented olives etc. Acetic fermentation involves alcoholic fermentation followed by acetic fermentation for the manufacture of vinegar. Vinegar can be prepared from a number of fruits such as grapes, apple, oranges etc. Yogurt, fermented cheese, alcohol, kimchi, sauerkraut, etc., are all products of fermentation.

v. Fruit juices

Fruit juices are preserved in different forms such as pure juices and beverages and beverages are further classified into two groups called unfermented and fermented beverages. Fruit juices that do not undergo alcoholic fermentation are termed as unfermented beverages and include natural and sweetened juices, ready-to-serve beverage, nectar, cordial, squash, syrup, fruit juice concentrate and fruit juice powder. Fermented beverages are those that have undergone alcoholic fermentation by yeasts and bacteria. They include wine, champagne, port, cider, etc. juices and beverages can be preserved by pasteurization, carbonation and use of chemical preservatives (potassium metabisulphite, sodium benzoate, etc).

Figure 4.9 Fruit juice and squash

vi. Dried products

Fruits or vegetables may be dried mechanically or under the sun for increasing their shelf life. Some of the dried products include raisins from grapes, dried vegetables, dehydrated powders of citrus for reconstitution into a refreshing beverage, and dehydrated onions and ginger, etc.

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vii. Baked products

Several agricultural produce can be used for baking of cookies, cakes, doughnuts, breads, etc. Flours from cereals such as wheat, buckwheat, etc are mostly used as main ingredient for baking of goods.

c) Food quality and safety

The basic quality and safety measures should be adapted during and after processing so as to produce and maintain a food that is safe to consumers. The basic functions of a food quality and safety control programs are:

1. Physical and chemical evaluation of raw materials and processed products
2. In-process control of raw materials, ingredients, packaging supplies, processing parameters and finished products
3. Microbiological analysis
4. Control of storage and handling conditions
5. Sanitation and control of waste products
6. To assure and produce final products that are within the legal and established marketing standards

The quality of food can be ensured through quality control and quality assurance. Quality control refers to evaluation of a final product prior to its marketing while quality assurance is the implementation of quality checks and procedures to immediately correct any failure and mistake at every production step to be able to reduce the quality of the products. A good manufacturing practice (GMPs) should be followed to meet the desired final product which is safe for consumption. Good Manufacturing Practices (GMPs) are guidelines that deal with persons involved in food processing, building, premises as well as construction and design. It assures that the food for human consumption is safe and has been prepared, packed and held under sanitary conditions.

To assure that final food products meet safety and quality requirement a general points to be followed during processing are;

1. Follow state regulations and laws regarding food processing
2. The employees should be educated and trained in proper food handling

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practices and personnel hygiene

3. Good Manufacturing Practices (GMPs) should be strictly followed or adhered
4. Food processing and storage areas need to be designed to allow for easy cleaning and sanitation
5. Raw materials for processing should be checked and monitored for quality
6. Processing facility and the surrounding should be clean and free from litter
7. Enclose processing facility completely by walls from the outside environment
8. Food processing area should be free of windows or other glass panes
9. Maintain processing facility including floors, walls and ceilings clean
10. Lighting should be adequate in the processing facility protected in case of breakage
11. Suspension of pipes, ducts and fixtures to be avoided over processing areas
12. Water quality should be monitored regularly and only potable water is to be used
13. The processing area and food rooms should be separated from toilet facilities
14. Establish a written sanitation schedules and procedures and monitor on a regular basis with proper documentation
15. Effective program to control rodent and insect should be taken up at regular intervals
16. Workers should be regularly checked for any contagious diseases

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Student Activity

Discuss with students the options of carrying out activities on this chapter, group them into manageable and assign them activities such as:

1. ***Activity***: Survey to compare the cost of agriculture produce and the value added food products sold in the market, compare quantity and quality, choice of consumer against health benefits, date of expiry and the reason for the cost.
2. ***Activity***: Prepare values added and preservation of agriculture produce of student's choice such as (a) Vegetables, (b) Fruits and (c) any other agriculture produce following the lesson learned from this chapter.
3. ***Activity***: Organise value added food tasting competition and award prizes and marks.

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Chapter 5

Starting a Fish Farm

Nutrient security is one of the sustainable development goals. Many important nutrients are available through fish. It provides proteins, lipids, minerals, and vitamins. Currently, we import fish products and by-products from neighbouring countries, and it contributes to Bhutan's huge trade deficit. Therefore, we need domestic production to meet the demands and there is an ample opportunity to pursue fish farming entrepreneurial ventures in its products and by-products. Therefore, this chapter gives information about fish farming or pisciculture, a husbandry of growing economically important fish. These fishes grown in Bhutan are discussed in detail. The detail managemental practices such as pre-stocking, stocking, and post-stocking must be understood to have successful fish farms. Moreover, we need to understand the post-harvest changes that take place which deteriorates the quality of fish which entails identifying fresh and spoilt fish. Therefore, student activities are recommended to provide experience and skills in pisciculture.

Fish farming comes under Aquaculture. Aquaculture is the farming of aquatic organisms including fish, molluscs (mussel, pearl oysters etc.), crustaceans (prawn, shrimp, lobsters, etc.) and aquatic plants (sea weeds). Fish Farming implies some sort of intervention in the rearing process to enhance production, such as regular stocking, feeding, protection from predators, harvesting. It also implies individual or corporate ownership of the stock being cultivated". The term Aquaculture includes:

- The type of aquaculture system utilized eg. ponds, cages, raceways, pens, rack, raft etc.
- Type of organism cultured eg. Fish, prawn, crustaceans, sea weeds etc.

Aquaculture particularly fish farming is an age old practice. In China, carps were cultured as long as 2698 B.C. in ponds on silkworm farms. Fan Lai, a Chinese fish farmer has credit of having first written account of fish farming in ponds

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in 475 B.C, in his book titled "The Classic of Fish Culture". Similarly, Romans introduced carps from Asia to Greece and Italy. By seventeenth century carp was being cultured all around Europe. Apart from carps, the culture of tilapia, catfishes, salmonids, and mullet flourished around the world.

In Bhutan, aquaculture, particularly fish farming was introduced during 1980's with the establishment of Fish Seed Production Centre at Gelephu, currently known as National Centre for Aquaculture, under the Department of Livestock, Ministry of Agriculture and Forests. In Bhutan fish farming is more prominent along the southern foothills where temperatures are more favorable. However, it is hoped that fish farming will gain popularity in other suitable places in Bhutan and will be able to reduce fish import that creates trade deficit affecting Bhutanese economy.

5.1 Pisciculture or fish culture

Pisciculture or fish culture, included under the broad term "aquaculture" can be defined as the "farming and husbandry of economically important fish, under controlled conditions". Based on the environment in which the culture is done, fish farming may be categorized into freshwater fish farming, brackish water (intermediate between freshwater and salt water which is found in estuaries, or in meeting point of river and sea) fish farming and saltwater of marine fish farming (mariculture). In Bhutan, fish farming is solely freshwater based carp polyculture in earthen ponds. Carp are various species of oily freshwater fish of the family Cyprinidae, a very large group of fish native to Europe and Asia.

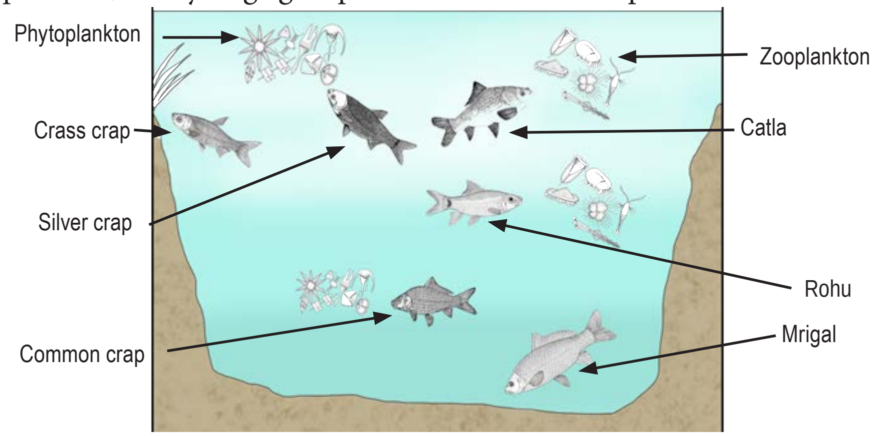

Figure 5.1 Polyculture of carps (Catla, rohu, mrigal, silver carp, grass and common carp)

Polyculture is culture of more than one species of fish in same pond. Fish ponds with help of fertilization or feeding practices contain abundant natural fish food organisms (planktons which are microscopic in nature and compromise of the plant component known as the phytoplankton, the animal components known as the zooplanktons). Most fish feeds on selected group of these organisms. Hence, polyculture combines fish having different feeding habits in ratio such that they can effectively utilize these organisms. As a result, higher yield are obtained.

a) Importance of Fish

Fish contains water, proteins and other nitrogenous compounds, lipids, minerals and vitamins. The main constituent of fish flesh is water, which usually accounts for about 80 per cent of the weight of a fresh fish. In general, the protein content of fish varies from 15-20% of body weight. The advantage of fish protein is that they contain all the essential amino acids in required proportions. Fish fat which varies from 15-18% of the body weight, are source of polyunsaturated fatty acids which are helpful in cholesterol regulation and promoting cardiac health.

Fish meat is generally good source of vitamin B, and the meat of fatty species, especially in the liver of species such as cod and halibut are good source of fat soluble vitamins A and D. As for minerals, fish meat is a valuable source of calcium and phosphorus as well as iron, copper and trace elements like zinc and selenium. In addition, saltwater fish contain high levels of iodine.

b) Fish in human health

Regular consumption of fish can reduce the risk of various diseases and disorders. Selected research findings indicate the following:

1. ***Asthma*** - children who eat fish may be less likely to develop asthma.
2. ***Brain and eyes*** - fish rich in omega 3 fatty acids can contribute to the health of brain tissue and the retina.
3. ***Cancer*** - the omega 3 fatty acids in fish may reduce the risk of many types of cancers by 30 to 50 per cent, especially of the oral cavity, esophagus, colon, breast, ovary and prostate.
4. ***Cardiovascular disease*** - eating fish every week reduces the risk of heart disease and stroke by reducing blood clots and inflammation, improving blood vessel elasticity, lowering blood pressure, lowering blood fats and boosting 'good' cholesterol.

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5. ***Depression*** - people who regularly eat fish have a lower incidence of depression (depression is linked to low levels of omega 3 fatty acids in the brain).
6. ***Diabetes*** - fish may help people with diabetes manage their blood sugar levels.
7. ***Eyesight*** - breastfed babies of mothers who eat fish have better eyesight, perhaps due to the omega 3 fatty acids transmitted in breast milk.
8. ***Prematurity*** - eating fish during pregnancy may help reduce the risk of delivering a premature baby.

c) Characters of cultivable fish

Selecting proper fish species is one of the important aspects in fish farming. Followings are the criteria to be considered while selecting fish species for culture:

1. ***Rate of Growth:*** Fish which grows to larger size within shorter duration are suitable for culture.
2. ***Adaptation to climate:*** The selected species of fish should be able to adapt to local climatic condition of the farm area.
3. ***Resistance***: the cultured fish should be hardy enough to resist the common disease and attacks of parasite.
4. ***Acceptance of artificial feed:*** When fishes are stocked in high number in fish ponds, there is need for supplementary feedings as the available fish food organisms are not sufficient for fish. Hence in such cases, the fish should show preference towards these feeds.
5. ***Tolerance:*** The fish should be able to tolerate wide fluctuations of physio chemical conditions such as oxygen, temperature etc.
6. ***Compatibility:*** The fish proposed to be cultured together (polyculture) should be non-predator and compatible without infringing or attacking each other.
7. ***Feed Conversion Efficiency:*** The species of fish which gives more edible flesh per unit of feed consumed is preferred.
8. ***Consumer preference:*** Must have a good demand market demand and should be easily marketable locally or to the targeted consumers.

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d) Cultivable fish species in Bhutan

Polyculture of six carp species are currently popular in Bhutan. These includes all the three species of Indian major carps (IMC's), namely catla (*Catlacatla*),rohu (*Labeorohita*) and mrigal (*Cirrhinusmrigala*); two species of Chinese carps, namely silver carp (*Hypophthalmichthys molitrix*) and grass carp (*Ctenopharyngodonidella*) and the European common carp (*Cyprinuscarpio*).

i. Catla (Catlacatla)

Catla have deep body with prominent head, large upturned mouth with non-fringed lips, devoid of barbels. It is surface feeder, filter feeding on zooplankton present within pond surface. It uses its gill rakers to filter the zooplankton, however, young ones feed on phytoplankton. In Bhutan it grows to maximum size of 300-500 gm during the first year.

Figure 5.2 Catla

ii. Rohu (Labeorohita)

This is considered as tastiest among the carps. It has small and pointed head, terminal mouth with fringed lower lip and dull reddish scales. It is column feeder which feeds on phytoplankton, plant debris or decaying debris of aquatic plants; however young ones feeds on zooplanktons. In Bhutan it attains maximum size of 150-200 gm during the first year.

Figure 5.3 Rohu

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iii. Mrigal (Cirrhinusmrigala)

A linear body with small head; snout is blunt, sub terminal mouth with thin non fringed lips; pair of barbel, bright silvery body with golden tinge are its identifying features. It is bottom feeder feeding on decaying organic and vegetable debris; however young one feeds on zooplankton. Its growth during the first year in Bhutan is same as that of rohu.

Figure 5.4 Mrigal

iv. Silver carp (Hypophthalmichthys molitrix)

Upturned mouth, laterally compressed body with small silvery scales is its identifying features. Silver carp are typical planktivores, the gillrakers being the main means of filtration. They are surface feeders and mainly consume phytoplankton; small crustaceans are other major components of their natural diet. During the first year of culture cycle it can grow attain 300-500 gm.

Figure 5.5 Silver Carp

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v. Grass carp (Ctenopharyngodonidella)

Body elongated and cylindrical, round abdomen. Body is greenish yellow laterally, dorsal portion dark brown; grayish white in abdomen. Broad head with terminal mouth; upper jaw extends slightly over lower jaw, Broad head with rounded snout. Moderately sized scales with light greenish tinge. Grass carp normally dwell in mid-lower layer of the water column and feeds on aquatic weeds and terrestrial grasses and vegetable matters. It can consume four times its own weight of which 50% is defecated in semi digested condition. It is fast growing species attaining about 0.5-1.0 kg during the first year.

Figure 5.6 Grass Carp

vi. Common carp (Cyprinuscarpio)

Deep, elongated and somewhat compressed body, colour variable, the fins are dusky ventrally with a reddish tinge. Short head, lips thick; two pairs of barbels at angle of mouth, shorter ones on the upper lip. With or without scales (depending on the variety). Carp are omnivorous and bottom feeder, with a high tendency towards the consumption of animal food, such as water insects, larvae of insects, worms, molluscs, and zooplankton. Additionally, the carp consumes the stalks, leaves and seeds of aquatic and terrestrial plants, decayed aquatic plants, etc. It is hardy fish with fast growth and can attain 500 gm-1.0 kg in Bhutan.

Figure 5.7 Common carp (Cyprinuscarpio var. specularis- mirror carp)

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Catla, rohu and mrigal are suitable for culture along the southern foothills and the optimum temperature required for these warm water fish is 25-32°C. Silver carp, Grass carp and common carps are suitable for culture in higher altitudes like Tsirang and Dagana however, silver carp is less hardy fish with lower tolerance towards to transportation.

Table 5.1 Feeding habits of cultivable carps

Species	Feeding Habits
Silver carp (*Hypophthalmichthys molitrix*)	Surface feeder - Phytoplankton
Catla (*Catlacatla*)	Surface feeder - Zooplankton
Grass carp (*Ctenopharyngodonidella*)	Surface/column feeder – Aquatic grass and plants
Rohu (*Labeorohita*)	Predominantly column feeder - phytoplankton, plant debris or decaying debris of aquatic plants
Mrigal (*Cirrhinusmrigala*)	Bottom feeder – Detritus (decaying organic and vegetable debris)
Common carp (*Cyprinuscarpio*)	Bottom feeder – Omnivore (water insects, larvae of insects, worms, molluscs, and zooplankton. Additionally, the carp consumes the stalks, leaves and seeds of aquatic and terrestrial plants)

In contrast to these stunted fingerlings are reported to attain up to 1 kg size during 8-10 months of culture duration.

The technology of stunted carp fingerling production and subsequently raising to table fish is developed by fish farmers of Andhra Pradesh. This technique involves stocking fingerling in high density and sub optimal level of feeding (maintenance feeding), over 4-5 months during winter season. The assumption is that the weaker ones dies and the surviving ones gets stunted in growth. When these stunted fingerlings are then reared under optimal conditions then they exhibit good survival rate and faster growth rate within short culture duration. Further, the stunted fingerlings are less vulnerable to predation, disease and are more tolerant to environmental fluctuations.

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5.2 Procedures of fish farming

Broadly, various steps fish farming can be classified into following three categories namely pre-stocking Management, stocking management and post-stocking management practice.

a) Pre-stocking Management Practice

The word pre-stocking is divided into two words. "Pre" means before and "stocking" means storing or introducing. So, literally pre-stocking management means, management practices which are to be followed in fish pond before stocking of fish. The followings are the main purpose of pre-stocking management practices:

- Eliminate poor survival rate and unsatisfactory growth,
- Reduce the chances of disease outbreak,
- Ensure availability of natural fish food organism in sufficient quantity and quality

Pre-stocking includes in following sequence.

i. Conditioning or Liming

Figure 5.8 Liming of fish ponds

In case of newly constructed fish ponds, a layer of lime is spread over the bottom and side of the ponds. It removes the acidity of soil and buffers against drastic change in pH, kills unwanted soil organisms and facilitates desirable geochemical cycles. Two weeks after liming, water may be let in the fish ponds to desirable depth (1-1.5 m, the desirable depth of fish pond is 1.5-2.0 m). Liming is usually done at the rate 200 kg/ha/year.

ii. Manuring

15 days after liming, manuring is to be done to develop fish food organism (plankton). Organic as well inorganic manures and fertilizers can be used. Organic manure may be animal urine, cow dung, pig dung, poultry manure, compost etc.

