12 Climate Change Adaptation

Abstract

There is a need to improve and promote existing management strategies for dealing with climate variability. This will enhance farmers' capacity to plan for, and deal with, extreme events (droughts, floods, fire, hail, etc.) in the medium and longer term. Using climate forecasts at a range of time scales to make preemptive, tactical management adjustments will help to track the early stages of climate change, until the longer-term trends and necessary adaptations in particular regions become clearer.

It is important to note that many climate adaptation options are similar to existing "best practice" and good natural resource management and do not require farmers to make radical changes to their operations and industries in the near term. These options can, and should, be prioritized as part of a "no regrets" or win–win strategy for agriculture because they will provide immediate and ongoing benefits, as well as prepare the sector for climate change.

Information delivery to farmers from climate analyses can be enhanced by providing projections of management and policy-relevant weather metrics (e.g., cold indices for stone fruit), providing climate information at scales relevant to the decisions being made, and combining information on both climate variability and trends in seasonal and medium-term (decadal) forecasts. Biotechnology and traditional plant and animal breeding have the potential to develop new "climate-ready" varieties and new crops or pastures preadapted to future climates. Plant nutrition can be adjusted by measures such as precision fertilizer use, legume rotations, and varietal selection to maintain the quality of grain, fruit, fiber, and forage sources. Irrigation efficiency will become critical as water resources become more constrained. This can be assisted by identifying less water-intensive production options, by developing better water delivery technologies, and by implementing water markets and water-sharing arrangements. Soil and water conservation methods and new systems become even more important as climates fluctuate more and extreme events become more frequent. Biosecurity, quarantine, monitoring, and control measures can be strengthened to control the spread of pests, weeds, and diseases under a warming

P.P. Reddy, *Climate Resilient Agriculture for Ensuring Food Security*,
DOI 10.1007/978-81-322-2199-9_12, © Springer India 2015

climate. Better models of agricultural systems can assess climate change impacts and more reliably explore and improve adaptation options. Monitoring and evaluation systems are needed to track changes in climate, impacts on agriculture, and the effectiveness of adaptation measures, to help decide when to implement particular options and to refine them over time. Policy and management decisions require timely inclusion of climate information as it becomes available, as well as closer collaboration between policy makers, managers, researchers, extension agencies, and farmers.

Keywords
Improved crop seeds • Livestock and fish cultures • Crop production adaptation • Water adaptation • Agro-forestry • Pest management • Livestock adaptation • Energy adaptation • Early warning systems • Crop insurance schemes • Livelihood diversification • Access to information

Adaptation is defined as a response to actual or expected climate stimuli or their effects, which moderates harm or exploits beneficial opportunities. In human systems, adaptation can be both anticipatory and reactive and can be implemented by public or private actors (UNDP 2007/2008).

Adaptation refers to efforts by society or ecosystems to prepare for or adjust to future climate change. These adjustments can be protective (i.e., guarding against negative impacts of climate change) or opportunistic (i.e., taking advantage of any beneficial effects of climate change). Adaptation is changing activities and processes in order to lessen negative impacts of climate change that is already taking place, and to open the agricultural sector to new opportunities that might arise from a changing climate.

Historically agriculture has shown a considerable ability to adapt to changing climatic conditions, whether these have stemmed from alterations in resource availability, technology, or economics. Many adaptations occur autonomously and without the need for conscious response by farmers and agricultural planners (Brooks et al. 2013).

To deal with the impact of climate change, the potential adaptation strategies are: developing cultivars tolerant to heat and salinity stress and resistant to flood and drought, modifying crop management practices, improving water management, adopting new farm techniques such as resource-conserving technologies (RCTs), crop diversification, improving pest management, better weather forecasting and crop insurance, and harnessing the indigenous technical knowledge of farmers.

Easterling et al. (2007) describe a range of options, at the level of autonomous adaptation, for cropping and livestock systems:

- Use of different varieties or species with greater resistance to heat or water stress, or adapted phenology (maturation times and responses)
- New cropping practices, including adjustments in timing and locality of crop production, and changed water and fertilizer management to maintain yield quality and quantity
- Greater use of water conservation technologies, including those to harvest water and conserve soil moisture, or, in flood-prone areas, water management to prevent water logging, erosion, and nutrient leaching
- Diversification of on-farm activities and enhancement of agrobiodiversity, with greater integration between livestock and cropping systems
- Adapted livestock and pasture management, including rematching stocking rates and timing with pasture production, new varieties and species of forage and livestock, updated fertilizer applications, and using supplementary feeds and concentrates

- Improved management of pests, diseases and weeds, for example, through integrated pest management, new crop and livestock varieties, improved quarantine, and sentinel monitoring programs.
- Better use of short-term and seasonal climate forecasting to reduce production risk

12.1 Improved Crop Seeds, Livestock, and Fish Cultures

12.1.1 Key Issues

- Promoting use of biotechnology
- Research and promotion of C4 pathways in C3 plants
- Conserving indigenous genetic resources
- Management and dissemination of improved varieties
- Conserving "Agricultural Heritage"

The introduction of new cultivated species and improved varieties of crop is a technology aimed at enhancing plant productivity, quality, health and nutritional value, and/or building crop resilience to diseases, pest organisms, and environmental stresses. The use of the appropriate crop varieties reduce their vulnerability to risks associated with climate change (e.g., harvest losses due to pests, diseases, or droughts) and improve their livelihoods.

The traits that may be important for climate change adaptation include:

- Capacity to tolerate high temperatures and droughts
- Fire resistance and tolerance, especially for trees
- Resistance or tolerance to diseases and pests
- Phenotypic plasticity

Breeding new and improved crop varieties enhances the resistance of plants to a variety of stresses that could result from climate change. These potential stresses include water and heat stress, water salinity, and the emergence of new pests. Varieties that are developed to resist these conditions will help to ensure that agricultural production can continue and even improve despite uncertainties about future impacts of climate change. Varieties with improved nutritional content can provide benefits for animals and humans alike, reducing vulnerability to illness and improving overall health.