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Cow and pig dung can be used at the rate 2000 kg/ha and poultry manure at the rate 1000 kg/ha of pond surface area during the pond preparation. Ammonium sulphate, single super phosphate and triple super phosphate can be used at the rate 30 kg/ha, 2/ha and 8 kg/ha as monthly installments (1 ha = 10000 sq.m). The manures can be dumped in various corner of fish ponds and in case of chemical fertilizers, they can be put in sacks and hanged along the water column.

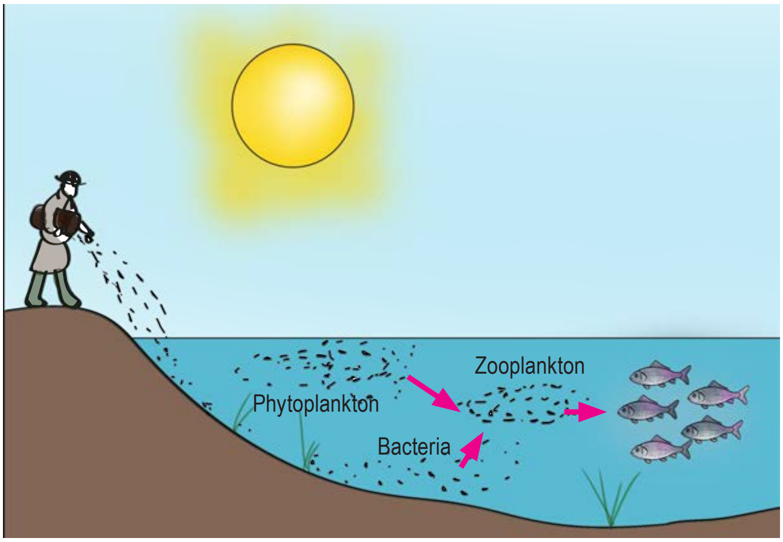

Figure 5.9 Importance of manuring

However, in case of ponds which have been used for culture, all fish must be harvested, which involves complete draining of fish ponds; then it should be dried for two to three weeks during which it facilitates decomposition of built up organic matter in soil. When pond is being dried, outlet and dikes (walls) of ponds should be repaired and strengthened. This will then be followed by liming and manuring.

b) Stocking Management Practices

These practices refer to the act of releasing fry/ fingerling or fish in ponds, rivers or any other water bodies. Package of methods to be followed during stocking is known as stocking management practices. Stocking is among the most stressful process, the fish go through in the course of production. The purposes of stocking management practice:

- To prevent mortality due to sudden change in temperature and other water quality parameters,

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- To ensure adequate natural food is there within the pond before stocking the pond with fish.

Points to be considered during Stocking are:

i. Time of Stocking

- The fingerlings should be stocked preferably during early morning or evening hours when the temperature is cool.
- If stocking is done during afternoon hours then, mortality due to thermal shock is inevitable. Never stock your ponds during afternoon hours.
- Do not stock when there is rainfall.
- Ensure availability of sufficient planktonic organism within the pond water. This can be judged by greenish water colour due to presence of fish food organisms (planktons). It can be achieved within one to two weeks after fertilization.

ii. Stocking Density

- Fish should be stocked @ 1 fingerlings/sq.m (fish which is about size of finger, 4-10 cm is known as fingerling). Over stocking should be avoided to prevent sub optimal growth.
- The required amount of fingerlings can be procured from the carp hatchery of National Centre for Aquaculture, Gelephu and Regional Centre for Aquaculture, Phuntshothang.

iii. Acclimatization

Fish is usually transported in plastic bags which contains 1/3 of water and 2/3 oxygen. By doing so fish can be transported to longer duration. However, since the water quality parameter (pH, temperature, etc.) of transport water is not same with that of the pond water, acclimatization is mandatory to prevent mortality of fish due to sudden thermal shock or pH shock. Acclimatization is the process in which an organism is adjusted to a gradual change in an environment (such as a change in temperature, pH etc.), so that it gets adapted to it. Acclimatization of fish should be done as follows:

- Float the plastic bag on the surface of pond water for 15-20 minutes during which the fingerling gets acclimatized to temperature; then open its mouth.
- Gradually add the pond water inside the transport bag, during which the fingerlings gets acclimatized to pH of water in the stocking pond.

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- The amount of water added should be double or triple the amount already in the bag.
- Slowly dip and tilt the transport bag so that all the fingerlings swim out.
- Allow the fingerlings to swim on its own and observe how it swims.

c) Post-Stocking Management Practices

Post-stocking management refers to those practices which are to be followed after stocking fish in a pond. It involves supplementary feeding, maintenance of optimum productivity of fish pond and maintenance of pond environment suitable for fish husbandry. The main purpose of post stocking management practices are

- To ensure optimum growth of fish through proper feeding.
- To ensure adequate natural food within the pond during the culture cycle.
- To ensure optimum environment during culture cycle thereby preventing disease, mortality and unsatisfactory growth.

i. Supplementary feeding

It refers to feeding fishes. Fish needs more food than what is usually present in the fish pond, hence apart from natural food, they should be provided with artificial feeds such as commercial pellet feeds or locally formulated feeds. Local cereals like mustard oil cake, rice bran, maize flour etc. can be used to formulate the feed. The daily supplementary feeding should be provided at the rate 2-3 % of the standing biomass of fish in the pond. Grass carps should be provided with napier, tender leaves of vegetables such as cabbages, cauliflowers, banana leaves etc.

The daily feed requirement should be split into two halves and should be done two times a day, half during morning and other half during evening hours at same time and same place. (Preferably 8-9 PM and 5 PM). The feed can be dispensed within two to three sites within fish ponds.

ii. Regular Fertilization

In order to maintain the optimum productivity in fish ponds regular fertilization should be done during course of culture cycle. Cow dung, poultry manure and pig dung can be used at the rate 1000 kg/ha, 240 kg/ha and 480 kg/ha as monthly dosage. Ammonium sulphate, single super phosphate and triple super phosphate can be used at the rate 30 kg/ha, 2/ha and 8 kg/ha as monthly installments. The application will be more effective if the monthly dosage is split and applied on

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daily basis. Bio gas slurry can be used at the rate 20 l/ha as daily dosage.

iii. Water quality and health management

Maintenance of pond environment suitable for fish farming is one important thing to be considered. Temperature should be preferably in range of 25-32 °C, dissolved oxygen should be not less than 5 ppm and pH should be in range of 6-9. Replenishment of water, observation of mortality and disease symptoms should be done and during case of disease and high mortality it should be immediately reported to livestock officials.

iv. Harvesting

It is the final step in fish farming and is done usually after completion of culture duration which may vary from 6-12 months. Harvesting can be either complete or partial. Complete harvesting is done whenever the growth rate of stocked fish is found to be uniform where as partial harvesting is done when there is no uniformity in growth. The pond is netted several times during partial harvesting so to harvest larger fish. Smaller fish gets retained within ponds. The harvested ones are then replaced with required number of fingerlings. In case of complete

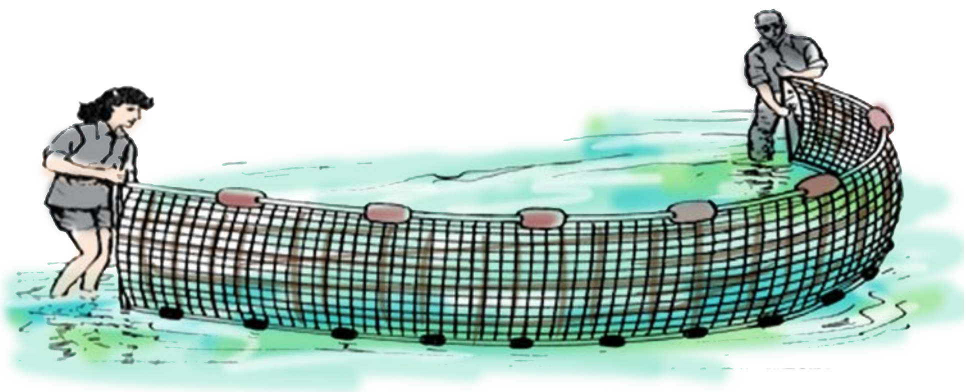

Figure 5.10 Harvesting of fish using drag net

harvesting, the ponds are dragged several times and are completely drained to harvest the remaining fish.

After these the sequential steps mentioned for fish farming should be followed which starts with drying, liming, manuring and so on.

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5.3 Post-Harvest Technology

As discussed in class X, post-harvest technology is the science of keeping agriculture fresh before the produce reaches the consumers. It is important to understand what happens to the fishes after they are harvested so that farm management can take care of harvested fishes. Spoilage of fish begins as soon as fish dies. It is as result of series of deteriorative changes which are broadly classified into autolytic, bacterial and chemical changes.

a) Autolysis or self-digestion

It is breakdown of tissue caused by enzymes which acts as biological catalyst in chemically breaking down the food taken in by the fish. They are very powerful in their action and their action is controlled in the live tissues. As soon as fish dies, the control is lost and the enzyme which still remains active acts on fish muscle instead of acting on food. This results in softening of fish flesh. In addition to these naturally occurring enzymes in fish, bacteria which are introduced into fish muscles, and those present in gills and intestines secretes enzyme which also acts on fish flesh.

b) Bacterial decomposition

Bacteria are not present in flesh of living fish. However, shortly after the capture they enter the flesh by way of the gills, kidneys, blood vessels and skin. Also, soon after death, the body's defense mechanism against this invasion ceases to operate, and bacterial activity is enhanced. The bacteria grow rapidly and increase in number so fast that, unless checked, they continue their spoiling action. They have been found to be most active spoilers of fish. Since spoilage starts from surface, we can prevent contamination of fish muscle by proper washing, gutting and chilling.

c) Chemical Changes

In addition to the above two changes, chemical changes involving oxygen from air and the fat in the flesh of fish can produce rancid odours and flavours. These changes overlap with enzymatic and bacterial activities. Rancidity develops more in fatty fish (7-25% fat content) than in lean fish (0.3-3% fat content).

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Table 5.2 Characteristics of fresh and spoiled fish

Quality Parameters	Fresh Fish	Spoiled Fish
Eyes	Bright and bulging; transparent cornea, velvet black pupil	Dull, wrinkled and sunken, opaque cornea, dull black pupil
Gills	Bright red, covered with slime; odour under gill cover is fresh	Dull brown or grey with cloudy slime; odour under gill cover sour and offensive
Flesh	Firm; body is stiff; impression made by finger does not remain	Soft and flabby, impression made by fingers remains
Body	Stiff	Flaccid
Vent	Pink and not protruding	Brown and protruding
Odour	Fresh, fishy odour	Stale, sour or putrid
Colour	Bright	Faded

d) *Handling of fish*

Care, cleanliness and cooling are the three important ways of preventing fish from spoiling too quickly. Care in handling is essential to prevent unnecessary damages (cuts, wounds) which provide access to spoiling bacteria. Fish is soft and fragile and hence proper care must be taken from the time of caught till it reaches consumers. Cleanliness should be observed throughout the fish handling chain. All surfaces which may come in contact with fish should be cleaned and kept as free as possible from bacteria-laden materials. Fish will remain longer if they are kept free from contamination with bacteria. Temperature is most important factor in controlling the speed at which fish spoils. The higher the temperature, the faster the bacteria multiply; the lower the temperature, slower the bacterial and enzymatic activities. Therefore, the most important step to slow down these activities is to lower the temperature of fish near to 0˚C, as quickly as possible.

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5.4 Preservation of fish

Fish is highly perishable food commodity and hence application of appropriate preservation techniques is necessary to retain the quality and extend shelf life. Of various techniques for preservation of fish such as canning, freezing, drying etc.; preservation of fish by ice storage, salting and smoking are discussed here in detail.

a) Ice storage

Icing is one of the methods deployed for preservation of fish. The major advantage of using ice for chilling is that it is capable of removing large amount of heat (high latent heat of fusion) as it melts without changing temperature at 0˚C. During transition from ice to water, 1 kg of ice absorbs 80 kcal of heat and this will be sufficient to cool about 3 kg of fish from 30˚C to 0˚C. However, since ice is needed to maintain temperature and control heat from environment, 1:1 fish to ice ratio is ideal for ice storage in tropical conditions. Icing of fish can slow down the spoilage process, but it cannot stop it. Therefore, it is a race against time and fish should be moved to consumer points as quickly as possible.

Boxing is one of methods employed during ice storage. The bottom of the box is covered with ice followed by alternate layers of ice and fish; and subsequently ice on top of box, until it is almost full. The boxes are then kept one above another. Sometimes insulated boxes are also used for ice storage of fish. By keeping your catch well iced, carps can be stored in good condition for 16-21 days in tropical conditions.

Figure 5.11 Icing preserves fish and extends shelf life by lowering temperature

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b) Salting

This is one of the oldest methods of fish preservation. During salting osmotic transfer of water out of the fish and salt into fish takes place, absorbing much of the water in fish and makes it difficult for micro-organisms to survive thereby prolonging the storage life. It also limits enzymatic activity. Of various method of salting dry salting or kench salting is described here.

c) Dry salting

Coarse salt is more suitable for dry (kench) salting. Fine salt will draw water too quickly from the outside of the fish, making the outside hard. As a result, the water inside the fish cannot escape and the salt cannot penetrate deep into the fish. Therefore, the fish spoils despite being salted. This is known as "salt burn". Coarse salt does not have this effect. Salted fish have longer shelf life of few months depending upon methods and species used. 3 parts of salt should be used for every10 parts of fish.

Procedures

1. Remove the scales, gills, and viscera of fish and wash it thoroughly. Head can be discarded or retained. Small fish can be used as whole; large fish should be split into half from head to tail so that all the fish flesh will get exposed to salt.
2. Rub the fish well with salt. Use more salts where deep cuts have been made or where the flesh is thicker.
3. Put a thick layer of salt in the bottom of the basket or container.
4. Place one layer of fish with the skin facing up on the salt. The fish are not allowed to overlap.
5. Follow with one layer of salt, one layer of fish, etc. until the basket is full. The last layer should be of salt.
6. Cover the basket with a layer of plastic and put any weights on it and leave the fish in the container for 3-15 days. By adding salt to fish, moisture is drawn out of the fish. This moisture, with the salt dissolved in it, is called brine.
7. Remove the fish from the container when they are fully salted. The fish are properly salted when they are firm and have a whitish salt layer on

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their flesh. A fishy smell and the smell of brine must dominate

8. Place the fish on a flat surface and press them down with boards and weights to make them as flat as possible before drying in sun for desirable duration.

9. Pack and store fish in water proof packaging materials.

Figure 5. 12 Salting of fish

d) Smoking Fish

Smoking is another traditional method of preserving fish. It is generally a combination of salting and drying. Smoked fish are prepared in a smoke house which is merely a shed or a box over a fire which is controlled so that it produces smoke instead of flames. The preserving effect of the smoke is a result of drying (withdrawal of moisture) of the product during the smoking. The smoke particles, absorbed by the flesh, also have a preserving effect. The smoke particles, after being absorbed by the product, inhibit bacterial growth on the surface of the product. The smoke particles also have a positive effect on the taste and colour of the product. Nya-Doesem is traditionally smoked fish prepared from wild fishes (particularly snow trout's) and has its origin from Harachhu region of Adang Gewog in Wangdue Phordang.

Figure 5.13 Nya-Doesem

Method

After the scales, gills and viscera are removed, they are split from head to tail. They are then washed in freshwater and placed in saltwater brine made by dissolving 1 kg of salt in one liter of water for one hour. Then the fish are removed from the brine and washed in clean, fresh, water again. The fish are then drained and hung in a cool breezy place for about an hour.

At this point, the fire can be built in the smokehouse. While the fishes are being smoked properly, place the fish on hooks and hang (or tie) the fish in the top of the smoke house. Make sure the fish are placed securely so they will not drop. Watch the fire carefully to make sure it is smoking, and not burning, the fish.

After the fish are smoked for six hours, they can be eaten immediately, or stored in jars (to be canned), or stored frozen or refrigerated until they are eaten. Smoked fish do not last as long as salted fish, so do not smoke all of the fish, unless it will be used soon after harvesting. Smoked products have shelf-life ranging from few days to few months depending upon the species used and smoking method employed.

Aquaculture, particularly fish farming is one of the easiest and profitable ventures among various farming methods. It has great scope for development in Bhutan citing the annual increase in import and consumption of fish and fishery products over the years. In addition to the carps, Bhutan has huge potential for trout farming within the northern belt where temperature is favorable for trout's culture.

Pursuing entrepreneurship in pisciculture can improve nutrient security and help in alleviating poverty as there are possibilities to start fish farms in small-scale. This will also help in meeting the domestic needs of fish and related products in Bhutan. In turn, it will help in reducing imports and our trade balance can improve too. Therefore, generating self-employment through entrepreneurial venture is crucial for Bhutan as the employment in the government is getting saturated year after year.

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Student Activity

1. Plan and start a fish culture in a pound (if your school is in the Southern region and if fresh water is not a problem).
2. Contact officials of the Fish Seed Production Centre at Gelephu or National Centre for Aquaculture (NCA), department of Livestock, Ministry of Agriculture and Forests, to support your experiment as a part of implementing AgFSC in school.
3. Start fish culture on a small scale following the procedures of the text analytically, plan a field trip to a fish farm and learn about aquaculture or invite an expert from MoAF or NCA as a guest speaker to your school.

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6 Chapter

Starting a Goat Farm

Goats are usually referred to as "poor man's cow," and provide crucial nutrients to rural and urban poor. They are reared worldwide with limited resources including weeds. This chapter aims at providing basic ideas of goat farming and its management to generate income by the farmers with limited land and other resources. Many breeds of goats are available and some of them are discussed in this chapter. Moreover, breeding strategies, management, housing, diseases, and record keeping are included.

Figure 6.1 goat

Goats (Capra hircus) are one of the earliest ruminants to be domesticated and are found world-wide. They are used for producing milk, meat and fine fibres. Besides, goats are being used for biological control of troublesome weeds in many countries. These animals have ability to utilize and survive on otherwise wasted fodder resources such as weeds (Artemisia, Eupatorium and other wasted plants) which are less palatable to other livestock.

Goat population in Bhutan is concentrated in sub-tropical belt viz. Chukha, Samtse, Sarpang, Tsirang and Dagana dzongkhags. They are used for meat, manure, religious offerings and commercial purposes. Goats are mostly reared by poorer section of rural communities. Goat milk has smaller fat globules thus it is easily digested by human babies than milk from other livestock. In Switzerland, babies are fed with goat milk abundantly. Thus, goats are also called 'Swiss baby's foster mother'.

This chapter aims at providing basic ideas of goat farming and its management as a mean to generate income by the farmers with limited land and other resources. Varieties of goat breeds are available and some of them are discussed in this chapter.

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6.1 Goat breeds and breeding

a) Breeds for milk production

i. Saanen

The breed has originated from Saanen valley in Switzerland. This is a popular dairy breed known for persistent high milk production. Saanens are the largest and one of the calmest of the dairy breeds.

The Saanen breed also produces the most milk on average and tends to have a lower butterfat content, about 2.5%-3%. Milk yield: 2.4-3.0 litre/day (max: 6.2 litre/day).

Figure 6.2 Saanen

ii. Alpine

It is also known as French Alpine. This breed originated in Alps in France. The Alpine dairy goat is a medium to large size animal, alertly graceful, and the only breed with upright ears that offers all colours and combinations of colours giving them distinction and individuality. They are hardy, adaptable animals that thrive in any climate while maintaining good health and excellent production. The hair is medium to short. Milk yield: 2.0-2.5 litre/day.

Figure 6.3 Alpine

iii. Nubian

The Anglo-Nubian, or simply Nubian in the United States, was developed in Great Britain by crossing of native milking stock and goats from the Middle East and North Africa. Its distinguishing characteristics include large, pendulous ears and a "Roman" nose. It is considered a dual-purpose goat breed used for milk and meat production.

Figure 6.4 Nubian

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b) Goat Breeds for meat production

The Boer goat of South Africa is a meat type goat with good conformation, high growth rate and fertility. They are well known goat breeds for meat production. Live weight of doe: 80-100 kg, buck: 90-140 kg

Figure 6.5 Boer

c) Dual purpose goats

Four dual purpose goat breeds were imported to Bhutan for breeding trials with the objectives to improve the local goats.

i. Beetal

Figure 6.6 Beetal

The breed originates from Gurdaspur and Amritsar district of Punjab, India. It is also known as Amritsari goat. Beetal is considered to be a good milker with large body size and high fecundity. It usually gives birth to two or three kids at a time. The skin of these goats is considered to be of high quality because of larger size and yield finest leather such as velour, suede and chamois for manufacturing clothes, shoes and gloves. Beetal goats have been widely used for improvement of local goats throughout the subcontinent. These goats are also adapted to stall feeding and thus preferred for intensive goat farming. It is a dual purpose breed. Their performance is as follows:

- Live body weight of doe : 45-55 kg, buck 70-80 kg
- Milk yield: 1.4-2.5 litre/day

ii. Jamnapari

This breed originates from areas between river Ganga and Jamuna in Uttar Pradesh (UP), India. Their heads tend to have a highly convex nose, which gives them a parrot-like appearance. They have long flat drooping ears which are around 25 cm long. Both sexes have horns. The udder has round, conical teats and is well

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developed. They also have unusually long legs. The Jamnapari male can weigh up to 120 kg, while females can reach around 90 kg. The average lactation yield per day has been found to be slightly less than two kilograms. Jamnapari meat is said to be low in cholesterol. They are good for milk and meat. Live body weight of doe is about 45- 60 kg and buck weighs 80-90 kg. Milk yield is about 1.4 to 2.0 litre a day.

Figure 6.7 Jamapari

iii. Barbari

This breed is found in Etawah, Agra and Mathura districts of Uttar Pradesh India. They are small breed with erect ears. They are adapted to different climatic conditions. They are very prolific with twinning and triplet common.

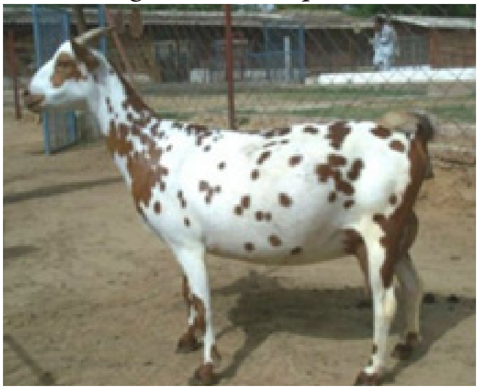

Figure 6.8 Barbari

6.2 Goat breeding and reproduction

In the broadest sense, all goats are meat goats. However, certain breeds are better suited for meat production than others. Therefore, identification and selection of breeds suitable for meat or milk production is necessary for profitable goat enterprises. Breeding plan of production traits is most important. For a successful meat goat enterprise, adaptability, reproduction, growth rate and carcass characteristics have to be considered.

Adaptability trait is the most important of all the production traits. If an animal's ability to survive and reproduce is affected due to different production environment, then the profitability of that enterprise may be greatly diminished. Adaptability is a lowly heritable trait, which responds slowly to selection pressure.

Reproductive rate is the single most important factor contributing to the efficiency of production. Reproductive traits of interest in a meat goat enterprise are high

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conception rate, kidding rate and the ability to breed out of season.

Prolificacy is defined as the number of kids born per doe, is an important reproductive criterion. Goats that have evolved in the temperate zones in the world tend to be seasonal breeders. On the other hand, goats from the tropics are non-seasonal breeders and kid year-round. This desirable trait of non-seasonality should be incorporated into a meat goat enterprise.

Growth rate can be effectively divided into two periods: growth before weaning or pre-weaning average daily gain (ADG) and growth after weaning or post-weaning average daily gain. A high pre-weaning ADG reflects the genetic potential of the kid and also the mothering ability of the doe. Post-weaning ADG is of importance if kids are sold as yearlings or older and post-weaning ADG becomes an important production factor.

Carcass characteristics of interest are dressing percentage, ratios of lean: fat: bone. Generally, the dressing percentage of goats is around 50%. As an animal grows, it tends to increase the percentage of fat in the carcass, decrease the percentage of bone while the percentage of lean stays about the same. The portions of the carcass with the largest muscle mass are the leg and shoulder; however, these portions tend to decrease, percentage-wise, as the goat grows.

a) Breeding strategy

i. Selection criteria for does

- Purchase from an area with similar climatic conditions.
- Should weigh a minimum two thirds of adult weight at breeding.
- Udder should be palpated for size, lumps and other abnormalities. Teats should be uniform in length and large enough for easy milking.
- Needs good appetite and alert eyes.
- Do not purchase from small animal auctions or markets. This is where farmers dispose off culls.

ii. Selection of bucks

- One-year-old breeder buck that has previously successfully mated at least once is desirable.
- Purchased buck should be accompanied by pedigree and production records.
- Buck must come from a doe with high twinning rate.

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- Buck must be active and ready to breed in-heat doe.
- Replace buck as needed to prevent inbreeding.

iii. Care of the breeding buck

- The breeding buck should always be confined separately but always visible to the does.
- Provide area for exercise.
- One or two-year-old bucks can perform 25 to 50 doe services per year, an older buck even more.
- Hand mating, rather than pasture mating will enable the manager to predict the kidding date.

b) Age of puberty and mating

- Doe reach puberty from 4 to 8 months of age depending upon breed and level of nutrition.
- Does should be at 60-75% of their adult weight at breeding to prevent difficult kidding.
- Limit yearling buck services to 25 doe services per year. Older bucks can cover up to 75 per year. Buck to doe ratio is 1: 25.

c) Signs of heat or estrus

- Mucus discharge from the vulva causing matting of tail hair
- Uneasiness, constant urination, lack of appetite and bleating
- Seeks out or stays near the buck and allows herself to be mounted

d) Mating

- Take the in-heat doe away from the herd and present her to the buck. Two to four services during the heat period are sufficient to ensure conception.
- Anestrous or failure to come into heat is a common problem particularly with high producing does. The various causes may include vitamin, mineral or nutrient deficiencies, genital tract infections and hormone deficiencies.
- Routine check-up of the buck's health condition, especially of the genito-urinary tract should be done.

e) Procedures for breeding and management of goats

Step 1. Evaluate if doe is good breeding quality: good body conformation, temperament, and bloodlines.

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Step 2. Select a buck whose temperament and confirmation will complement your doe's best traits and help improve the progeny.

Step 3. There are two methods commonly used for breeding goats: natural breeding and artificial insemination. If you can find a buck near you or own a suitable buck, natural breeding is more reliable and cheaper. Artificial insemination is also possible if facilities are available.

Step 4. Implement good herd management practices to ensure doe is fit and healthy before breeding. Make sure all your goats are on a diet of good quality hay and grain, dewormed regularly and hoof trimmed when needed.

Step 5. Watch for signs of heat in your doe. Signs include: tail wagging, bleating for no reason, loss of appetite, restlessness, mounting other goats, letting other goats mount her, a mucous discharge from the vagina, a swollen vulva. During the breeding season a doe will come into estrus or heat every 18 to 21 days.

Step 6. Breed doe early in her estrus/heat cycle for best results as ovulation occurs 12 to 36 hours after the onset of heat.

Step 7. Prepare a kidding once goats are successfully mated. Gestation in goats lasts approximately 150 days, but it is not uncommon for a doe to kid a week early.

6.3 *Housing of goat*

Goats are kept successfully in all climates. They do not need elaborate housing, but do require clean, dry, well ventilated shelter.

a) Floor space

Each goat should have about 4 sq.m. of floor space. If the goats are housed in a group in the same area a minimum of 2 sq. m. per goat needs to be provided. Floor should be slatted to allow the faeces and urine to pass through. Provision for separate compartment for kids, yearling, stud and does if possible. Pen and door heights vary

Figure 6.9 Stall feeding

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according to breed and 3.5-4 feet (1.3 m) is a recommended. Houses with a slatted floor should be raised 1 to 1.5 feet or more, above the ground to facilitate cleaning and collection of dung and urine.

b) *Hygienic feeding*

Goats must have quality roughage such as grass hay. Feed goats a minimum of 150-250gms grain ration for maintenance and production. Make sure goats have free choice minerals at all times. Goats should never feed off the ground due to the risk of feed contamination with fecal worm load and unhealthy Coccidiosis load. Water should be clean and free of dirt and faecal contamination. Feed and feeders should be free of mold and mildew.

c) *Management of raising kids*

- Kids should be fed their mother's colostrum for at least seven days.
- The kids can have free choice of good hay and water once they are a month old.
- Kids should be weaned when they are two and a half to three times their birth weight. This generally occurs at around three months.

d) *Castration and disbudding*

- All males should be castrated as soon as possible or when testicles drop (usually around seven to ten days.)
- All kids in the dairy herd should be disbudded

e) *Sustainable management*

- The animals should be strictly under stall feeding system or grazed within paddock in registered land or tethering in the home stead
- Farmers are to develop fodder garden/fodder bank at least five decimals per goat
- Feed locally available fodder such as fodder grasses/legumes, maize stover and other feed stuff
- Does should be supplemented with concentrate (grains, roasted soya beans /mustard cake and rock salt) about 150-250 g/ animal/day
- Make available mineral lick and fresh water all the time.

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f) Diseases, prevention and control

i. Minimal preventive health care

Half yearly deworming, vaccination against common disease, isolation and treatment of sick animals shall be advocated involving community/group leader and extension staff

ii. Bloat

Goats infected by Bloat show symptoms of tightly inflated flanks, extreme discomfort, collapse and eventual death. It is caused by over eating of lush wet grass or clover, over eating of anything unsuitable or foreign. It can be cured by feed goats with eight ounces (one ounce = 28.35 gm) of vegetable oil for adult or two ounces for kids. Massage flanks and walk goats about continually until symptoms subside.

iii. Hoof rot

Lameness in feet, stinking smell in hoof, black soft deterioration of inner ridge of hoof of goats is the symptoms of hoof rot in goats. It is caused by prolonged exposure to wet ground or pasture, hoof trimming negligence. Regular exercise on dry ground, proper and regular trimming of hoofs can prevent it.

iv. Mastitis

It causes hardening of udder, clotting and blood streaking in milk, fever, tenderness in udder. It is caused by exposure to bacteria due to poor hygienic conditions. Keeping the goats hygienic and healthy is the remedies against mastitis.

v. Peste des petits ruminants (PPR)

It is also known as goat plague, is a disease of increasing concern to Bhutan. PPR affected animals are markedly depressed and appear sleepy. There is clear watery discharge from the eyes, nose and mouth, later becoming thick and yellow. Mucous membranes of the mouth and eyes become red.

Control of PPR outbreaks relies on movement control and prophylactic immunization in high-risk populations. Homologous PPR reconstituted vaccine of 0.5 mL can be given subcutaneous near neck region. The vaccines can protect small ruminants against PPR for at least a year.

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vi. Internal parasites

They are recognized as a prominent goat disease. Goats that become infected may become ill or even die. They may become lethargic, have diarrhoea, lose weight or just maintain their weight. Sometimes these signs may go undetected. Internal parasites infect the gastrointestinal tract, liver, lungs, blood system, lymphatic system, and skin.

Goat herd should be on regular worming schedule at least once in six months with broad spectrum antihelminthics.

6.4 Record keeping, culling and control of flock size /population

Farmer should keep minimal records on litter size, use of spring balance to measure weight: birth weight, weaning weight and weight in one year. Farmers should be assisted to action plan for regular culling of poor performing animals to control flock size and to match with available fodder resource.

Important points to remember

- Train farmers on proper breeding strategy to improve the flock and maintain faster growing but manageable number of goats
- Assist farmers to develop action plan for regular culling of poor performing animals so as to control flock size and to match with available fodder resource
- Advise farmers to rear goats under stall feeding system or graze within paddock in registered land or tether in the home stead
- Each farmer (goat keeper) should develop at least ten decimal fodder plantation per goat to reduce dependency on the forests fodder
- Promote feeding of locally available fodder such as grasses/legumes and maize stover
- Provide proper housing
- Take measures for proper disease prevention and control

To conclude, this chapter provides Bhutanese youths with options to take goat raising enterprise, contribute to the economic development of this GNH society and lead a successful life or look for blue coloured jobs with meagre monthly salary that can hardly feed a small family. It is important to decide oneself what is important and good rather than living under the fear of social taboo – raising animal is for meat is not a good choice but most Bhutanese love consuming meat

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bought from the market. Mutton is an expensive commodity of the Bhutanese market and not readily available. It is hoped that young educated Bhutanese will make wise choices in life for themselves. Taking up any job/entrepreneurship that is honourable such as goat farming /livestock farming is more desirable for a GNH society and its sustenance in the 21st century and beyond. 'Take up Agriculture Entrepreneurship to serve your GNH society'.

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Student Activity

1. Starting goat farm in the campus

   a) Design housing for goats in the campus (if feasible) as an alternative to raising of pigs or cows and poultry farm or an option for some students.

   b) Select appropriate goat greed and start goat farm through which students can learn about goats and their breeding, to take care of goats, milking the goats, and sell milk and goats or consumed.

   c) Maintain records of care required (feed and medicines, etc.), investment made, work involve and the economy returns.

2. Invite a farmer who raise goats in their farm to talk to about raising goats, challenges, benefits and suggestions as to whether goat should be raised or not.

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7

CHAPTER

Pasture development and management

Pasture development activity in Bhutan is a recent phenomenon. It is due to the fact that Bhutanese farmers depended on forest for fodder. However, with increased number of dairy farms with imported breed of cattle competing with the local cattle for fodder has necessitated farmers to look for alternative sources. Pasture development is economical and is seen as a business opportunity. This chapter explores concepts and skills of starting pasture development as a part of dairy farm for sustenance and better economic returns or it can be started as a part of animal feed production. Animal feed is a good business in Bhutan, especially for the dairy farms located at the suburb of urban centres as well as in the rural areas where animals are also kept for producing biogas for cooking and lighting purposes.

The highest annual biomass production is obtained from the flat and fertile land where irrigation is possible when required. Success and failure of pasture development is also determined by factor such as selection of fodder species, sowing time and method of sowing- direct/transplanting of any species, altitude and soil condition.

7.1 Improved Pasture and Fodder Species

Many species of fodder have been introduced in Bhutan. Under temperate conditions such as in Bumthang the highest yielding legume and grass species are white clover (*Trifoliumrepens*), Italian ryegrass (*Loliummultiflorum*), Tall fescue (*Festucaarundinacea)*, Cocksfoot (*Dactylisglomerata*) and are used in mixtures. Oats (*Avena sativa*); three varieties in field use are Fodder Oats of Bhutan (FOB), Stampede and Naked Oats. They are grown in the fallow period (after paddy) and as a hay crop in yak herding areas. Under sub-tropical conditions: Ruzi grass (*Brachiariaruziziensis*), Molasses grass (*Melinisminutiflora*) and stylo (*Stylosanthesguianiansis*) are popularly grown.

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a) Fodder seed production

In Bhutan it is done by contract farmers who are Registered Seed Grower (RSG) of the National Research and Development Centre for Animal Nutrition Centre for Animal Nutrition (NRDCAN) in Bumthang. The RSG follow specific guidelines on seed production. These farmers produce seeds from a number of fodder species for different agro-ecological zones, earning good cash income. Fodder seeds produced by these selected farmers is purchased by NRDCAN and distributed to the farmers on demand. However, all grasses and legume seeds procured are tested for quality (moisture content, purity and germination as per the standard set) in the Seed Testing Laboratory at NRDCAN, before they are paid.