12.1.2 Advantages

The process of farmer experimentation and the subsequent introduction of adapted and accepted varieties can potentially strengthen farmers' cropping systems by increasing yields, improving drought resilience, boosting resistance to pests and diseases, and also by capturing new market opportunities. To make the products of the research process more relevant to the needs of smallholder farmers, research organizations are increasingly engaged in participatory research in recognition of its potential contribution to marginal areas with low agricultural potential. There is a need to identify crops and varieties that are suited to a multitude of environments and farmer preferences. Participatory approaches increase the validity, accuracy, and particularly the efficiency of the research process and its outputs. Researchers are better informed and can better inform about the traits that should be incorporated in improved varieties. Participatory processes also enhance farmers' capacity to seek information, strengthen social organization, and experiment with different crop varieties and management practices.

12.1.3 Disadvantages

Farmer experimentation using only native varieties can limit the range of benefits and responses that may be found among the materials being tested, although local adaptation and acceptance are ensured. At the same time, problems can arise with the introduction of exotic species (from other origin centers) that after being introduced turned into pests. There are several examples of introduced species that have escaped control becoming pests or agricultural weeds.

12.1.4 Developing Climate-Ready Crops

Development of new crop varieties with higher yield potential and resistance to multiple stresses (drought, flood, salinity) will be the key to maintain yield stability. Improvement in germplasm of important crops for heat-stress tolerance should be one of the targets of breeding program. Similarly, it is essential to develop tolerance to multiple abiotic stresses as they occur in nature. The abiotic stress tolerance mechanisms are quantitative traits in plants. Germplasm with greater oxidative stress tolerance may be exploited as oxidative stress tolerance is one example where plant's defense mechanism targets several abiotic stresses. Similar to the research efforts on conversion of rice from C3 to C4 crop, steps should be taken for improvement in radiation-use efficiency of other crops as well. Improvement in water-use and nitrogen-use efficiencies is being attempted since long. These efforts assume more relevance in the climate change scenarios as water resources for agriculture are likely to dwindle in future. Nitrogen-use efficiency may be reduced under the climate change scenarios because of high temperatures and heavy precipitation events causing volatilization and leaching losses. Apart from this, for exploiting the beneficial effects of elevated CO_2 concentrations, crop demand for nitrogen is likely to increase. Thus, it is important to improve the root efficiency for mining the water and absorption of nutrients. Exploitation of genetic engineering for 'gene pyramiding' has become essential to pool all the desirable traits in one plant to get the 'ideal plant type' which may also be 'adverse climate-tolerant' genotype.

Farmers need to be provided with cultivars with a broad genetic base. Their adaptation process could be strengthened with availability of new varieties having tolerance to drought, heat, and salinity and thus minimize the risks of climatic aberrations. Similarly, development of varieties is required to offset the emerging problems of shortening of growing season and other vagaries of production environment. Farmers could better stabilize their production system with basket of technological options.

12.1.5 Drought-Tolerant Varieties

Different agronomic adaptation practices are applicable to different farming systems and agro-climatic zones, including drought tolerance for adaptation to climate change. Many research institutions have developed various crop varieties suitable for specific climatic zones. For instance, new rice varieties with acceptable grain quality and yield and shorter growing duration need to be developed or introduced into rice-growing areas. The adoption of direct seeding pre-germinated seed, either by broadcasting or drum seeding, into flooded paddy fields can reduce the crop cycle by 10–45 days. Farmers need to be linked to leading research institutions to get certified seeds to increase production under changing rainfall regimes.

Fifty new maize hybrids and open-pollinated maize varieties have been developed and provided to seed companies and NGOs for dissemination, and several of them have reached farmers' fields. These drought-tolerant maize varieties produce 20–50 % higher yields than other maize varieties under drought conditions. Farmers choose their crops according to the climate in which they operate. For example, in Sahelian West Africa, farmers prefer drought-tolerant crops such as sorghum and cowpea (Kurukulasuriya and Mendelsohn 2006). Moreover, introduction of improved crop varieties should consider the local community's eating habits, cultural practices, agroecological conditions, and markets.

Several horticultural crop varieties have been released which are resistant to abiotic stresses such as heat and moisture (Table 12.1).

12.1.6 Promoting Use of Biotechnology

Biotechnology is an important tool for the development of genetic resources with greater adaptive capacity to cope with changing environments. It has huge potential for combating vulnerabilities in crops, livestock, and fisheries. Research and promotion of higher carbon (C4) pathways in low carbon (C3) plants and genetic

Table 12.1 Horticultural crop varieties resistant to major abiotic stresses

Vegetable crop	Abiotic stress	Resistant varieties
Tomato	Moisture	Arka Meghali
	Hot set	Pusa Hybrid-1
	Hot and cold set	Pusa Sadabahar
Chili	Moisture	Arka Lohit
Field bean	Moisture	Arka Jay, Arka Vijay, Konkan Bushan
Cowpea	Moisture	Arka Garima
French bean	Heat tolerant	Arka Komal
Cluster bean	Moisture	Pusa Nav Bahar, Pusa Sadabahar
Lima bean	Moisture	IIHR Sel-1, IIHR Sel-4
Round melon	Heat tolerant	Arka Tinda, Punjab Tinda
Long melon	Heat tolerant	Arka Sheetal, Punjab Long Melon
Bottle gourd	Heat tolerant	Pusa Summer Prolific Long
Bitter gourd	Heat tolerant	Pusa Do Mousami, Kalyan Sona
	Warm humid climate	Arka Harit, Coimbatore Long, Konkan Tara, Priya, CO-1, MC-84, MDU-3
Cabbage	High temp. tolerant	Pusa Ageti
Cauliflower	Curd development in May in lower hills	Pusa Him Jyoti
Turnip	Hot and humid climate	Pusa Sweta
Radish	High temp. tolerant	Pusa Chetki
Carrot	Temperate type, bolting, and seed setting under high temp.	Pusa Meghali
Palak	Not bolting in plains	Pusa Harit
Turmeric	Tolerant to drought	CO-1, BSR-1

manipulation of enzymes such as RuBisCo would help in increasing effectiveness of use of CO_2 and thus helping the reduction in GHG emissions.