The seed demands are collected from the Dzongkhags and Government livestock farms three to four months in advance of every cropping year. Standard mixture and packing is done upon receiving the demand and seed supply is arranged. Seed is supplied on cash and carry system to the Dzongkhags who then supply to the farmers on fully subsidy (free of cost to farmer as of 11th FYP).

i. Pasture seed requirement

Temperate grass- legume mixture consist of 5 kg Italian Rye Grass, 1 kg White clover and 5 kg Cocksfoot. This quantity of mixture is enough to sow in an acre of pasture. Among many species of subtropical/mid altitude grasses and legume available, commonly grown species and their seed rates per acre are as follows:

- Ruzi (*Brachiariaruziziensis)*: 12 kg/acre
- Molasses (*Melinisminutiflora*): 1 kg/acre
- Stylo (*Stylosanthesguianensis*): 1-3 kg/acre
- Napier Grass (*Pennisetum purpureum*): 10,000 stem cutting/acre
- Guatemala grass (*Tripsacumlaxum)*: 4000 stem cutting/acre
- Oat (*Avena sativa*): 50 kg/acre

ii. Inoculation of legume seed

Legumes such as clover, stylo, desmodoum live in symbiosis with nitrogen fixing bacteria. These bacteria (*Rhizobium species*) live in nodules in the root of legumes. If legumes are to be introduced in areas where they are never grown before the bacteria are probably not present in the soil and formation of nodules and fixation of nitrogen may not take place. Therefore, while planting new legume in a field, we have to introduce the bacteria also. This is usually done by mixing legume seeds

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with bacteria. This process is called inoculation.

iii. Fertilizer requirement

- Single Superphosphate (SSP) 150 kg/acre but it can depend on soil test result
- Urea 100 kg/acre. Urea at the rate of 25 kg/acre should also be applied after each cut.
- If above chemical fertilizers are not available, well-decomposed Farm Yard Manure (FYM) can be applied at the rate of 8-10 MT/ acre/year.

iv. Pasture establishment

Pasture land should be prepared by slashing of bush and cleaning of farm areas followed by ploughing, field preparation and planting (sowing of seed or planting slips) in a leveled seed bed. Grass seed are mostly broadcast sown on seed beds. Napier and Guatemala stem cuttings should be planted in furrows made with a spade at a distance of 1 meter between furrows and 30-50cm within the furrows. The stem cutting should have minimum of three nodes while planting. Soil should be pressed firmly after planting.

b) Pasture management

The objective of the grassland management is to:

- Maintain high production of good quality fodder for longest period possible
- Make efficient utilization of fodder produced
- Maintain favorable balance between fodder species (grasses and legumes)

For good pasture management, use of fertilizer/manure is necessary. Dry matter production and the quality are influenced by the availability of the required nutrients for the cover crop to grow efficiently. Quality of the fodder depends at the stage of crop being harvested, as right time of harvesting gives the maximum nutrients required for the maximum production. Harvest at the early stage gives high protein, and later at the mature stage high fiber. The best time to harvest pasture is before flowering stage (about 5% flowering). During this stage fodder will have good protein and energy. Cutting frequency depends on the soil type and how you use it. Normally 5-7 cuttings in a year are recommended. A rest period is essential between harvesting (cut/grazing). Cutting too frequently affects the fodder growth and the root development and leads to disappearance of the desirable fodder species and opens chance for undesirable species and weeds. If fodder is not harvested for too long, the quality of the fodder is deteriorated, thus,

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at least 30-45 day interval between harvesting is required.

Maintaining cutting height and grazing intensity is important. If fodder is cut or grazed too low, the re-growth/re-generation will be damaged, therefore at least maintain up to 6-7 cm heights especially for leguminous species.

The quality of the pasture production and life of pasture depends on how the field is managed. Periodic cleaning and cutting (weeding), irrigation to provide water is necessary for maintaining the good pasture. Weeding is essential because normally animal will leave the unpalatable plant behind and it should be cut and cleaned, otherwise, it will mature and produce seed, spread and dominate the pasture. Therefore, periodic cleaning and cutting are ways for maintaining the good pasture.

Water is essential for growth of pasture as well as use in the farm. If field could be irrigated when moisture requirement is low it could maximize production (early growth) and could also extend the growing period, especially in the warmer areas.

If you practiced continuous grazing or extensive grazing system in which livestock remain on the same pasture for a prolonged period (over grazing), many of the desired fodder species cannot survive, because they are not given rest period. Over grazing pasture will decrease the yield and after few years the species will disappear and will be overtaken by weeds. If the pasture grazing is not controlled, the maintenance cost will be high and it should also be avoided. This can be done through rotational grazing, tethering and cut and carry system.

i. Rotational grazing

The livestock is moved from one paddock to another as soon as fodder has been grazed (after 4-8 days) in order to give good rest period. This system need high investment in fencing so it is recommended for productive pasture.

ii. Tethering

The animals are confined to a particular area by a rope (tether) fixed to a post. Changing the post everyday makes this system comparable to rotational grazing, however with less investment in fencing.

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iii. Cut and carry system

The fodder is cut and carried to feeding place (shed or stall). This system requires high labor input; however, the use of fodder is optimal. Manure accumulated at the feeding place can be carried back to the pasture.

c) Pasture renovation

With proper maintenance and management, pasture will remain as good as a newly sown pasture for decades. However, if certain factors limit pasture production then renovation is needed. There are different methods of pasture renovation:

i. Complete re-sowing

The whole field will be ploughed and all swards (grassy surface of pasture) are removed from the field to make fine seed bed for easy establishment. Following which Farm Yard Manure (FYM) or chemical fertilizers at recommended rate should be applied and recommended quantity of seed is sown.

ii. Over seeding

If whole field is not very poor/bad for economical reason overseeding is recommended. Depending on the field condition, if the swards are not very heavy, light rotaring/ploughing is necessary. The area is then over sown pasture seeds (half of the normal seed rate). Application of nitrogen/ phosphate is necessary.

iii. Tillering and broadcasting

After a long life of the pasture, normally the soil gets so compact thus the soil condition becomes poor (poor soil aeration). In this condition soil aeration is necessary. Light harrowing/ ploughing will boost the growth and production.

d) Fodder conservation

Winter is the most difficult part of the year to feed animals sufficiently as there will be fodder scarcity in most places.

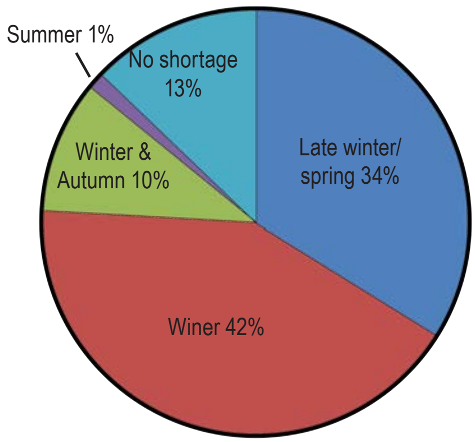

Figure 7.1 Fodder shortage seasons

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However, animal needs equal quantity of feed throughout the year for maintenance and production and hence conservation of fodder resource for lean season is essential. Different fodder conservation methods practiced are:

i. Hay making

Hay is a green grass turned into dry grass by drying when there is sufficient fodder grown during the season. It consists of cutting the green biomass of the fodder plot, spreading, turning, gathering each day till it is dried to 15% humidity from initial 85%. It is possible to make hay on hay racks or tripods for suspending the pre-dried hay during bad weather period. Hay is usually made from autumn saved pasture during October and November. For making good quality hay, grass or grass legume mixture should be cut before flowering stage.

Figure 7.2 Hay making

ii. Silage making

Silage is fermented, high-moisture stored fodder which can be fed to ruminants (cud-chewing animals such as cattle and sheep). It is fermented and stored in a process called ensiling or silaging, and is usually made from grass, fodder maize, sorghum or other cereals, using the entire green plant.

Purpose of making silage is to:

- Build up forage reserves for utilization during periods of feed deficiency, e.g. dry season.
- Feed supplement to increase or maintain productivity of animals.
- Utilize excess growth of pasture for better management and extended utilization.

During the summer season forage species grow very fast, with forage yields often exceeding animal requirements. If not cut and fed to animals, it will continue to grow, producing very long fibrous material, low in feeding value. Excess forages can be conserved as hay or silage to feed during lean season. However, ensiling generally produces better quality roughage than hay because less time is required to wilt the feed, causing little reduction in feed quality. Hay making requires a longer period of rain-free days, which are often rare in many areas during the rainy season when fodder is in plenty. Silage making is a viable option under such circumstances. Silage retains much larger proportion of nutrients compared to

(a) Bringing fodder to a central location

(b) Chaff cutter placed at central location for chopping grasses

(c) Gathering of chopped grass

(d) Pressing chopped grass in a plastic bag

(e) Removing air using vacuum cleaner

(f) Packing and sealing of plastic bag

(g) Carrying ensiled plastic bag home

(h) Staking before use

Figure 7.3 Silage making using plastic bag

(Photo courtesy: Mr. Thinley Rapten, Dzongkhag Livestock Officer, SamdrupJongkhar)

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dried crop stored as hay. It is easily digestible and milk produced by animals eating silage maintains its quality and taste.

The silage making procedures is demonstrated in pin Figure 7.3. It is a simple procedure but an effective one and it can be made anywhere.

Silage can be made any time when there is surplus pasture. The pasture should be cut in the morning, dried for some time to evaporate excess moisture/water. The grass is filled in the silo pit, spreading it evenly in the pit. After every layer of fodder, it should be pressed by stamping over it to expel air as much as possible between layers. If the air remains inside, either the material gets rotten or the silage quality will be poor that animal will not eat at all. The top portion must be sealed air tight and pressed down by any heavy materials to keep it compact and airtight for anaerobic fermentation that starts about 48 hours after the silo is filled.

Silage can be made in Silo pit. The pit can be square or cylindrical hole of required size dug in the earth. In the event silo pits are not available, silage can also be easily made in thick plastic bag (preferably double layered). Chopped fodder should be put into the bag, pressed to remove air. Vacuum cleaner if available is more reliable to remove air. The bags are then packed, sealed and kept undisturbed for three weeks to complete fermentation. The silage can be either fed immediately or reserved for future use.

7.2 Fodder tree plantation

Fodder tree plays an important role in livestock farming especially to supply fodder during lean seasons (mostly winter and early spring) of the year. It can be planted from seeds or cuttings; depending on species both techniques can be successful. Fodder trees are mainly planted near houses, along fences and field boundaries. Elevation and other climatic factors dictate the type of fodder species available. Presently species that are widely used in field are of the genus *Ficus*, *Bambusa*, *Bauhinia*, *Quercus* and *Salix*. In Bumthang and similar high altitude areas willow (*Salix babylonica*) is traditionally used as

Figure 7.4 Local fodder trees

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fodder. *Ficusroxburghii* also *Ficusacuriculata* and *Ficuscuniathat* can grow well upto 1500 masl are most popular fodder trees in mid and low altitude areas. Willow leaves have a high fodder quality, far better than that of any other traditional tree fodder used in Bhutan.

Feeding animal with fresh green grass about 10% of its body weight is one of the good feeding practices. 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 litter 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 accordingly to feed animals. This can provide adequate energy and protein required by animal in production.

Figure 7.5 Fodder for stall feeding

On an average feed required by adult livestock unit weighing 400 kg is 10 kg DM (Dry Matter)/day (2.5 kg for every 100 kg live body weight). 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 years the species will disappear so it should be avoided. If the pasture

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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.

Commercialization of farms and rearing of exotic breeds demands more feed compared to local breeds. Therefore, pasture development provides unique opportunity for entrepreneurship opportunities and self-employment.

1. Carryout a small survey for the need of fodder by the community around the school campus and advocate the developing pasture or planting fodder trees on the unused /barren land or nearby government land.
2. If feasible, explore pasture development project trial in the school campus, discuss with the principal, prepare land and start pasture development on a small plot.
3. For the schools having a huge campus with livestock can develop pasture and plan the harvest systematically and use fodder sustainably.
4. Plan a field trip to a nearby government farm and study the processes pasture development, care, use and management of fodder for the livestock.

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8
CHAPTER

Climate Change and its impact on Agriculture Sector

Climate Change refers to changes of the earth's atmosphere leading to changes in the climate system, such as climate warming and more frequent and intensive extreme weather events. The consequences of climate change are numerous, for instance changes in rainfall and snow, melting of icecaps and glaciers, more frequent and severe flooding, rising temperatures and more intensive and prolonged droughts. These outcomes directly affect people and in particular the poorest, making livelihoods and living conditions more vulnerable. This chapter explores on the concepts of climate change and its impact on life on this earth, with special focus on Bhutan and its agriculture, and how Bhutanese need to cope up with changes for sustenance.

8.1 Climate change and global warming

The *climate change* is referred specifically to climate change caused by human activities, as different to changes in climate that may have resulted due to part of Earth's natural processes. *Global warming* refers to increase in surface temperature while climate change includes global warming and everything else that increasing greenhouse levels will affect.

Climate and *weather* are closely related but there are important differences. Weather is the day-to-day state of the atmosphere (combination of temperature, humidity, rainfall, wind, etc.), and its short-term variation in minutes to weeks. Climate is the weather of a place averaged over a longer period of time, often 30 years. Confusion between weather and climate arises when we try to predict climate in the long term (30 years) while we cannot even predict the weather a few weeks from now. Prediction of the weather is based on the understanding of how the atmosphere moves, warms, cools, rains, snows, and evaporates water. A major limiting factor to the predictability of weather is related to its dynamic property of the atmosphere as slight differences in initial conditions can produce

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very different forecast results and also small changes in certain variables can cause apparent randomness in the complex weather pattern (Lorenz, 1960s).

8.2 Causes of climate change

The earth's climate is changing and this change is a natural process. Climate change and weather patterns are influenced by changes in solar radiation, changes in composition and circulation of atmospheric air and gases, changes in the hydrological cycle, changes in snow, ice and glaciers, changes in land use, vegetation and ecosystem, changes in the sea level and ocean current circulation and complex interactions with entire Earth system, including the human and other living things (Figure 8.1). Climate change can be measured and forecast through long term study of parameters such as temperature, rainfall and snowfall and extreme events. The evidence of climate changes and impact are found through the studies of tree rings, pollen samples, ice cores and sea sediments.

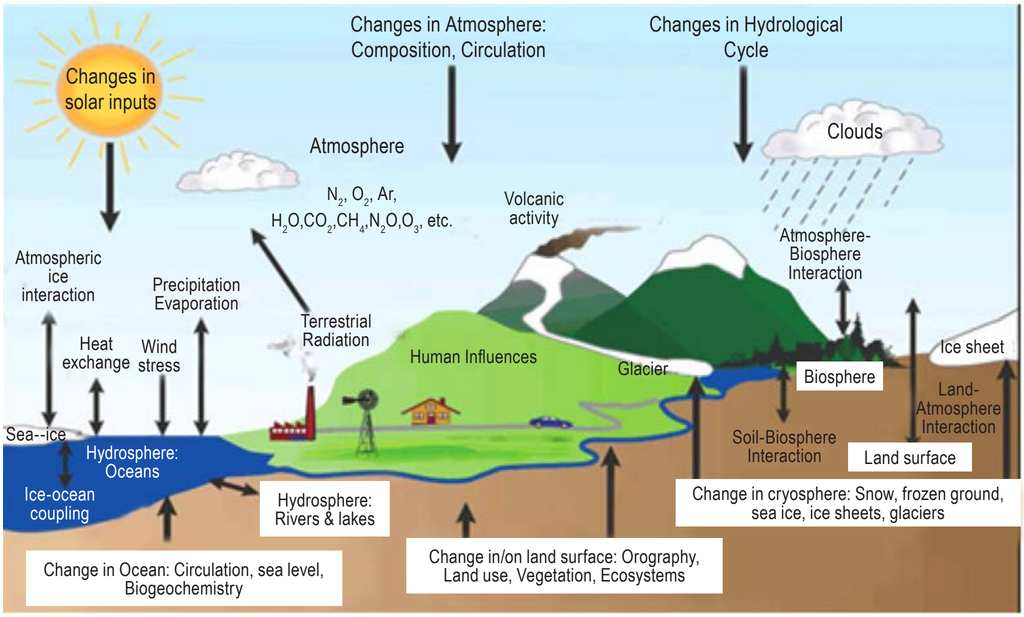

Figure 8.1 Components of the climate system, (Source:http://co2now.org)

a) Natural causes of climate change

The causes of climate change can be divided into two categories - those that are due to natural causes and those that are created by human. There are a number of natural factors responsible for climate change. Some of the more prominent ones are continental drift, volcanic eruption, ocean current movement, the earth's tilt and rotation. The theories on how they influence climate change are described below:

i. Continental drift

Continental Drift theory states that about 250 million years ago the present continents were clustered together as one large landmass known as *Pangea Ultima.* Then this landmass gradually drifted apart forming the present 5 continents. For instance, South America and Africa on a map of the world seem to fit into each other like pieces in a jigsaw puzzle. Proof of this comes from the similarity between plant and animal fossils and broad belts of rocks found on the eastern coastline of South America and western coastline of Africa, which are separated by the Atlantic Ocean. The discovery of fossils of tropical plants (in the form of coal deposits) in Antarctica has led to the conclusion that this frozen land at some time in the past, had been situated closer to the equator, where the climate was tropical, with swamps and lush vegetation.

This continental drift can also have an impact on the climate because it changes the physical features of the landmass, their position and the position of water bodies. The separation of the landmass changes the flow of ocean currents and winds, affecting the climate. This drift of the continents continues even today. It is reported that the Himalayan range is rising by about 1 mm every year because the Indian land mass is moving slowly but steadily towards the Asian land mass.

ii. Volcano eruption

When a volcano erupts it throws out large volumes of sulphur dioxide (SO_2), water vapour, dust, and ash into the atmosphere. The large volumes of gas and ash can influence climatic patterns for years. Millions of tonnes of sulphur dioxide gas on reaching the upper levels of the atmosphere can block the incoming rays of the sun, leading to cooling. Sulphur dioxide combines with water forming tiny droplets of sulphuric acid which can stay in the air for several years while winds in the upper strata carry the aerosols rapidly around the globe. Movement of aerosols north and south is always much slower by which cooling can be brought about for a few years after a major volcanic eruption.

Mount Pinatoba, in the Philippine islands erupted in April 1991 emitting thousands of tonnes of gases into the atmosphere. This volcanic eruption has reduced the amount of solar radiation reaching the Earth's surface, lowering temperatures in

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the lower levels of the atmosphere, and changed atmospheric circulation patterns. Volcanoes erupt in different parts of the world as we discuss this chapter, affecting the climatic conditions of our earth and it is likely to continue.

iii. The earth's tilt and rotation

The earth rotates one full orbit around the sun in a year and it is tilted at an angle of 23.5° to the perpendicular plane of its orbital path. For one half of the year when it is summer, the northern hemisphere tilts towards the sun. In the other half when it is winter, the earth is tilted away from the sun. Changes in the tilt of the earth can affect the severity of the seasons – more tilt means warmer summers and colder winters; less tilt means cooler summers and milder winters.

We usually think that the earth's axis is fixed, as it always seems to point toward Polaris (also known as the Pole Star and the North Star). Actually, it is not quite constant: the axis does move, at the rate of a little more than a half-degree each century. So Polaris has not always been, and will not always be, the star pointing to the North. This gradual change in the direction of the earth's axis, called *precession* is responsible for changes in the climate.

iv. Ocean current movement

The oceans cover about 71% of the Earth and absorb about twice as much of the sun's radiation as the atmosphere or the land surface. As the oceans are surrounded by land masses, so heat transport takes place through water. Winds push horizontally against the sea surface and drive ocean current patterns. Certain parts of the world are influenced by ocean currents more than others. The coast of Peru and other adjoining regions are directly influenced by the Humboldt Current that flows along the coastline of Peru. The El Niño event (cycle of warm and cold temperatures) in the Pacific Ocean can affect climatic conditions all over the world.

Another region that is strongly influenced by ocean currents is the North Atlantic. If we compare places at the same latitude in Europe and North America, the effect is immediately obvious. Take a closer look at this example - some parts of coastal Norway have an average temperature of -2°C in January and 14°C in July; while places at the same latitude on the Pacific coast of Alaska are far colder: -15°C in January and only 10°C in July. The warm current along the Norwegian coast keeps much of the Greenland-Norwegian Sea free of ice even in winter. The rest of the Arctic Ocean, even though it is much further south, remains frozen.

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b) Human causes

The Industrial Revolution in the 19th century saw large-scale use of fossil fuels for industrial activities. These industries created jobs and people moved from rural areas to the cities. More and more land that was covered with vegetation has been cleared to make way for human settlements, towns and cities. Natural resources are used extensively for construction, industries, transport, and consumption. Consumerism (increasing want for material things) has increased by leaps and bounds, creating mountains of waste. Also, our population has increased to an incredible extent.

All the above factors have contributed to a rise in greenhouse gases (water vapour, carbon dioxide, methane, nitrous oxide and ozone) in the atmosphere. Fossil fuels such as oil, coal and natural gas supply most of the energy needed to run vehicles, and generate electricity for industries and households. The energy rich sector is responsible for emission of carbon, methane and nitrous oxide. It also produces nitrogen oxides and carbon monoxide which are not greenhouse gases but have an influence on the chemical cycles in the atmosphere that produce or destroy greenhouse gases.

8.3 Greenhouse gases and their sources

Carbon dioxide is the most important greenhouse gas in the atmosphere. Changes in land use pattern, deforestation, land clearing, agriculture, and other activities have all led to a rise in the emission of carbon dioxide.

Methane is another important greenhouse gas in the atmosphere. About ¼ of all methane emissions are said to come from domesticated animals such as dairy cows, goats, pigs, buffaloes, camels, horses, and sheep. These animals produce methane during the cud-chewing process. Methane is also released from rice or paddy fields that are flooded during the transplanting and maturing periods. When soil is covered with water it becomes anaerobic or lacking in oxygen. Under such conditions, methane-producing bacteria and other organisms decompose organic matter in the soil to form methane. Methane is also emitted from landfills and other waste dumps. If the waste is burnt in the open, carbon dioxide is emitted. Methane is also emitted during the process of oil drilling, coal mining and from leaking gas pipelines (due to accidents and poor maintenance of pipelines). Nearly 90% of the paddy-growing area in the world is found in Asia, as rice is the staple

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food there. A large amount of nitrous oxide emission has been attributed to fertilizer application. This in turn depends on the type of fertilizer that is used, how and when it is used and the methods of tilling that are followed.

8.4 Climate and its links with agriculture, forest and water resources

The Renewable Natural Resources sector in Bhutan comprises agriculture, livestock, forestry and water resources which are closely integrated at the farm level. This sector supports the livelihood of over 69% of the population and provides employment to over 56% of the total population.

Another vital role of the sector is the management and conservation of natural environment and in maintaining the health of the eco-system. The RNR sector is affected more than other sectors as a result of the impact of climate change and climate induced disasters. Consequently, the Ministry of Agriculture and Forestry (MoAF) plans to focus on climate smart RNR programs that will entail on development of research technologies and use of traditional and local knowledge to ensure increased productivity even during the incidences of severe drought, erratic rainfalls and pressure from new pests and diseases.

8.5 Climate and Climate Change in Bhutan

The climate in Bhutan varies substantially from one place to another due to changes in the topography, elevation and altitude. Bhutan's location at the northern periphery of the tropical zone is an important feature that determines its climate. Around 70% of the precipitation is generated by the monsoons while pre-monsoon activities generate about 20% of the precipitation. The monsoons last from late June through late September. The annual precipitation decreases largely from south to north. The southern foothills receive annual precipitation of more than 4000 mm while the northern mountain region gets about 40 mm of annual precipitation, mostly in the form of snow. Bhutan has three climatic zones:

- The high mountain region in the north encompasses snow-capped peaks and alpine meadows above 4000 m with cold winter and cool summers.
- The central belt consists of the main valleys with altitude ranging from about 2000 m to 4000 m and is characterized by cool winters, hot summers with

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moderate rainfall. The temperature ranges from 15°C to 26°C during the monsoon season (June through September) and -4°C to 15°C during the winter season, and

- The southern belt is made up of the Himalayan foothills with an altitude ranging from under 200m to about 2000m. It has a typical subtropical climate characterized by high humidity and heavy rainfall. In this climatic zone, the temperature ranges from 15°C to 30°C all year round.

On a local scale, the climatic condition largely differs between the ridge and the bottom of valley based on the climatic observation in the Punatsangchu basin. The difference in temperature between the ridge (Dochula, Thimphu) and the bottom of the valley (Bajo, Wangdue) becomes higher during the daytime and lower during the night-time and early morning. This indicates that the relatively high temperature condition prevails during the daytime at the bottom of valley. The relative humidity is found higher along the higher altitudes. At the valley bottom, the dry condition prevails. The annual precipitation of the ridge (Dochula) is found twice more than that of the valley bottom (Bajo). These phenomena show that the hot and dry climatic condition is dominant at the valley bottom compared to the higher ridges (Figure 8.2).

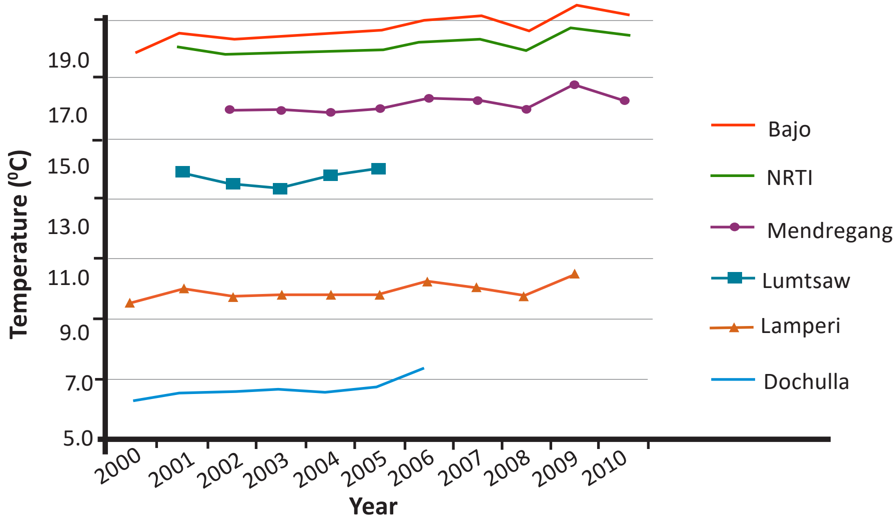

Figure 8.2 Inter-annual variation in annual mean temperature (Eguchi & Wangdi 2011)

During the pre-monsoon season, the difference of temperature between the ridge and the valley bottom becomes larger and, the relative humidity at the valley

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bottom becomes lowest. The valley wind during the daytime is found strongest compared to night time. This season is coincided with the end of dry season and the soil moisture is also found low. Considering these conditions, the dry climatic condition during the pre-monsoon season is the important factor in making the dry valleys in Bhutan.

8.6 Climate Change Trend and Projection

a) Temperature trend change

The global mean surface temperature has increased by 0.6°C (0.4-0.8°C) over the last 100 years (Gitay et al, 2002). The analysis of climate parameters of the Eastern Himalayas has shown that the Eastern Himalayan regions mean annual temperature is increasing at the rate of 0.01oC per year or more (Chettri et al, 2010). The analysis of surface air temperature data in Bhutan from 1985 to 2002 has shown a warming trend of about 0.5°C, mainly during the non-monsoon season (Tse-ring et al, 2010).An analysis of surface air temperature data for the last 10 years (2000-2009) from 4 representative agro-ecological zones showed that summer and winter mean temperature trend had increased in the past 10 years (Figure 8.3 & Figure 8.3). However, at present with the short time-series data on temperature, it is difficult to estimate as to by how much degree Celsius temperature is increasing annually.

b) Rainfall pattern change

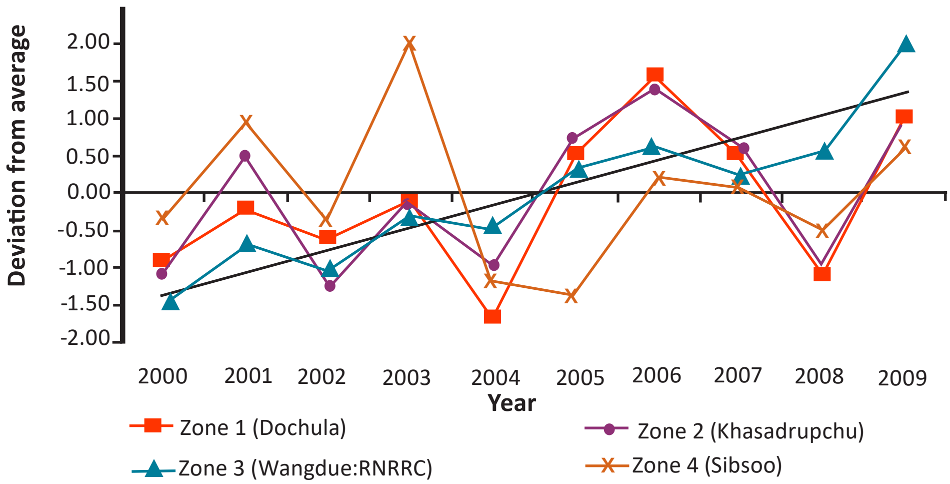

Figure 8.3 Summer mean temperature (2000-2009)

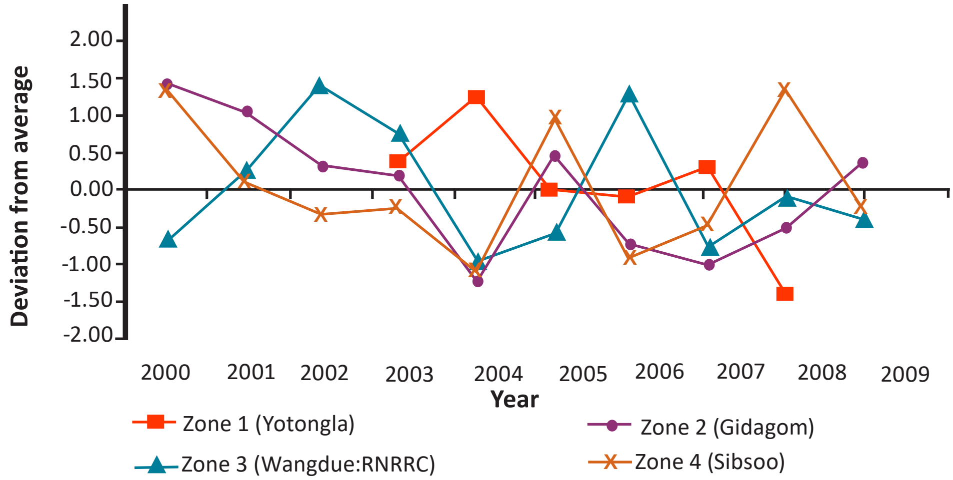

Figure 8.4 Winter mean temperature (2000-2009)

Unlike temperature, throughout the Eastern Himalayan region, the precipitation shows no consistent spatial trends. The changes in annual precipitation are variable, increasing at one site and decreasing at a nearby site (Tse-ring et al, 2010).

In Bhutan too, rainfall pattern fluctuates with no systematic change detectable on either annual or monthly scale (Tse-ring 2003). Also, an analysis of rainfall data from 2000 to 2009 across four agro-ecological zones of Bhutan shows that the annual rainfall fluctuation within the country does not show any detectable trend (Figure 8.5).

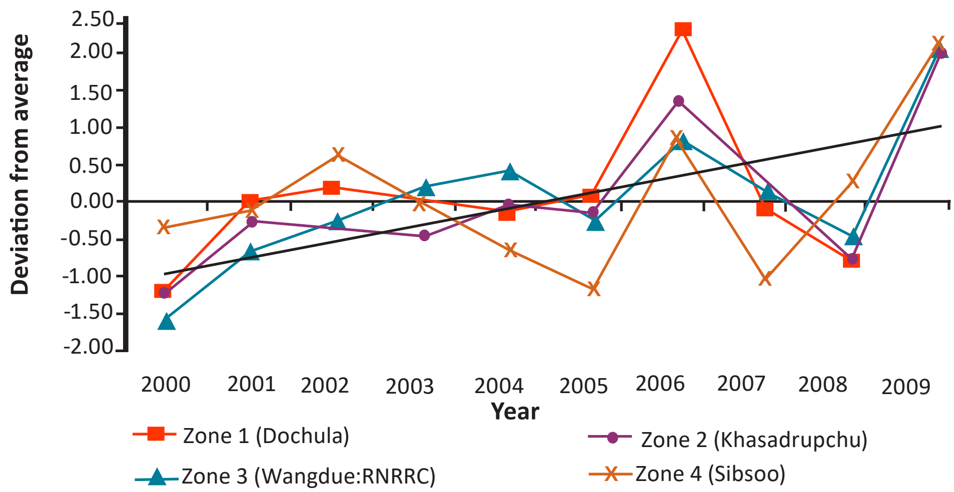

Figure 8.5 Rainfall pattern change

c) *Community observations on climate parameters*

There is no systematic record of data and observation on temperature and precipitation including snow cover, frost and fog. The climate impact survey 2010 showed that the community understanding on climate and climate change was poor. However, majority of the respondents reported to have observed some changes in climate parameters such as rising temperature, erratic rainfall pattern, less snowfall incidence and early flowering of some plants and trees.

The survey conducted by ICIMOD in 2011 on impacts and vulnerability to climate change in Trashiyangtse and Pemagatshel dzongkhags reported that farmers saw windstorms as the greatest weather-related risk and they felt that storms had increased over the past years, causing damage to property and crops. The most observable change seemed to be the increased unpredictability and variability of weather patterns leading to unpredictable harvests. The communities did not have access to river water and were dependent on rainfall, which limited the production when rains did not arrive in the expected amount at the expected times. Although the households in the survey area are mostly food sufficient, yields are affected by changes in rain patterns, temperature, and storms; disturbance from wildlife and lack of labour.

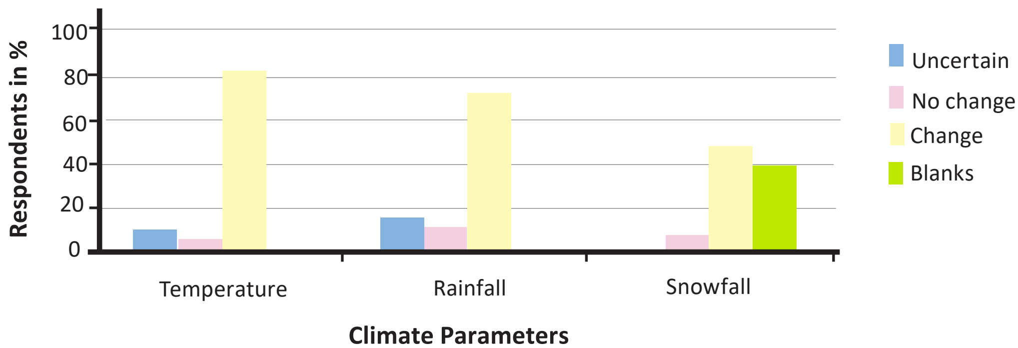

Figure 8.6 People's perception on temperature, rainfall and snowfall (CIS 2010)

d) *Climate Projection*

Understanding climatic characteristics of the mountains is difficult due to the complexity of the topographic features. Existing knowledge of the climatic characteristics of Bhutan being mountainous is limited by both lack of long term observation data and the limited theoretical studies done to understand complex interaction of spatial scales in weather and climate phenomena. A study done for

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the Eastern Himalayas by ICIMOD in 2010 provides a comprehensive analysis of the climate projection of the region including Bhutan.