DroughtGard maize will be the first commercially available transgenic (GM) drought-tolerant crop if it is released in 2013 as planned. Hybrid seed sold under this trademark will combine a novel transgenic trait (based on the bacterial *cspB* gene) with the best of Monsanto's conventional breeding program. The best performing lines of *cspA* and *cspB* showed yield increases of 30.8 % and 20.4 %, respectively. The best two *cspB* lines (CspB-Zm events 1 and 2) also showed significant gains in leaf growth, chlorophyll content, and photosynthetic rates. Non-transgenic controls suffered 50 % or 30–40 % yield losses under the two drought stresses (well-watered, drought immediately preceding flowering, drought during grain fill), respectively. Thus, the *cspB* gene appeared capable of minimizing kernel abortion, an irreversible (and therefore very important) component of yield loss under drought (Fig. 12.1).

Overexpression of *AVP1* in cotton not only improved drought and salt tolerance under greenhouse conditions but also increased fiber yield in dryland field conditions. The increased yield by *AVP1*-expressing cotton plants is due to more bolls produced, which in turn is due to larger shoot system that *AVP1*-expressing cotton plants develop under saline or drought conditions. The larger root systems of *AVP1*-expressing cotton plants under saline and water-deficit conditions allow transgenic plants access to more of the soil profile and available soil water, resulting in increased biomass production and yield (Fig. 12.2) (Pasapula et al. 2011).

The HRD gene in transgenic rice has improved water-use efficiency and the ratio of biomass produced to the amount of water used, through enhanced photosynthesis and reduced transpiration. Correlation of drought tolerance with root architecture (spread, depth, and volume) has been examined in cowpea (South Africa, West Africa, and India), rice (India), and beans (Central and South America). Other modifications are further from commercialization (Table 12.2).

12.1.7 Interventions

12.1.7.1 Research and Development

- Development of plant genetic resources to combat changing environments with special focus on plant physiological processes such as flowering, seed development, photosynthesis, respiration, water retentions, and plant growth regulation

Fig. 12.1 Monsanto's drought-resistant corn, at *right*, was tested next to traditional corn plants on the *left* (drought-aborted kernels)

Fig. 12.2 Field performances of cotton plants. (*Left*) Phenotypes of segregated non-transgenic line, (*Right*) Phenotypes of AVP1-transgenic line

Table 12.2 Biotechnology products showing longer-term promise for adaptation to climate change

Product	Trait	Function	Reference
Drought-tolerant rice	HARDY (HRD) gene from *Arabidopsis*, reducing transpiration and enhancing photosynthetic assimilation	Reduced transpiration, increasing biomass/water use ratio, adaptive increase of root mass under water stress	Karaba et al. (2007)
Drought-tolerant tobacco (model)	Delayed drought-induced leaf senescence	Retained water content and photosynthesis resulting in minimal yield loss under drought (30 % normal water requirements)	Rivero et al. (2007)
Drought-tolerant maize	Expression of glutamate dehydrogenase (gdhA) gene from *E. coli*	Germination and grain biomass production under drought increased	Castiglioni et al. (2008)
Drought-tolerant maize	Enhanced expression of phosphatidylinositol-specific phospholipase by ZmNF-YB2 reducing stomatal conductance and so leaf temperature and water loss	Grain yield increases through reduced wilting and maintenance of photosynthesis under drought	Nelson et al. (2007)
Salt-tolerant rice	A QTL (Saltol) associated with drought resistance	Allows close to normal yield under high salinity situations (Bangla Desh)	IRRI News (2009)

- Development of crop varieties tolerant to biotic and abiotic stresses, drought, salinity and high temperature, flood and submergence, etc., through marker-assisted selection process
- Transgenic approaches to retard senescence in fruits to reduce postharvest losses
- Development of livestock and fish varieties to cope with biotic and abiotic stress levels
- Development of crops with enhanced water and nitrogen use efficiency and CO_2 fixation potential to increase productivity and for reducing emissions of greenhouse gases
- Building of soil carbon banks through fertilizer trees for enhancing soil nutrient status
- Screening of indigenous plant and animal gene pools and cataloguing them according to specific traits of agronomic value and conservation and establishment of gene banks in situ and ex situ
- Strengthening basic research in plant sciences including phenomics and linking basic research to farm level
- Developing and spreading true potato seed (TPS) methodology for potato
- Development of hybrid rice strains characterized by hybrid vigor in the development of root system
- Breeding salinity-tolerant crop varieties for cultivation in coastal areas, based on genetic engineering techniques

12.1.7.2 Technologies and Practices

- Use of micro-propagation and tissue-culture techniques for rapid bulking of improved varieties
- Formulation of a dynamic contingent seed production and distribution plan
- Application of modern biotechnology tools such as genetic transformation, marker-assisted selection, doubled haploid, and mutation breeding to supplement traditional breeding methods
- In vitro conservation of critical adaptive genes and genetic traits
- Shifting the breeding strategy to per day rather than per crop productivity for wheat
- Promotion of sea-water farming through agri–aqua farms and below sea-level farming as in vogue in some parts of Kerala

12.1.8 Conclusions

Genetic resources for food and agriculture safeguard agricultural production and provide options for coping with climate change (e.g., seeds with higher yields, better quality, earlier maturity, better adaptation, and higher resistance to diseases, insects, and environmental stress). Domesticated species, breeds, and varieties and their wild relatives will be the main source of genetic resources for adaptation to climate change. In situ and ex situ conservation and sustainable use of genetic resources for food and agriculture and their wild relatives will be critical for the development of climate-resilient agriculture. With the interdependence of countries increasing, the transfer of genetic resources and the knowledge related to their use needs to be supported through effective cooperation between countries. The fair and equitable sharing of benefits arising from the use of genetic resources also needs to be properly addressed.