The projection for Bhutan indicates that surface air temperature will increase with the greater change in the west, gradually decreasing towards the east. The projected surface warming will be more pronounced during the pre-monsoon than during the summer monsoon season. The temperature increase will be higher in the inner valleys than in the northern and southern parts of the country. The model predicted peak warming of about 3.5°C by the 2050s in Bhutan (Tse-ring et al, 2010). In general, Bhutan is expected to experience a significant overall increase in precipitation, but with an appreciable change in the spatial pattern of winter and summer monsoon precipitation, including a 20-30% decrease in winter precipitation, over the north-east and south-west parts of Bhutan for the 2050s (Tse-ring et al, 2010).

8.7 Climate Risk and Vulnerability

In Bhutan climate is changing as elsewhere on the earth. The RNR sector (Agriculture, livestock and Forestry) is perceived to be more vulnerable to climate change and climate induced disasters. This is because the forest, agriculture, livestock, water and environment that support the livelihood and wellbeing of the population are directly impacted due to changing climate.

a) Agriculture and its vulnerabilities to Climate Change

Bhutan is agrarian with nearly 69% of the people depending on agriculture directly for their living. Agriculture is practiced by subsistence farmers who occupy the majority of the arable land and produce crop and livestock products. The challenges of the farmers are low productivity contributing from poor agriculture practices, unproductive small holding farmland, lack of access to markets, credit and technology. The challenge is compounded by pests and diseases and wildlife encroachment and natural calamities influenced by global warming. Livestock is an important component of agriculture that is engaged in domestic production of livestock commodities such as milk/milk products, egg and meat in the country. Climate change is likely to affect Bhutanese agriculture.

- Loss of production of both crops and animals to outbreaks of pest and diseases, erratic rainfalls, windstorms, droughts and flash floods and landslides are increasing annually. In crops, diseases like rice blast, Gray Leaf Spot in maize, Citrus greening and diseases in cardamom and ginger have become very serious problems. During the rice blast epidemic in 1996, the high altitude farmers lost 80 to 90% of their rice harvest. The maize harvest loss by the farmers above 1800 masl during outbreak of Gray Leaf Spot was more than 50% of their production in 2007. In animals, with the increase in temperature and rainfall, incidences of vector borne diseases like *piroplasmosis* could increase and expand into cooler areas. The variation in temperature and humidity can have a significant effect on helminthes infections. At present there are very limited climate resilient varieties of crops and fodder.

- Selection and adaptation of crop and fodder varieties resistant to biotic and abiotic stress are limited. Farmers continue to depend on traditional varieties that are highly vulnerable to pest and disease, drought and heat stress. Local and rare breeds will become extinct as a result of climate change and disease epidemics will increase.

- More than 31% of agriculture land is on slopes which is greater than 50%, and the environmental effects, in particular in relation of frequency and intensity of soil drainage (leading to nitrogen leaching), soil erosion, reduction of crop diversity is a problem in the farming system. Fodder trees and grasses promoted along sloping farmland as hedges provide animal feed, and minimize the environmental degradation. The loss of soil has been reduced by half through the introduction of the hedgerow systems, and also helps to build up carbon stock in soil organic matter. The extreme weather patterns could further enhance soil loss and erosion due to runoff, landslides and lack of cover crops.

- The natural variability in altitudes and local climate has allowed the Bhutanese farmers to cultivate a wide range of food crops, vegetable and fruits. However, farmers normally practice mono-cropping and cultivate major cereals like rice and maize. Many farmers, of late, have started to switch over from cereal crops like wheat, barley, and buckwheat and millet production to horticulture crops. Local livelihoods of traditional farming are already made vulnerable by human-wildlife conflicts. It is possible that the situation will be exacerbated with climate change due to the effects on behaviours and habitats of wild animals. There are reports of change in the movement and feeding patterns of the wild boar, bear, elephants and monkeys, leading to more conflicts with farmers. With the increase in the numbers of small poultry and dairy farms, demand for feed and fodders have also increased by many folds. Increasing farm level diversity will be an important means to adapt to the impact of climate change as well as address nutritional security.

- Rugged terrain and difficulty to deliver agricultural inputs like seed, fertilizers and extension services are the biggest challenges. Disruption in communication has a huge impact on the food distribution and stability dimensions of food security. Improving accessibility will help farming communities to improve their livelihood and food security which could be accelerated by climate change.

- Agriculture farming emits Green House Gas (GHG) like methane and nitrous oxide but if managed well, it is a solution to global warming. The use of chemical fertilizers (herbicides, insecticides and fertilizers) is increasing as a means to accelerate food production. There is also a major emphasis to enhance rice production which is the primary source of methane. The livestock production system contributes to climate change directly through the production of GHG emissions and indirectly through the destruction of biodiversity and degradation of land and water and air pollution. In light of this, there is a need to develop and promote good agriculture practices like proper management of manure and chemical fertilizers, promotion of agro-forestry in the farming system, adopt proper husbandry practices and management strategies for livestock to reduce GHG. The promotion of Organic program should be pursued strongly to reduce dependency on external inputs.

b) Forest and its vulnerability to Climate Change

Bhutan has 72.46% of the total area under forest cover and 51.32%is managed as protected areas and biological corridors. Bhutan is home to a diverse array of flora and fauna including 5603 species of vascular plants, 400 lichens, 200 mammals and about 700 birds. Forests can be threatened by a combination of climate change and associated human disturbances through changes in distribution and population status. It will also affect phenology, which in turn could affect the plant-pollinator interactions and prey-predator dynamics. These phenomena raise concerns for Bhutan to about 105 endemic plants and a number of globally threatened species. There could be potential loss of restricted Himalayan endemics such as the pygmy hog, Himalayan field mouse, and flying squirrel and high altitude medicinal plant species. In addition, large predators such as tiger and snow leopard are already threatened by shrinking habitats and they will become more vulnerable in the

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face of changing climate.

Several studies indicate that climate change can cause shift in forest boundaries, alter ecosystems, change composition of forests, and loss of species, that can lead to changes in the ecosystem functions and services. Examples of forest vulnerability due to climate change:

1. The climate impact survey 2010 indicated that Juniper scrub forests in the Alpine ecosystem (above 4000 masl) are increasing in area. Local communities also reported that the discontinuation of the use of fire in rangeland management regimes, has led to the invasion woody species into alpine meadows. It is likely that with the increasing upward movement of conifer scrub forest could result in habitat encroachment of alpine medicinal plants such as *Picorrhizaspp, Ophiocordycepssinensis,Gentianaa* and *Rhodiola spp*.
2. Fir trees that thrive well on moist mountain tops, declined and died in the 1980s due to moisture stress (Gratzer et al, 1997). With rising temperature, and increasing incidences of moisture stresses, fir forests on the ridge tops is becoming highly vulnerable to periodic diebacks and may result to extinction in the process.
3. Climate change combined with human activities can accelerate the upward shift of these forest types and displacing the upper forest types by the lower forest species. The upward movement of blue pine forests into spruce/maple/birch forests is observed in the temperate valleys of Paro, Haa, Thimphu, Phobjikha and Bumthang. The distribution of evergreen broad-leaved species along the altitudinal slope of dry valley of mid-hills is limited by winter temperature (coldest month's mean temperature) of minus one degree Celsius which coincides at 2900 masl (Wangda & Ohsawa 2006a). With the increasing trend of winter temperature, the upper limit of evergreen broad-leaved species from 2900 m (current) to higher altitudes. Therefore, the montane cloud forests which occur around 2500 m in the valley slopes of Dochuala and around 2000 m along the mid hills of Gedu-Darla are vulnerable to this change. This could lead to habitat loss for some important relic plant species like T*axus, Magnolia*, and *Tetracentron*.
4. Climate change and human-induced activities can accelerate the damage to wetlands and fresh water ecosystems, such as lakes, marshes and rivers. Presently, the wetlands of Phobjikha, which is the habitat of the black-necked cranes, is becoming unsuitable for the birds due to intensive agriculture,

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continuous grazing and encroachment by blue pine forests.

5. Moderate warming has been linked to improved forest productivity especially in conifer forests, but these gains are expected to be offset by the effects of increasing drought, fire and insect outbreaks as a result of further warming. The pests and disease incidence in blue pine, spruce, fir and oak forests had increased over the years causing setback in the productivity of forest.
6. The alien invasive species is a threat to forest and biodiversity and climate change can speed up the colonization of invasive species that can have severe implications on native species. A significant increase in invasive species such as *Mikaniami, Parthenium, Opuntia, Eupatorium, Lantana, Commelina, Galinsoga* and *Phyllanthus* is reported. The increase of noxious invasive species may result in lowering forest and agriculture productivity and environmental services.
7. Forest fire is a threat to coniferous forests in the country with 526 incidents of forest fire, affecting over 70,000 ha of forest between 1999/2000 to 2007/2008 (BAP, 2009). The rising temperature and long spells of drought are likely to increase the risk of forest fires resulting in further destruction of forests. However, forest fires are also an essential part of the natural process in the functioning of many ecosystems.

c) *Water and its vulnerabilities to Climate Change*

Based on ICIMOD study, it is reported that there are 677 glaciers and 2674 glacial lakes covering an area of 1317 km^2 and 107 km^2 respectively in Bhutan. The glacier forms a huge ice reserve of 127 km^3 which is a perpetual and crucial source of water for most river systems. The World Resource Institute estimated the per capita renewable freshwater resource in Bhutan at 43,214 m^3 per person signifying its richness of water resources(Earth Trends, 2003). The Amo Chhu, the Wang Chhu, the Punatsang Chhu and the Drangme Chhu form four major river basins. All the river systems originate within the country except three rivers viz. Amo Chhu, Gongri and Kuri Chhu all of which originate in the southern part of the Tibetan Plateau. The North-South Rivers are the larger rivers originating from the highest mountains down to the lowlands near the Indian border. The second category of rivers, designated as the east-west Rivers flow as tributaries into the North-South Rivers. These streams are mainly rain-fed and supply water to both the rural and urban areas. At the present, water demand is for hydropower generation, municipal use, domestic use, irrigation, industrial use, and livestock rearing and production.

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Currently with four hydropower projects around 86% of electricity generated is exported to India which earns around 60% of the annual export earnings. The risks on the water resources due to climate change are enormous and would be on the following areas:

a. Mountain regions provide more than 50% of the global river runoff, and more than one-sixth of the Earth's population relies on glaciers and seasonal snow for water supply. In Bhutan, climate change induced glacial melt could seriously affect thousands of people who depend on glacial recharge for their water supply. The current trends in glacial melt suggest that the low flow will become substantially reduced as a consequence of global warming. The effect of this on food production and economy is likely to be unfavourable. The situation may appear to be normal in the region for several decades to come, and even with increased amounts of water available to satisfy dry season demands. However, with onset of water shortage from plenty to scarce in a few decades, some areas may run out of water during the dry season if the current warming and glacial melting trends continue resulting in drought like situation. People will face acute shortage of water for drinking, irrigation and other domestic uses.

b. Wetlands and fresh water ecosystems such as lakes, marshes and rivers may also be damaged due to change in climate. The quality of water will deteriorate due to increase in temperature and there will be negative impacts on aquatic organisms with the possibility of some species becoming extinct. Further, many wetland ecosystems will also be threatened by combination of climate change and associated disturbances like flooding, water logging and drought.

c. Water demand is increasing for consumption and irrigation. The irrigated land is less than 18% of the total arable land and mostly focused on rice cultivation. There are 1307 existing irrigation schemes mostly of conventional open canal (gravity fed) where water seepage and evaporation rates are very high. The seepage of water and poor paddy field tail water management are also identified as one of the main causes of landslides and soil erosion. Programs on water harvesting, efficient conveyance system, water storage structures, use of groundwater, and modern irrigation technologies (drip, sprinkler) are at infancy.

d. In livestock, shortage of water will have a major impact on change in feed resources showing in the forms of decreasing fodder production, degradation of pasture and rangelands which will significantly impact livestock productivity, carrying capacity of rangelands, the buffering ability of the ecosystems and their sustainability. The primary productivity of crops, forage and rangelands could change depending on location, system and species. Lack of water could lead to degradation of nutrient of different plant species which will then influence consumption and digestibility.

e. In the mid-mountains a landslide triggered by cloudburst often falls into a river, damming it temporarily and creating an impoundment in the upstream reach. The steeper the slopes, the greater are the possibility of formation of a landslide dam. In narrow valleys, massive slope landslides can completely block the path of a river, impounding a huge quantity of water. When the dam breaks after it is over-topped or when it fails to withstand water pressure, a sudden flood is created.

f. Most of the industries are located in the young, fragile and geologically unstable southern foothills that are prone to natural soil erosion and landslides. The industries that are heavily dependent on water are distilleries, agro industries, breweries, beverage industries, food industries and metallurgical industries that require a continuous flow of water for the cooling process. Water supplies for most of the existing industries are currently met from the local tributaries, but some are served from the associated municipal water supply. The water need for these water intensive industries are tapped from the springs and streams. There are reported cases of drying up of water and dwindling of water yield at the sources. This is even more frightening since the availability of an alternate source was never ascertained.

d) Human Heath and its vulnerabilities to Climate Change

Weather and climate play a significant role in people's health. Climate change has more subtle and sustained impacts on human health by affecting the three basic elements of life namely air, water and food. The impact of climate change on health conditions of direct impacts are of drought, heat waves, and flash floods, while indirect effects are economic dislocation, decline, conflict, crop failure, and associated malnutrition and hunger.

1. Warmer temperatures could increase the concentrations of unhealthy air and water pollutants. Changes in temperature, precipitation patterns, and extreme events alter the geographic range of insects, snails and cold blooded animals that transmit diseases. The impact in distribution and seasonal transmission of vector-borne illnesses like malaria (anopheles mosquito), and schistosomiasis/

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bilharzia (a snail) is already felt and is projected to widen significantly enhancing the spread of some diseases such as Malaria and Schistosomiasis. Outbreaks of diseases and pest usually localized in lower elevations are now being reported in cooler areas.

2. Climate change and associated disasters (floods and droughts) can increase the risk of contaminating fresh water supplies and communicable diseases such as diarrhoea. The prominent negative impacts of climate change on sanitation and hygiene are:
   a. increased operation and maintenance costs for treatment of water due to degradation of water quality input
   b. pollution induced by capacity of low cost surface water protection system, including pathogen loading, water borne diseases propagation
   c. water borne diseases by dry spells/droughts and degradation of quality of shallow water, ponds and marshes.

3. Bhutanese have always lived in harmony with nature and have used biodiversity for many purposes such as fuel-wood, food, fibre, shelter, medicine, household implements and handicrafts. Bhutan's rich tradition is closely linked to biodiversity. For example, the use of *Dru Na Ngu* (nine important food crops) in offerings and rituals signifies the sacred role of biodiversity in culture and traditions. The changes in rainfall patterns (drought, floods) and land-use change can lead to decrease in production of staple crops and losses in agro-biodiversity, including discontinuation of traditional practices where the culture of local communities will be adversely affected. As a result of decreasing crop production and crop diversity besides losing the tradition, the malnutrition and sickness will increase in the rural areas.

8.8 Climate Change and Adaptation Policies, Plans and Actions

a) Policy and Legal Framework

The Constitution of the Kingdom of Bhutan provides the overriding policy and legal framework for enacting legislations and acts. For the RNR sector, the most notable clause in the Constitution of 2008, is the maintenance of a minimum forest cover of 60% for perpetuity. The Vision 2020, the Land Act of Bhutan (2007), Biodiversity Act of Bhutan 2003, the Biodiversity Action Plan (BAP, 2009, 2002, 1998) provide the key policy and legal framework for planning and developing programs in the RNR Sector.

National Adaptation Program of Action (NAPA 2012) is a report of prioritized adaptation activities/actions that are needed to address the impacts of climate change. The more specific policies are developed by relevant sectors. Ministry of Agriculture and Forests (MoAF) has prepared Sectoral Adaptations Plan of Action (SAPA) through extensive stakeholder consultations in order to integrate climate adaptation options into Sectoral programs and sub-programs of the MoAF. The SAPA document consolidates and integrates the climate change adaptation related programs, themes and actions of the RNR sector as proposed in the 11th FYP Plan. The three core themes are Agriculture and Food Security, Forest and Biodiversity and Water Resources.

b) Individual contribution in reducing GHG and other pollutants

Everyone in daily life can contribute on own small way in reducing emission of Green House Gases (GHG) and impact of climate change. Many industrial activities are taken at the macro level and perhaps such activities are inevitable for the nation. However, individual behaviour can make a lot of difference in reducing or limiting the emission of GHG and other pollutant that cause damages to our natural environment. 'Think globally and act locally' is an environment education slogan and all can adopt change in our behaviour that can ease the environment degradation by the following:

a. Electricity is the main source of power in both urban and rural areas. All our gadgets run on electricity generated mainly from hydropower plants. These power plants contribute to destruction of land and environment while construction of the plant facilities and also cut down of huge areas of forest for erecting power transmission lines.

    - Save energy by changing habit to

        ✓ Use energy when absolutely necessary,

        ✓ Switch off light when not needed,

        ✓ Use energy saving equipment and devices,

        ✓ Use electrical appliances for cooking instead of fossil fuels and wood.

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- Plant trees /protect trees.
- Use timber and wood sustainably, if there is no choice but to use.

b. Cars, buses, and trucks are the main ways by which goods and people are transported in most towns and villages. These are run mainly on petrol or diesel, both fossil fuels which are responsible for the emission of huge amounts of greenhouse gases and other pollutants.

- Walk short distances instead of using cars /transportation,
- Use public transportation,
- Use fuel efficient vehicles .

c. We generate large quantities of waste in the form of plastics that remain in the environment for many years and cause damage

- Don't waste or minimize waste,
- Re-use, re-cycle waste and refuse the use of goods in plastics bags.

d. Wood is used in large quantities for construction, cooking and heating of houses which means that large areas of forest have to be cut down. We use a huge quantity of paper in our work at schools and in offices. Have we ever thought about the number of trees that we use in a day? Can we change our ways to:

- Minimize use of wood for fuel (use electricity) and construction materials?
- Use electronic or email /internet instead of paper?
- Adopt 'plant two trees for every tree that is being cut' behaviour?
- Conserve forest for sustainable use?

e. A growing population means more mouths to feed. As the land area suitable for agriculture is limited, high-yielding varieties of crops and animals are being introduced to increase the agricultural output from a given area of land. However, such high-yielding varieties of crops require large quantities of fertilizers; more fertilizer means more emissions of nitrous oxide, both from the field into which it is applied and the fertilizer industry that makes

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it. Pollution also results from the run-off of fertilizer into water bodies.

- Use land sustainably and environment friendly ways.
- Adopt 'eat to live' and not 'live to eat' philosophy of life.
- Attempt to grow individual's own vegetables with organic fertilizers.

Climate change occurs mainly due to human activities and humans have moral responsibility to adopt changes in our behaviours to correct or at least minimize the cause of change. The only way to sustain life on this earth is to 'think globally and act locally at individual level'. Sustainable agriculture technologies are available and suitable for 21st century and Bhutanese farmers must choose and employ them wisely for the sustenance of the GNH society.

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Student Activity

1. Plan to carry out an advocacy survey to find out how many teachers, support staff and students are aware of climate change, causes of climate, risk and vulnerability climate change on agriculture, forests, water and health and what they are doing to reduce the GHG in the atmosphere.
2. Design a poster to educate teachers, staff and students to reduce GNH by changing our outlook on the nature and ourselves.
3. Write articles on climate change, factors, impact on our lives, and what everyone of us have to contribute to save ourselves and our world. Display the articles or read out on occasions.

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9

CHAPTER

Agricultural Research and Development

The acronym RNR stands for Renewable Natural Resources include three important disciplines like Agriculture, Livestock and Forestry. This chapter on Research and development deals mostly with the RNR sector and not on the research of other disciplines. It is important for us to understand what we mean by research and development. Overall, the research purpose is to develop technologies that can sustain Bhutanese agriculture for the sustenance of the GNH nation and its population in the changing world of the 21st century. For this purpose, the definition of research, types of agriculture research, the process of research, different institutions involved in agriculture research and how the research results or technologies generated by research are transferred to the farmers are explained. A brief history of agriculture research in Bhutan is included in order to understand this chapter in a better way.

Agriculture started with the domestication of useful plants and animals and with this began the process of technology development. Scientific knowledge, when put to routine use for the benefit of mankind, is called technology. Any new technology to find acceptance must be competitive in today's and tomorrow's environments, and bring about economic benefits at all levels of a society while maintaining eco-friendliness, self-sustainability of the system, and social and cultural compatibility. Technology development is an on-going response of scientific knowledge to changing requirements of society. It focuses on a target group keeping in mind the resource base, socio-cultural factors, and government policies to exploit the available opportunities and match scientific knowledge with requirements.

A good development process should be flexible and offer options to the target group for successful adaptation (suiting to local conditions) and adoption (acceptance by farmers) of any new technology. Generation of new scientific knowledge is essential to upgrade the existing technology, so a strong and well-focused research

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program is a prerequisite for any technology development. The research program may involve both on-station and off-station research which complement each other and help in developing the most appropriate technology. Verification of the technology in the targeted system is an important part of the technology development process. In the current agricultural context, the development of a new technology involves increasing productivity at the farm level in an eco-friendly and sustainable manner. A simplistic approach is to first identify those constraints that affect production at the farm level, and to devise appropriate solutions to tackle them. The role of farmers and extensionists in this process is crucial.

Research can be defined as scientific studies designed to discover new information and validate previous findings or any systematic investigation to establish new facts. Research may vary from discipline to discipline. Research starts generally with an educated guess known as a hypothesis, and uses tests of different kinds to generate new understanding within the field. The meaning of research and creative activities may vary across the disciplines, however, the recurring theme is that research is an activity based on analysis which leads to innovative discoveries. Research may have a short or long term perspective. Short-term research is directed towards finding solutions to problems of immediate concern. Such problems arise in the context of the transition of agriculture from subsistence (for home consumption only) to commercial (for sale in market). In contrast, long-term research is oriented towards solving future problems, perceived in the context of expected economic or biological development.

9.1 Need for research

The agricultural sector of Bhutan is the source of livelihood for about 58% of the population. It contributes 16% of the Gross Domestic Product. The rugged hilly terrain in Bhutan limits the scope for farm mechanization (use of machines in crop production). The land holding of the farmers are small with an average holding of less than 2.5 acres which makes it difficult for commercialization. Despite various developmental efforts put in place over the years, agriculture is constrained with many problems. The productivity is low, labour shortage is acute and there are many other problems like lack of improved seeds and planting materials, inadequate irrigation facilities, limited arable agriculture land and encroachment of agriculture areas for urban development and road infrastructures. The human wildlife conflict resulting into crop depredation is another big problem faced by the

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Bhutanese farmers. In order to overcome the above mentioned obstacles, the role of research and development is of paramount importance. The enhancement of yield of crops and livestock will be possible through the introduction of high yielding varieties of different crops and livestock breeds, and management practices.

Research and development in agriculture has played a pivotal role in increasing the yield of the crops and livestock. This has helped many farmers in the country to enhance their source of income, improve the nutritional status and to some extent provide employment. Research followed by proper dissemination of its result is an integral part of development for any country and needs to be continued forever.

The problems of global warming and climate change caused by rising temperature, erratic rainfall, landslides, wind storms, flash floods are very serious and need concerted effort to address them. Under such situation, the farmers need to be provided with the best technological options to increase their production for which research plays a vital role.

Ultimately, the main objective or purpose of research in agriculture is to increase agricultural production (total yield) and productivity (yield per unit area), to ensure food security for the rising population, to develop economically viable and location-specific technologies.

a) Types of research

There are different types of research in agriculture which are undertaken to generate technologies for use by the farmers. They are as follows:

i. Basic research

It is also called pure research or fundamental research is a systematic study directed toward understanding of the fundamental principles without specific applications or products in mind. Basic research has been described as arising out of curiosity. Basic research is the basis for all other research. Many times the end results of basic research have no direct or immediate commercial benefits. The knowledge of basic research helps the researcher to think as to how to use that information for developing some useful technology which is beneficial to society. For example, the high yielding varieties of wheat which brought about green revolution and helped many countries to boost their food production would not have been possible without knowing the genetic composition of wheat crop. Today’s computers could

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not exist without the pure research in mathematics conducted over a century ago, for which there was no known practical application at that time.

ii. Applied research

It refers to scientific study that seeks to solve practical problems. Applied research is undertaken to find solutions to everyday problems and develop new technologies. It is primarily geared towards application by end users. For instance, when there was an outbreak of rice blast disease in Bhutan in 1995, Bhutanese rice varieties were crossed with disease resistant varieties from the International Rice Research Institute (IRRI), Philippines and disease resistant varieties were developed. This helped to overcome the problem of blast disease.

iii. Adaptive research

It is that in which the technologies developed elsewhere are borrowed and adapted with certain modification to suit the need of the place where the research is to be done. This will help to expedite the process of technology adoption in the place where it has been introduced. For example, Red Delicious variety of apple was introduced in 1960s which adapted very well under Bhutanese condition and is still preferred by Bhutanese farmers. The high yielding variety of rice called IR 64brought from IRRI performed very well under Bhutanese condition and is adopted by farmers. In livestock, high yielding Jersey cattle breed introduced from other countries is popular among farmers in Bhutan.

iv. Collaborative research

It is any research that is carried out by at least two people or organizations. Collaborative research is usually done by involving more than one party in which one can provide the fund and technical inputs and the other party may conduct research in the field to find out the solution to the identified problem. In collaborative research, expertise of different individuals or organizations are combined to solve a problem.

v. Policy research

It is concerned with determining which of the various alternative policies will best achieve a given set of goals in light of the relations between the policies and the goals. Policy research can be divided into three major fields that are mutually inclusive:

1. descriptive policy research which just attempts to explain policies and their development;
2. analytical or strategic policy research which is involved with formulating alternative policies and proposals; and
3. policy studies which are a combination of policy analysis together with program evaluation. The area of interest and the purpose of analysis determine what type of policy research is conducted.

iv. Socio-economic research

It includes impact assessments of research and development, policies and regulations on local communities, market research, farmer group formation, land tenure and opportunities for resettling the poor, and research on legislation on sustainable use of non-timber forest products.

b) Agriculture Research in Bhutan

Most of the agricultural research in Bhutan is adaptive or applied. Very little or no basic research is done in Bhutan on crops. For this, new crop germplasm (seeds or seedlings capable of reproduction) are imported from other countries and tested for their suitability and performance under the Bhutanese conditions. In livestock, some basic research is done where vaccines for some specific diseases are developed in the country. In Forestry, research on management aspects of forest is done to find out the best way of maintaining our forest ecosystem. Research on wildlife conservation and habitat studies are also done. Overall, the research purpose is to discover technologies that can sustain Bhutanese agriculture for the sustenance of the GNH nation and its population.

While discussing research in this chapter, it will be worthwhile for the students to know what the elements of research are. The first step is to identify the problem. The identification of problem can be done in two ways. First, it could be the problem coming from the field which can be termed as bottom-up approach. The other could be the problem identified by researchers aiming to solve pertinent problems faced by farming communities called top-down approach. The process of scientific inquiry is a carefully controlled systematic process for discovering the unknown. The scientific method helps to ensure that conclusions reached through study are scientifically valid and reliable.

The steps for conducting research are as follows:

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1. ***Identify the problem:*** The problem on which the research needs to be done.
2. ***Research the problem:*** Collect information on the identified problem through review of literature, past experiences and by other methods before undertaking the research.
3. ***Formulate the hypothesis***: Hypothesis is an idea or explanation that is tested through study and experimentation. Before conducting the research, hypothesis needs to be formulated.
4. ***Design and conduct experiment:*** There are different types of field experimental designs e.g. Complete Randomized Design (CRD) or Randomized Complete Block Design (RCBD). The survey design for socio-economic studies may include stratified or multi-phase sampling, Rapid Rural Appraisal (RRA) and Participatory Rural Appraisal (PRA).
5. ***Collect Data:*** Relevant data are collected during the course of the experiment.
6. ***Analyse the data***: The data are then analysed to meet the objective of the experiment. The analysis of data can be done by using various statistical packages among which Statistical Package for the Social Sciences(SPSS) and STAR (Statistical Tool for Agricultural Research) are commonly used in agriculture research.
7. ***Draw conclusions:*** Based on the result, conclusion of the experiment is drawn.
8. ***Make recommendations:*** After the whole process is completed, then the recommendation is made. If it is an experiment on the evaluation of a variety of a crop, recommendation for the release of that variety is done.

9.2 Innovation approaches of sustaining Agriculture

Looking back the history of mankind, humans started as hunter-gatherers, followed by sedentary farming which formed the foundation of modern day agriculture. The ability to identify and grow crops and rear animal, gradually transformed the nomadic lifestyle into a permanent settlement. It is often said that climatic change at the end of the last ice age that brought seasonal conditions favoring annual plants like wild cereals was the first illustration of crop cultivation. Ever since agriculture was invented some 10,000 years ago, somewhere in the fertile crescent of the Middle East (and simultaneously in some other places in the world), humans have innovated so rapidly that lead to transformational change in the way we farm. Generally the evolution of agriculture is viewed by two theories

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– materialistic and environmental theories. All through the centuries, agriculture and innovation went hand in hand. Not disregarding the two theories, as the physical, social and economic environment changed continually, farmers had to respond to the change and adapt thereby developing the agricultural system. This adaptation has consistently helped in evolution of agriculture over the centuries through a continuum of innovation and innovation systems.

Innovation is widely recognized as a major source of improved productivity, competitiveness, and economic growth throughout advanced and emerging economies. Innovation also plays an important role in creating jobs, generating income, alleviating poverty, and driving social development. A dynamic interaction among the actors involved in growing, processing, packaging, distributing, and consuming is the primary driver for agricultural innovation. This dynamic interaction is facilitated by specific engagement of knowledge from multiple sources representing its own routines and traditions that reflect historical origins shaped by culture, politics, policies and power. There are four related and overlapping adaptive collaborative approaches that consider learning and collaboration as central processes in agriculture innovation. They are described below.

9.3 Innovation Systems, Social Learning and Participatory Action Research

Innovation is a dynamic process of introducing new idea, solution or products. Innovation can be represented as a cyclical process in which available information is used to evaluate and understand the situation. Based on the situation, possibility to improve the situation is explored and a new solution is identified. The solution is applied in the context and tested. This search for new ideas continues and paves way for a new cycle.

The major goal of innovation in agriculture has been to increase productivity of the agricultural sector. As illustrated in Figure 9.1, the centre stage of innovation in agriculture is the farmer, as he is the one who is intimately involved in farming and has the full grasp of what is happening in agricultural systems in the locality. Further as the first person to be affected by any change, farmer is constantly searching for new ideas and techniques to optimize the systems production. Being at the helm of the agriculture systems, farmers have become the source of information and motivation for agricultural research and education systems.

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As shown in Figure 9.1, farmer is the primary source of information for agricultural research, extension, education, and administration to understand the issue and find solutions.

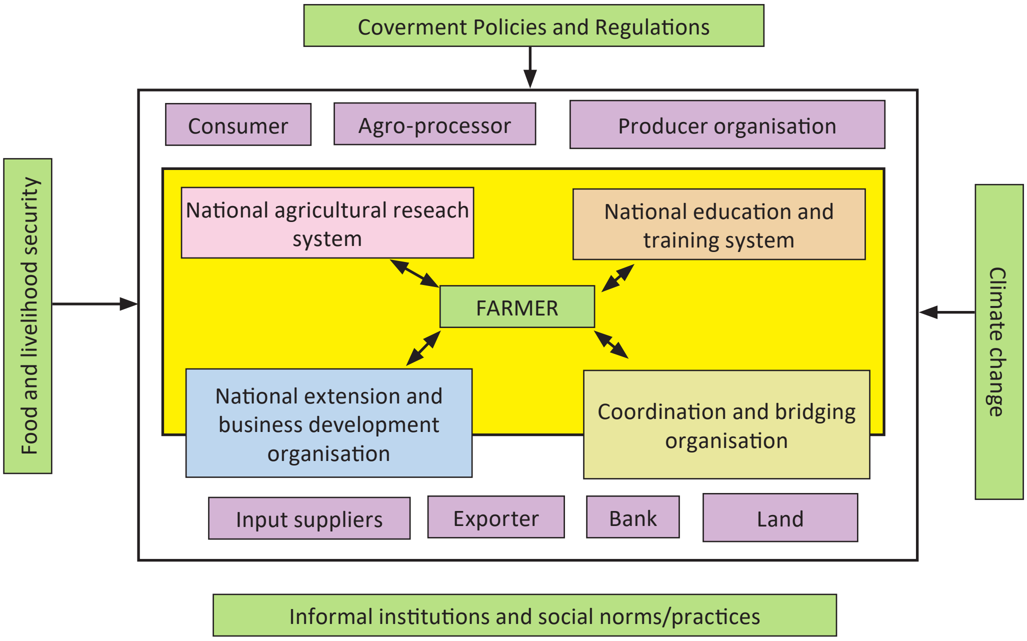

Figure 9.1 Agricultural innovation system (adopted from World Bank, 2012)

The production system is highly influenced by inputs, resources and management. Therefore it is imperative that innovation in agriculture is conscious of both internal and external factors. In real life situations, farmers based on their instinct continuously research in their small ways. It is an inherent characteristic of those who are striving to make a living out of the difficult situation they are in. Almost every single farmer who is living in such challenging circumstances has to innovate in order to survive. Farmers, especially resource-poor ones, continuously experiment, adopt and innovate (Chambers et al in Critchley, 1999). Farmers' innovations are useful either only to the individual farmer, sometimes even limited to specific circumstances (plot of land, category of animals, specific bio-physical nature) or to a wider range of application that can be used by many farmers.

Once a technology is innovated and tested, its adoption takes some times depending on the several factors. The technology adoption cycle (Figure 9.2) describes the adoption or acceptance of a new product or innovation. The process of adoption over time is typically illustrated as a classical normal distribution or "bell curve." The model indicates that the first group of people to use a new product is called "innovators," followed by "early adopters." Next come the early and late majority, and the last group to eventually adopt a product are called "laggards" as shown below.

- innovators – had larger farms, were more educated, more prosperous and more risk-oriented
- early adopters – younger, more educated, tended to be community leaders, less prosperous
- early majority – more conservative but open to new ideas, active in community and influence to neighbors
- late majority – older, less educated, fairly conservative and less socially active
- laggards – very conservative, had small farms and capital, oldest and least educated

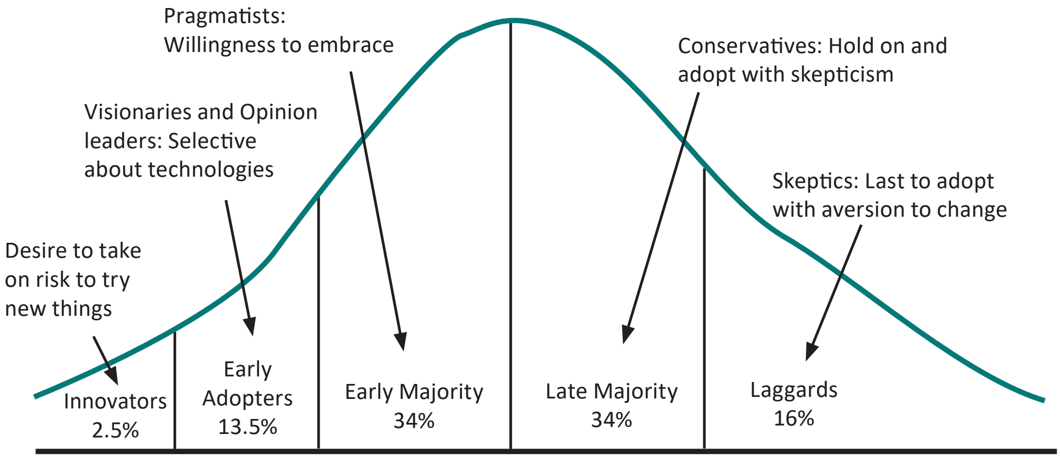

Figure 9.2 Pathway in innovation system (adopted from Geels, 2004)

Examples of farmer innovations in Bhutan:

» Extraction and use of Pangtshi oil (Symplocospaniculata): naturally growing in and around paddy field in Punakha, farmers have specialized in extraction of oil and its use as cooking oil, a natural substitute for edible oil.