12.2 Crop Production Adaptation

12.2.1 Key Issues

- Improved agronomic practices to reduce farm losses
- Conservation and precision farming
- Knowledge management
- Soil conservation, bio-fertilizer
- Policy instruments for optimum land use

The most effective way to address climate change is to adopt a sustainable development pathway by shifting to environmentally sustainable technologies and promotion and accelerated adaptation of energy-efficient equipments (Mathur 2009), renewable energy, and conservation of natural resources. Improved agronomic practices have the potential to help reduce farm level losses through improved soil treatment; increased water-use efficiency; judicious use of chemicals, labor, and energy; and increased soil carbon storage. Targeted resource-conserving technologies offer new opportunities for better livelihoods for the resource poor, small, and marginal farmers.

To cope with the challenges of climate change, crop production must adapt (e.g., crop varietal selection, plant breeding, cropping patterns, and ecosystem management approaches) and become resilient to changes (frequency and intensity). Adapting cropping practices and approaches will be related to local farmers' knowledge, requirements, and priorities. Sustainable crop production provides farmers with options for farming sustainably, taking into account the local ecosystem. Most adaptation options build on existing practices and sustainable agriculture rather than new technologies. Changes to water and soil management will be central to adaptation for most farming systems. Pest and disease management will also be critical.

Improving adaptation of the agricultural sector to the adverse effects of climate change will be imperative for protecting and improving the livelihoods of the poor and ensuring food security (FAO 2012). Environmental stresses have always had an impact on crop production, and farmers have always looked for ways to manage these stresses. In practical terms, climate change adaptation requires more than simply maintaining the current levels of performance of the agricultural sector; it requires developing a set of robust and yet flexible responses that will improve the sector's performance even under the changing conditions brought about by climate change engenders. Some ways of local adaptation to stress is through plant breeding, pest management strategies, and seed delivery systems, to name a few.

Indeed, by improving the efficiency of agricultural production, emissions can be reduced and sequestration capacity enhanced. Conversely, climate change will have a significant impact on crop production, but alternative adaptation approaches and practices can address this by helping to reduce the net GHG emissions while maintaining or improving yields (FAO 2011; Pretty et al. 2011).

Examples of changes in climatic conditions that influence crop systems include rain quantity and distribution, and consequently water availability; extreme events, such as floods and droughts; higher temperatures; and shifting seasons. The rate of climate change may exceed the rate of adaptation for natural systems, including crops, and this creates high concern for food availability (Allara et al. 2012). In essence, what this means is that crops that were usually planted in one area may no longer be able to grow there. In addition, the ecosystem services that ensure crop growth (e.g., pollination, soil biodiversity) may also be affected. For these reasons, it is necessary to address crop production at the farming systems level. With appropriate technical, institutional, socioeconomic, and policy infrastructure in place, there is a huge potential for crop management practices and approaches to adapt to, and contribute to, the mitigation of climate change.

Different approaches and practices for sustainable crop production can contribute to climate change adaptation. They provide options for location-specific contexts and should be adapted with local farmers/farming communities (FAO-PAR 2011; FAO 2012). Examples include:

- Ecosystem-based approaches
- Conservation agriculture
- Integrated nutrient and soil management
- Mulch cropping
- Cover cropping
- Alterations in cropping patterns and rotations
- Crop diversification
- Ecological pest management
- Grassland management
- Water and irrigation management
- Landscape-level pollination management
- Organic agriculture

12.2.2 Cultural Practices

Simple, affordable, and accessible technologies like mulching and use of shelters and raised beds help to conserve soil moisture, prevent soil degradation, and protect crops from heavy rains, high temperatures, and flooding. The use of organic and inorganic mulches is common in high-value crop production systems. These protective coverings help reduce evaporation, moderate soil temperature, reduce soil runoff and erosion, protect grains/fruits from direct contact with soil, and minimize weed growth. In addition, the use of organic materials as mulch can help enhance soil fertility, structure, and other soil properties. Rice straw is abundant in rice-growing areas and generally recommended for summer crop production. Polythene, *Saccharum* spp., and *Canna* spp. can also be used as mulching materials. In the areas where temperatures are high, dark-colored plastic mulch is recommended in combination with rice straw (AVRDC 1990). Dark color of plastic mulch prevents sunlight from reaching the soil surface, and the rice straw insulates the plastic from direct sunlight, thereby preventing the soil temperature rising too high during the day.

During the hot rainy season, vegetables such as tomatoes suffer from yield losses caused by heavy rains. Simple, clear plastic rain shelters prevent water logging and rain impact damage on developing fruits, with consequent improvement in tomato yields (Midmore et al. 1992). Fruit cracking and the number of unmarketable fruits are also reduced. Another form of shelter using shade cloth can be used to reduce temperature stress. Planting vegetables in raised beds can ameliorate the effects of flooding during the rainy season (AVRDC 1981).

12.2.3 Land Management Practices

Changing land management practices such as shifting production away from marginal areas and altering the intensity of fertilizer and pesticide application as well as capital and labor inputs can help reduce risks from climate change in farm production. Adjusting the cropping sequence, including changing the timing of sowing, planting, spraying, and harvesting, to take advantage of the changing duration of growing seasons and associated heat and moisture levels, is another option. Altering the time at which fields are sowed or planted can also help farmers regulate the length of the growing season to better suit the changed environment. Farmer adaptation can also involve changing the timing of irrigation or use of other inputs such as fertilizers.

12.2.4 Conservation Tillage

Tillage is the agricultural preparation of the soil by mechanical, draught-animal, or human-powered agitation, such as plowing, digging, overturning, shoveling, hoeing, and raking. Small-scale farming tends to use smaller-scale methods using hand tools and in some cases draught animals, whereas medium to large-scale farming tends to use the larger-scale methods such as tractors (Fig. 12.3). The overall goal of tillage is to increase crop production while conserving resources (soil and water) and protecting the environment.