» Planting time of vegetables and crops in changing climate.

» Modification of bullock drawn plough which varies across the country.

» Identification and use of natural dyes.

» Medicinal plants.

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» Plants used for Incense.

» Pest management.

» Food processing (ara brewing, zaw, puta, mekho).

a) Social learning theory

It focuses on the learning that occurs within a social context. It considers that people learn from one another, including such concepts as observational learning, imitation, and modeling. Social learning theory formulated by Albert Bandura explains human behavior in terms of continuous reciprocal interaction between cognitive, behavioral and environmental influences, therefore often referred as bridge between behaviorist and cognitive learning theories. It is to assume, therefore, that Social learning theory is concerned on observational learning process among people, which is grounded in the belief that human behavior is determined by a three-way relationship between cognitive factors, environmental influences, and behavior (Figure 9.3).

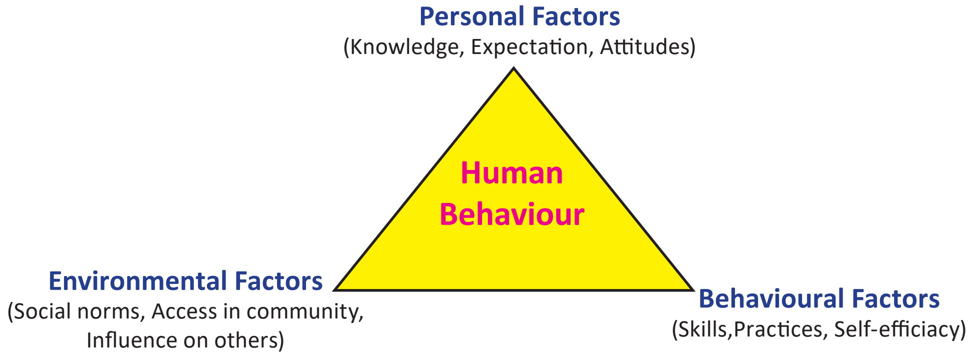

Figure 9.3 Determinants of human behaviour

General principles of social learning theory are as follows:

a) People can learn by observing the behavior

b) Learning can occur without a change in behavior

c) Knowledge plays a role in learning

d) Social learning theory can be considered as a bridge or a transition between behaviorist learning theories and cognitive learning theories.

e) There are four processes needed for social learning to occur. The four processes are attention, retention, reproduction, and motivation (Table 9.1).

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Table 9.1 Simple steps to determine the success of social learning

Step	Actions
Attention	Social Cognitive Theory implies that you must pay attention for you to learn. If you want to learn from the behavior of the model (the person that demonstrates the behavior), then you should eliminate anything that catches your attention other than him. Also, the more interesting the model is, the more likely you are to pay full attention to him and learn.
Retention	Retention of the newly learned behavior is necessary. Without it, learning of the behavior would not be established, and you might need to get back to observing the model again since you were not able to store information about the behavior.
Reproduction	When you are successful in paying attention and retaining relevant information, this step requires you to demonstrate the behavior. In this phase, practice of the behavior by repeatedly doing it is important for improvement.
Motivation	Feeling motivated to repeat the behavior is what you need in order to keep on performing it. This is where reinforcement and punishment come in. You can be rewarded by demonstrating the behavior properly, and punished by displaying it inappropriately.

As social learning promotes collective action and reflection amongst both individuals and groups when they work to improve the management of the interrelationships between social and ecological systems, it is considered as an approach to tackling the complex problem of human induced climate change. Social learning builds from an understanding that knowledge implies learning and the ability to use information. Examples of social learning in Bhutan are

» *Farmer Field School*: integrated pest management in vegetable and orchards, vegetable production and marketing

» *Participatory varietal selection:* rice in Punakha-Wangdi valley during 1987-88 and maize in Trashigang-Mongar during 2009-2012

b) Participatory Action Research (PAR)

It is a form of action research that is also referred to as collaborative inquiry, action learning or contextual action. Participatory action research is a research

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methodology which aims to pursue action and research outcomes at the same time (Figure 9.4). Participatory action research is an approach to research in communities that emphasizes participation and action. PAR emphasizes collective inquiry and experimentation grounded in experience and social history. Within a PAR process, "different types of inquiry and action evolve and address questions and issues that are significant for those who participate as co-researchers". It recognizes that people learn through the active adaptation of their existing knowledge in response to their experiences with other people and their environment. As such it is considered that learning by doing is an outcome of experimentation and reflections. It is also common to see that from actions people build their experience.

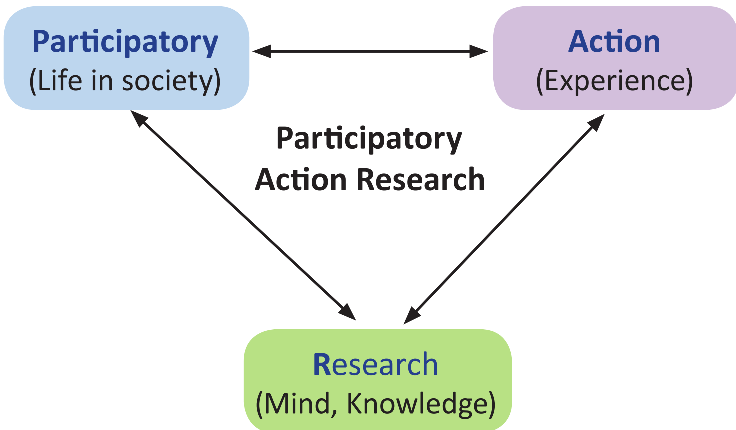

Figure 9.4 Elements of participatory action research (Adapted from: Chevalier and Buckles, 2013)

Participatory Action Research is a continuous cycle in which insiders and outsiders together decide what needs to be researched, designed the researched (what will be measured and how) and collect the necessary information. This information is then put into practical applications or used to identify new research ideas. For instance, when any project is planned for any area, it is essential to collect and analysis necessary information on the problems and action areas with close participation with beneficiaries. In the simplest form, it can be represented as a cycle of four steps of reflection, planning, action and observation (Figure 9.5). The diagram shows the four steps in action; the movement from one critical phase to another, and the way in which progress may be made through the system. One cycle of planning, acting, observing and reflecting, therefore usually leads to another, in which you incorporate improvements suggested by the initial cycle.

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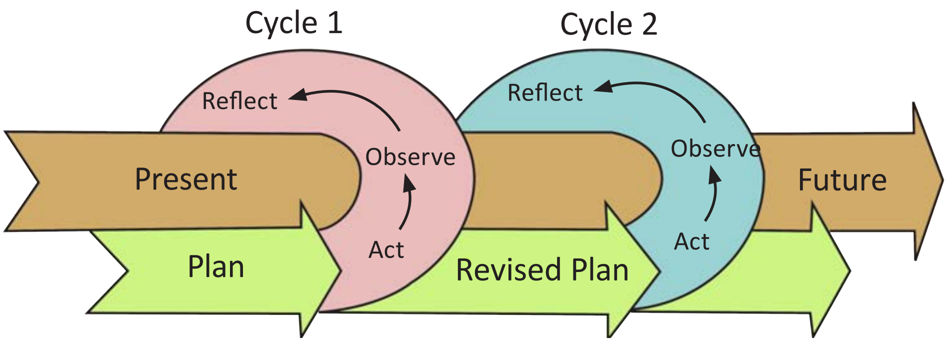

Figure 9.5 Action research model (Adopted from Carr and Kemmis, 1986)

Participatory action research operates within four general principles as listed below that are achieved through a cyclical process of exploration, knowledge construction, and action at different moments throughout the research process as indicated in Figure 9.5.

- collective commitment to investigate an issue or problem,
- desire to engage in self- and collective reflection to gain clarity about the issue under investigation,
- joint decision to engage in individual and/or collective action that leads to a useful solution that benefits the people involved, and
- building of alliances between researchers and participants in the planning, implementation, and dissemination of the research process.

Some of the differences between participatory action research and conventional research are as shown in table 9.2 below.

Table 9.2 Differences between PAR and conventional research

Key question	Participatory research	Conventional research
What is the research for?	Action	Understanding with perhaps action later
Who is the research for?	Local people	Institution, professional interest
Whose knowledge counts?	Local people's	Scientist
Topic choice influenced by?	Local priorities	Funding priorities, institutional agenda, professional interests

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Methodology chosen by?	Empowerment & mutual learning	Disciplinary conventions
Who takes part in data collection and problem identification?	Local people	Researchers
Who takes part in analysis, interpretation and presentation?	Local people	Researchers
Who takes actions?	Local people with/without external support	External agencies
Who owns the results?	Shared	Researcher
What is emphasized?	Process	Outcomes

Participatory action research is a learning process whose fruits are the real and material changes in:

i) what people do;

ii) how people interact with the world and with others;

iii) what people mean and what they value; and

iv) the discourses in which people understand and interpret their world.

c) RNR Research in Bhutan

The agriculture research started in Bhutan in early sixties when the Department of Agriculture was established with the objective of promoting agricultural crops and livestock. A network of research stations were established in Yusipang, (Thimphu), Khangma (Trashigang), Bhur (Gelephu) and Naspyel, (Bumthang), with technical guidance and resources provided by Indian Government.

Initially, the varieties which were doing well in India were introduced into Bhutan and tried under Bhutanese condition. Before that period, farmers in Bhutan were growing mostly indigenous crops and varieties at subsistence level. The best example of the research in horticulture in Bhutan is the introduction and trial

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of Red Delicious, Royal Delicious and Golden Delicious varieties of apple in the sixties which are still the most preferred varieties. Since then, the Department of Agriculture has continued to bring new varieties of crops from India and other countries for trial in Bhutan. Varieties which performed well under Bhutanese condition were adopted by farmers. One very important variety of Potato called Desiree with red skin was introduced and still one of the best and preferred varieties of potato in Bhutan.

The first organized Agriculture Research Station was established in 1982 as the "*Centre for Agriculture Research and Development (CARD)*" in Bajo, Wangdue with a focus on rice research. The research in potato production started in 1988 in Agriculture Research Station in Yusipang with the assistance from Switzerland and Food and Agriculture Organization. The National Research Program in Forestry was started in 1987 at Taba (Thimphu). The research on Renewable Natural Resources comprising of Agriculture, Livestock and Forestry were brought under one organization in 1991. After that, four Research Centres were established at Yusipang, Thimphu, for forestry research, Bajo, Wangdue for field crops, Jakar, Bumthang for livestock and Wengkhar, Mongar for horticultural crops. One more research centre has been established in Bhur, Gelephu for research on sub-tropical crops.

9.4 Institutions involved for RNR Research in Bhutan

There are many Institutes which undertake research in Bhutan spread over various departments in the Ministry of Agriculture and Forests. These institutes carry out research according to their mandates. The following institutions under the Department of Agriculture carry out research.

a) Institutes under the Department of Agriculture

i. Agriculture Research and Development Centre (ARDC Bajo)

This centre is located at Bajo, responsible for field crop research. It carries out research mainly on staple cereals like rice, wheat, oilseeds and some grain legumes. Apart from cereals, it also does research on horticultural crops like citrus, mango, guava, avocado etc. and responsible for technology generation and transfer of technologies in the farmers' field.

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ii. ARDC Wengkhar

This centre is located at Wengkhar, Mongar and is mandated to implement research on horticultural crops like citrus, pear, persimmon, peach, plum etc. Maize is an important crop of the Eastern Bhutan; hence the research on maize is also done by RDC, Wengkhar. Recently, the centre has developed maize varieties that are resistant to Gray Leaf Spot (GLS) disease which is a major production constraint. This centre also carries out research on rain water harvesting, and medicinal and aromatic plants, especially on lemon grass. It also disseminates technologies generated by the Centre.

iii. National Plant Protection Centre

This centre is located at Semtokha, Thimphu and is responsible to carry out research on insects-pests, diseases, weeds and integrated pest management. The centre works on development of non-chemical method of pest control and use of bio-pesticides. This centre is also responsible for procurement and supply of agro-chemicals for the whole country. Through research on integrated pest management, a number of extension materials on pest control on different crops for the use of the farmers and extension have been developed and distributed.

iv. National Soil Service Centre

This centre is located at Semtokha and responsible to carry out research on soil fertility management, soil nutrient management and analysis of soil samples for the clients. The Centre co-ordinates soil/land management research activities of the RNR sector. The Soil & Plant Analytical Lab was established in early 1990s to provide analytical services to the agriculture sector. The soil analysis services are provided free of cost.

v. National Mushroom Centre

This centre is located at Wangchutaba, Thimphu and is responsible to carry out research and development activities on edible mushroom. The production and supply of spawn (seeds) of mushroom all over the country is done by this centre.

vi. National Post Harvest Centre

This centre is located at Bondey, Paro and is responsible to carry out research on post-harvest aspects like value addition to the products and post-harvest control

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of storage insect pests and diseases. Areas for RNR research in post-harvest technology and farm infrastructure include cross-cutting issues mainly relating to harvest, storage and processing. They include the development of storage facilities, food processing equipment and thus the diversification of value-added products.

vii. National Seed Centre

This centre is located at Chunidingkha, Paro. Its main mandate is the production and supply of seeds and planting materials but also carry out research on vegetables and fruit plants on need basis.

viii. Agriculture Machinery Centre

It is located at Bondey, Paro and this centre is also responsible for conducting research on the farm equipment, tools and implements. Over the years, AMC has developed agricultural technologies and farming practices which are appropriate to the Bhutanese terrain and ecological conditions. It has not only contributed significantly in the national goal of food self-sufficiency but has also been instrumental in alleviating drudgery in Bhutanese agriculture.

ix. ARDC Bhur

This centre is located at Bhur, Gelegphu and is responsible for conducting research on low altitude crops like rice, maize, citrus, mango, litchi, oilseed etc. in terms of agriculture crops. It also carries out research in bamboo and has developed a live herbarium of Bamboo.

x. ARDC Yusipang

This centre is located at Yusipang, Thimphu. The center is responsible to plan and coordinate research on potato, medicinal plants and research on temperate fruits like apple, pear, peach etc. across the country. It also carries out research on vegetables and organic agriculture.

xi. Organic Agriculture

Bhutan is making all out efforts to go organic in food production and this program is under the Department of Agriculture. Research on different methods of organic farming practiced in other countries is tried and adapted under Bhutanese condition.

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b) Institutes under the Department of Forestry and Park Services

i. Department of Forestry and Park Services

Areas for research in forestry include nature conservation, conifer forest management, broadleaf forest management, reforestation, social forestry, non-timber forest products, wood products and forest protection. Further, research on species and plantation techniques in degraded areas and climatic zones, impact assessments of grazing on natural regeneration, wildlife management and human wildlife conflicts are conducted. In sustainable forest management, the researchable areas include domestication, sustainable harvesting methods, and ecological characterization and socio-economics of selected non-wood forest products. In nature conservation, research is needed in the area of water and forest relationships, payment for environmental services and forest succession.

ii. Ugyen Wangchuck Institute for Conservation and Environment Research

This Institute is located at Lamigompa, Bumthang and it is responsible to carry out research on sustainable forestry, conservation biology, water resources and socio-economic and policy sciences. It undertakes scientific forest research to support better ways of forest management and utilization. It also provides training on forest conservation and management. The Institute pays special attention to understanding climate change and associated impacts and accord high priority on understanding climate and rainfall variability in the Himalayan ecosystems.

c) Institutes under the Department of Livestock

There are four Regional Livestock Development Centers located at Chukha, Zhemgang, Wangdue and Khangma under the Department of Livestock and some production Farms located at different regions of Bhutan. Each centre supports to conduct research based on the region specific problem and general research.

i. National Centre for Animal Health

This centre is located at Serbithang, Thimphu and is responsible for carrying out research on aspects like vaccine development for treatment of livestock diseases, diagnosis of diseases etc. It is also focal agency for implementation of essential veterinary drug program. It coordinates and implements research and training in animal health in collaboration with the relevant institutes within the country.

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ii. National Research and Development Centre for Aquaculture

This centre is located at Gelephu, which does research on warm water fish and also engaged in distribution of fingerlings to the farmers.

iii. National Highland Research and Development Centre (Jakar)

This is located at Jakar and responsible for carrying out research on livestock related topics like yak, sheep, goat, horse and also apiculture (honeybee).

iv. National Poultry Research and Development Centre

This centre is located at Sarpang, and is responsible for research on poultry. This centre is instrumental in producing and supplying day-old-chicks to the Bhutanese farmers. Through the concerted effort of this centre Bhutan is almost self-sufficient in egg production.

v. National Diary Research and Development Centre

This centre is located at Yusipang, Thimphu and is responsible for doing research on dairy cattle, production, breeding and post production. This centre produces frozen bovine semen and liquid nitrogen to intensify artificial insemination and breed improvement programmes.

vi. National Research and Development Centre for Animal Nutrition

This centre is located at Batpalathang, Bumthang and conducts research on feed and fodder. This centre has developed, packaged and released 24 varieties of assorted fodder seeds which helped in reducing the shortage of winter fodder in the country.

vii. National Piggery Research and Development Centre

This centre is located at Gelephu and is responsible for conducting research on swine and is also mandated to supply piglets to the farmers.

To conclude, the research and development centres carryout numerous research activities to support the development of agriculture in Bhutan, it is important that the Bhutanese farmers make best use of the services provided by the centres as well as be innovative in their approaches. Hopefully, this chapter has provided you with some knowledge and some skills to conduct simple research.

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Student Activity

1. Plan for a field to nearby ARDC to find out what type of researches have been done on agriculture and improvement the researches have made on agriculture. Or
2. Following the research procedures mentioned in the text, plan and carryout simple research to improve school gardening, Or
3. Carryout a survey to find how our farmers in the villages are coping up with climate changes and the changes that they have been made in the cropping system or cropping pattern for their sustenance.

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