Conservation tillage refers to a number of strategies and techniques for establishing crops in a previous crop's residues, which are purposely

Fig. 12.3 Conservation tillage using disks and tines (Source: Peeters Agricultural Machinery, Netherlands)

Fig. 12.4 Happy seeder for sowing in presence of residues (Photo courtesy: CSISA (CIMMYT-IRRI), New Delhi)

left on the soil surface. Conservation tillage practices typically leave about one-third of crop residue on the soil surface. This slows water movement, which reduces the amount of soil erosion. Conservation tillage is suitable for a range of crops including grains, vegetables, root crops, sugarcane, cassava, fruit, and vines.

Conservation tillage is a popular technology in the Americas, with approximately 44 % practiced in Latin America. Studies suggest that there is great potential to bring this technology to Africa, Asia, and Eastern Europe, although limiting factors have to be taken into account (Derpsch 2001). The most common conservation tillage practices are no-till, ridge-till, and mulch-till.

No-till is a way of growing crops without disturbing the soil. This practice involves leaving the residue from last year's crop undisturbed and planting directly into the residue on the seedbed. No-till requires specialized seeding equipment designed to plant seeds into undisturbed crop residues and soil (Fig. 12.4). No-till farming changes weed composition drastically. Faster growing weeds may no longer be a problem in the face of increased competition, but shrubs and trees may begin to grow eventually. Cover crops – "green manure" – can be used in a no-till system to help control weeds. Leguminous cover crops which are typically high in nitrogen can often increase soil fertility.

In ridge-till practices, the soil is left undisturbed from harvest to planting and crops are planted on raised ridges (Fig. 12.5). Planting usually involves the removal of the top of the ridge. Planting is completed with sweeps, disk openers, coulters, or row cleaners. Residue is left on the surface between ridges. Weed control is accomplished with cover crops, herbicides, and/or cultivation. Ridges are rebuilt during row cultivation.

Mulch-till techniques involve disturbing the soil between harvesting one crop and planting the next but leaving around a third of the soil covered with residues after seeding. Implements used for mulch-till techniques include chisels, sweeps, and field cultivators.

Unpredictability of rainfall and an increase in the mean temperature may affect soil moisture levels leading to damages to and failures in crop yields. Conservation tillage practices reduce risk from drought by reducing soil erosion, enhancing moisture retention, and minimizing soil impaction. In combination, these factors improve resilience to climatic effects of drought and floods. Improved soil nutrient recycling may also help combat crop pests and diseases.

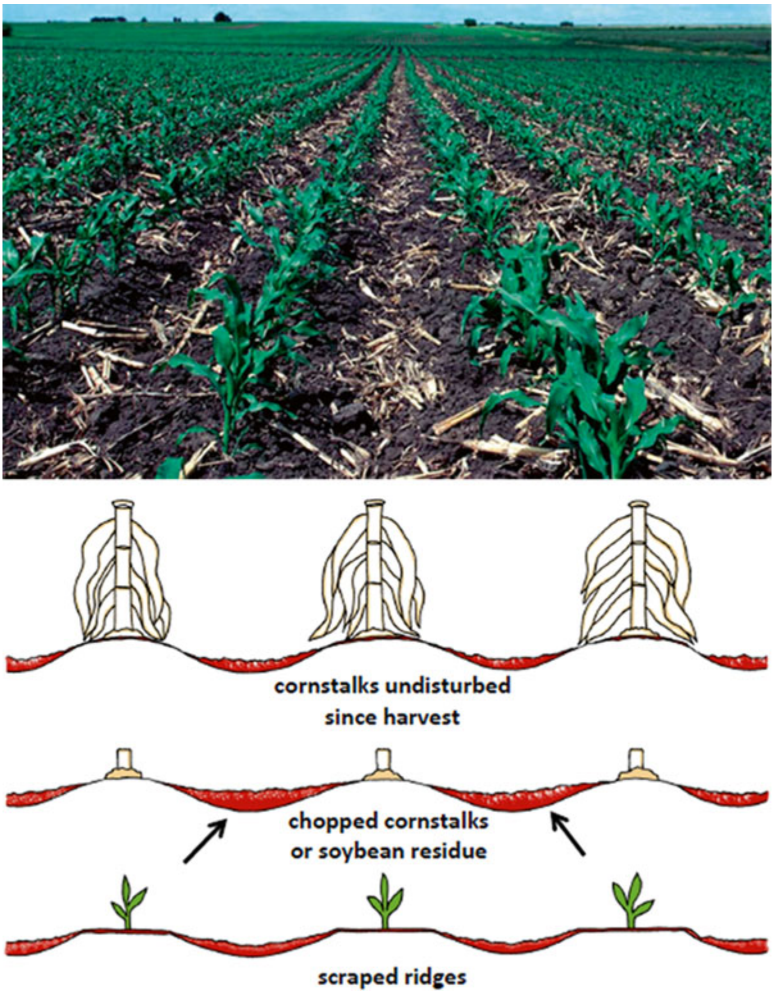

Fig. 12.5 Ridge tillage (Source: Adapted from Introduction to Ridge-Tillage for Corn and Soybeans. Purdue University Cooperation Extension Service ID-180)

12.2.4.1 Advantages

Conservation tillage benefits farming by minimizing erosion, increasing soil fertility, and improving yield. Plowing loosens and aerates the soil which can facilitate some deeper penetration of roots. Tillage is believed to help in the growth of microorganisms present in the soil and helps in the mix of the residue from the harvest, organic matter, and nutrients evenly in the soil. Conservation tillage systems also benefit farmers by reducing fuel consumption and soil compaction. By reducing the number of times the farmer travels over the field, farmers make significant savings in fuel and labor. Labor inputs for land preparation and weeding are also reduced once the system becomes established. In turn, this can increase time available for additional farm work or off-farm activities for livelihood diversification. Also once the system is established, requirement for herbicides and fertilizers can be reduced. The total economic benefits arising from adoption of the no-tillage technique in small farms of generally less than 20 ha in Paraguay have reached around $941 million.

12.2.4.2 Disadvantages

Conservation tillage may require the application of herbicides in the case of heavy weed infestation, particularly in the transition phase, until the new balance of weed populations is established. The practice of conservation may also lead to soil compaction over time; however, this can be prevented with chisel ploughs or sub-soilers. Initial investment of time and money along with purchases of equipment and herbicides will be necessary for establishing the system. Higher levels of surface residue may result in higher plant disease and pest infestations, if not managed properly. There is a strong relationship between this technology and appropriate soil characteristics. This is detrimental in high clay content and compact soils.

12.2.5 Adjusting Cropping Season

Adjustment of planting dates to minimize the effect of temperature increase-induced spikelet sterility can be used to reduce yield instability, by avoiding having the flowering period to coincide with the hottest period. Adaptation measures to reduce the negative effects of increased climatic variability as normally experienced in arid and semiarid tropics may include changing of the cropping calendar to take advantage of the wet period and to avoid extreme weather events (e.g., typhoons and storms) during the growing season. Cropping systems may have to be changed to include growing of suitable cultivars (to counteract compression of crop development), increasing crop intensities (i.e., the number of successive crop produced per unit area per year), or planting different types of crops. Farmers will have to adapt to changing hydrological regimes by changing crops.

12.2.6 Efficient Use of Resources

The resource-conserving technologies (RCTs) encompass practices that enhance resource- or input-use efficiency and provide immediate, identifiable, and demonstrable economic benefits such as reduction in production costs; savings in water, fuel, and labor requirements; and timely establishment of crops, resulting in improved yields. Yields of wheat in heat- and water-stressed environments can be raised significantly by adopting RCTs, which minimize unfavorable environmental impacts, especially in small- and medium-scale farms. Resource-conserving practices like zero-tillage (ZT) can allow farmers to sow wheat sooner after rice harvest, so the crop heads and fills the grain before the onset of pre-monsoon hot weather. As the average temperatures in the region rise, early sowing will become even more important for wheat. Field results have shown that the RCTs are increasingly being adopted by farmers in the rice–wheat belt of the Indo-Gangetic Plains because of several advantages of labor saving, water saving, and early planting of wheat. These approaches of crop management should be coupled with the measures of crop improvement for wider adaptation to climate change. Soil and water management is highly critical for adaptation to climate change. With higher temperatures and changing precipitation patterns, water will further become a scarce resource. Serious attempts towards water conservation, water harvesting improvement in irrigation accessibility, and water-use efficiency will become essential for crop production and livelihood management. Farmers have to be trained and motivated for adopting on-farm water conservation techniques, micro-irrigation systems for better water-use efficiency, selection of appropriate crops, etc. Principles of increasing water infiltration include improvement in soil aggregation; decreasing runoff with use of contours, ridges, vegetative hedges, etc.; and reducing soil evaporation with use of crop residues mulch for better management of soil water.

12.2.7 Crop Diversification

Crop diversification, which can be defined as increasing the number of crops or the varieties and hybrids of a particular crop, is a potential farm-level response to climatic variability and change (Bradshaw et al. 2005). Crop diversification in a subsistence farming system provides an alternative means of income generation for smallholder farmers, the majority of whom are vulnerable to climate change. Because of changing rainfall patterns and water resource depletion, the existing cropping pattern is becoming less productive. Thus, crop intensification, through mixed cropping and integration of high-value crops such as horticultural production, is gaining prominence as a climate change adaptation strategy. Riyannsh (2008) noted that "due to shrinking natural resources and ever-increasing demand for food and raw materials, agricultural intensification is the main course of future growth of agriculture." Bindhumadhavan (2005) stated that it is time to critically redesign alternative cropping patterns based on agroclimatic zones and to demonstrate them in farmers' fields. Hence the need for crop diversification from:

- Low-value to high-value crops (resulting in a price-risk benefit)
- Low-yielding to high-yielding crops (resulting in a yield-risk benefit)
- High water-use crops to water-saving crops
- Single cropping to multiple or mixed cropping
- Subsistence food crop to market-oriented crop
- Raw material production to processing and value addition

Diversification of crop varieties, including replacement of plant types, cultivars, and hybrids, with new varieties intended for higher drought or heat tolerance, is being advocated as having the potential to increase productivity in the face of temperature and moisture stresses. Diversity in the seed genetic structure and composition has been recognized as an effective defense against disease and pest outbreak and climatic hazards. Moreover, demand for high-value food commodities, such as fruits and vegetables, is increasing because of growing income and urbanization. This is reducing the demand for traditional rice and wheat. Diversification from rice–wheat towards high-value commodities will increase income and result in reduced water and fertilizer use. However, there is a need to quantify the impacts of crop diversification on income, employment, soil health, water use, and greenhouse gas emissions. A significant limitation of diversification is that it is costly in terms of the income opportunities that farmers forego, i.e., switching of crop can be expensive, making crop diversification typically less profitable than specialization. Moreover, traditions can often be difficult to overcome and will dictate local practices.

Shift to growing cash crops with existing irrigation technologies which will earn more income and enable farmer to invest in upgrading irrigation systems among other AWM interventions. Crop diversification also includes integration of different varieties of crops, both food and cash crops. In the African context, six crops seem to have large-scale potential: sugarcane, sweet sorghum, maize and cassava for ethanol, and oil palm and jatropha for biodiesel (Sielhorst et al. 2008).

At the individual farm scale, the simplest measure of crop diversity is the total number of different crops per farm. Crop diversification acts to reduce susceptibility to climatic variability such as floods or droughts that might result in crop failure. At the same time, it increases the number of marketable activities such as adding livestock to a cash crop operation or undertaking value-added processing and hence serves to reduce farmers' risks resulting from weather fluctuations. Additionally, other risk-reducing strategies, such as crop insurance or the securing of off-farm income, may be complimentary.

Increasing diversity of production at farm and landscape level is an important way to improve the resilience of agricultural systems (FAO and OECD 2012; HLPE 2012). Diversifying production can also improve efficiency in the use of land, as is the case in agro-forestry systems, for instance, and of nutrients with the introduction of legumes in the rotation or in integrated crop/livestock or rice/aquaculture systems. Studies show that they can also be more efficient in terms of income. Farms that both grow crops and exploit forest generate a higher and more stable income. Regions growing more diverse varieties of barley have a higher average yield than areas growing a single variety. More diversified systems can also spur the development of local markets.

12.2.8 Relocation of Crops in Alternative Areas

Climate change in terms of increased temperature, CO_2 level, droughts, and floods would affect production of crops. But, the impact will be different across crops and regions. There is a need to identify the crops and regions that are more sensitive to climate changes/variability and relocate them in more suitable areas. For example, it is apprehended that increased temperature would affect the quality of crops, particularly important aromatic crops such as basmati rice and tea. Alternative areas that would become suitable for such crops from quality point of view need to be identified and assessed for their suitability.

12.2.9 Integrated Nutrient Management (INM)

Soil is a fundamental requirement for crop production as it provides plants with anchorage, water, and nutrients. A certain supply of mineral and organic nutrient sources is present in soils, but these often have to be supplemented with external applications, or fertilizers, for better plant growth. Fertilizers enhance soil fertility and are applied to promote plant growth, improve crop yields, and support agricultural intensification.

Fertilizers are typically classified as organic or mineral. Organic fertilizers are derived from substances of plant or animal origin, such as manure, compost, seaweed, and cereal straw. Organic fertilizers generally contain lower levels of plant nutrients as they are combined with organic matter that improves the soils' physical and biological characteristics. The most widely used mineral fertilizers are based on nitrogen, potassium, and phosphate.

Optimal and balanced use of nutrient inputs from mineral fertilizers will be of fundamental importance to meet growing global demand for food. Mineral fertilizer use has increased almost fivefold since 1960 and has significantly supported global population growth. It is estimated that nitrogen-based fertilizer has contributed 40 % to the increases in per capita food production in the past 50 years. Nevertheless, environmental concerns and economic constraints mean that crop nutrient requirements should not be met solely through mineral fertilizers. Efficient use of all nutrient sources, including organic sources, recyclable wastes, mineral fertilizers, and biofertilizers, should therefore be promoted through INM.

The aim of INM is to integrate the use of natural and man-made soil nutrients to increase crop productivity and preserve soil productivity for future generations. Rather than focusing nutrition management practices on one crop, INM aims at optimal use of nutrient sources on a cropping system or crop rotation basis. This encourages farmers to focus on long-term planning and make greater consideration for environmental impacts.

INM relies on a number of factors, including appropriate nutrient application and conservation and the transfer of knowledge about INM practices to farmers and researchers. Boosting plant nutrients can be achieved by a range of practices such as terracing, alley cropping, conservation tillage, intercropping, and crop rotation. This section will focus on INM as it relates to appropriate fertilizer use. In addition to the standard selection and application of fertilizers, INM practices include new techniques such as deep placement of fertilizers and the use of inhibitors or urea coatings (use of urea coating agent helps to retort the activity and growth of the bacteria responsible for denitrification) that have been developed to improve nutrient uptake.

Key components of the INM approach include:

- Testing procedures to determine nutrient availability and deficiencies in plants and soils. These are:
  - Plant symptom analysis – visual clues can provide indications of specific nutrient deficiencies. For example, nitrogen-deficient plants appear stunted and pale compared to healthy plants.
  - Tissue analysis and soil testing – where symptoms are not visible, postharvest tissue and soil samples can be analyzed in a laboratory and compared with a reference sample from a healthy plant.
- Systematic appraisal of constraints and opportunities in the current soil fertility management practices and how these relate to the nutrient diagnosis, for example, insufficient or excessive use of fertilizers.

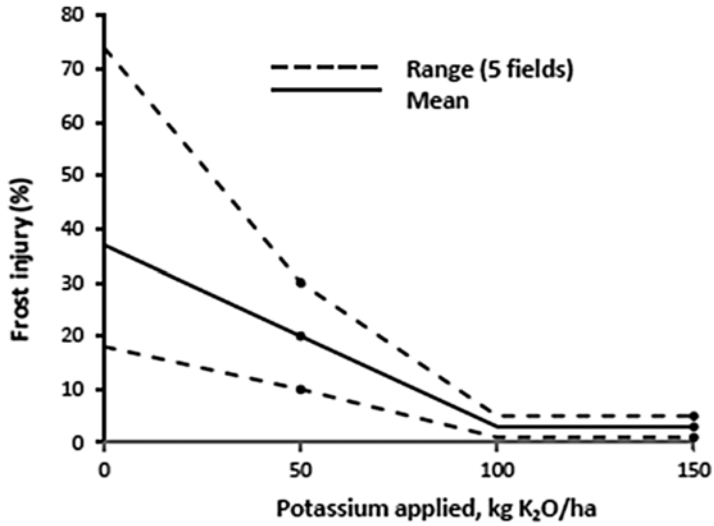

Fig. 12.6 Effect of potassium application on frost injury to potato crop

- Assessment of productivity and sustainability of farming systems. Different climates, soil types, crops, farming practices, and technologies dictate the correct balance of nutrients necessary. Once these factors are understood, appropriate INM technologies can be selected.
- Participatory farmer-led INM technology experimentation and development. The need for locally appropriate technologies means that farmer involvement in the testing and analysis of any INM technology is essential.

Harsh climatic conditions are a major cause of soil erosion and the depletion of nutrient stocks. By increasing soil fertility and improving plant health, INM can have positive effects on crops in the following ways:

- A good supply of phosphorous, nitrogen, and potassium has been shown to exert a considerable influence on the susceptibility or resistance of plants towards many types of pests and diseases.
- A crop receiving balanced nutrition is able to explore a larger volume of soil in order to access water and nutrients. In addition, improved root development enables the plant to access water from deeper soil layers. With a well-developed root system, crops are less susceptible to drought.
- Under increasingly saline conditions, plants can be supplemented with potassium to maintain normal growth.
- With appropriate potassium fertilization, the freezing point of the cell sap is lowered, thus improving tolerance to colder conditions (Fig. 12.6).

12.2.9.1 Advantages

INM enables the adaptation of plant nutrition and soil fertility management in farming systems to site characteristics, taking advantage of the combined and harmonious use of organic and inorganic nutrient resources to serve the concurrent needs of food production and economic, environmental, and social viability. INM empowers farmers by increasing their technical expertise and decision-making capacity. It also promotes changes in land use, crop rotations, and interactions between forestry, livestock, and cropping systems as part of agricultural intensification and diversification.

12.2.9.2 Disadvantages

Besides facilitating adaptation to climate change in the agriculture sector, the INM approach is also sensitive to changes in climatic conditions and could produce negative effects if soil and crop nutrients are not monitored systematically and changes to fertilizer practices made accordingly. In Africa, high transport costs in land-locked countries contribute to prohibitively high fertilizer prices (FAO 2008). In the case of small-scale farmers, these costs may represent too high a proportion of the total variable cost of production, thus ruling out inorganic fertilizer as a feasible option.

12.2.10 Biological Nitrogen Fixation

In agricultural systems, some types of microbes can carry out biological nitrogen fixation (BNF) as free-living organisms: heterotrophic and autotrophic bacteria and cyanobacteria. Other microorganisms can only fix nitrogen through a symbiotic relationship with plants, mainly legume species. In agricultural areas, about 80 % of BNF is achieved by the symbiotic association between legumes and the nodule bacteria, rhizobia. Farmers have some scope to influence BNF, through legume selection, the proportion of legume and grass seed in forage mixtures, inoculation with bacteria such as rhizobia, crop nutrition (especially nitrogen and phosphorous), weed, disease and pest controls, planting time, cropping sequence and intensity, and defoliation frequency of forage swards. In perennial temperate forage legumes, red clover and lucerne can typically fix 200–400 kg of nitrogen per hectare (whole plant fixation, above- and belowground) (FAO 2009).

12.2.11 Harnessing Indigenous Technical Knowledge of Farmers

Farmers in South Asia, often poor and marginal, are experimenting with the climatic variability for centuries. There is a wealth of knowledge on the range of measures that can help in developing technologies to overcome climate vulnerabilities. There is a need to harness that knowledge and fine-tune them to suit the modern needs. Traditional ecological knowledge of people developed and carried which have stood the test of time could provide insights and viable options for adaptive measures. Anthropological and sociological studies have highlighted the importance of community-based resource management and social learning to enhance their capacity to adapt to the impacts of future climate change. Tribal and hill knowledge systems are pregnant with potential indigenous practices used for absorption and conservation of rainwater, nutrient and weed management, crop production, and plant protection. Their belief systems have effectively helped in weather forecasting and risk adjustment in crop cultivation. During the course of their habitation, the indigenous people of Himalayan terrain region through experience, experimentation, and accumulated knowledge have devised ways of reducing their vulnerability to natural hazards. Studies have shown that their understanding was fairly evolved in the matters of earthquake, landslide, and drought and they have devised efficient ways of mitigating the effect of natural or climatic changes.

12.2.12 Interventions

12.2.12.1 Research and Development

- Promotion of organic agriculture research.
- Develop technologies for improvement of water-use efficiency.
- Develop technologies for management of salt-affected soils and waterlogged areas.
- Explore potential of change in sowing time as adaptation strategy.

12.2.12.2 Technologies and Practices

- Promoting agriculture heritage and traditional methods for conservation and management of resources
- Soil enrichment through intercrop transfers (use of legumes), promotion of conservation agriculture practices to enhance soil organic carbon, water conservation, and minimize soil erosion
- Developing and applying resource conservation technologies (RCTs) like zero-tillage, raised bed planting, laser land leveling, etc., for enhancing soil productivities
- Promoting inter-terrace land treatment, emphasis on soil quality, organic farming,

promotion of integrated farming systems, and other measures that encourage resource conservation
- Introducing improved farm machinery for enabling crops to be grown with minimal tillage (reduced tillage) or without tillage (no tillage) resulting in soil carbon gains
- Encouraging protected cultivation in areas which face extreme weather conditions
- Low-cost greenhouses, along with micro-irrigation and fertigation techniques
- Promoting new technologies such as SRI (System of Rice Intensification)
- Development of contingency plans for farming practices to cope with sudden climatic variability
- Introduction of post flood agriculture rehabilitation measures such as crops like yellow-flesh-sweet potato, sunflower, fodder, sathi maize, etc.
- Developing mangrove and non-mangrove bioshields to minimize the impact of coastal storms and sea-water inundation

12.3 Water Adaptation

12.3.1 Key Issues

- Promoting water-use efficiency in irrigation
- Research and development in the areas of energy-efficient water systems
- Developing mechanisms for integrated management of rainwater, surface, and groundwater
- Policy instruments for PPP
- Strengthen local institutions in managing water allocation and utilization

Two-thirds of the cultivated land is rainfed and suffers from water scarcity. Effective management of available water, increasing water-use efficiency, and establishment of additional sustainable sources of water emerge as the primary issues that need to be addressed. Strategies under this dimension would focus on the application of a range of technologies coupled with demand and supply-side management solutions to enhance water-use efficiency for irrigation. While some technologies are available for direct application and can be implemented in the short term, there are other emerging areas like recharging of aquifers, conjunctive use of surface and groundwater, controlled extractions, etc., that would require collaboration and capacity building for technology absorption before being put into sustainable use.

According to the IPCC, by 2020 rainfed crop yields in some countries will decrease by half. The impact of climate change on farmers and their livelihoods could be catastrophic. Several practical options for adaptation for livelihood systems to changing climatic conditions exist. All efforts should therefore be made to refine, augment, and deploy them appropriately and urgently. The slogan "more crop per drop" is becoming more appropriate as countries strive to contend with decreasing water resources. Existing agricultural water management (AWM) technologies, such as drip irrigation and rainwater harvesting, have the potential to double, even quadruple, rainfed crop yields in many parts of the world.

It is commonly acknowledged that most of the impacts from climate change will relate to water (UN-Water 2010). How water is managed will be at the center of climate change adaptation strategies. This is particularly true in rural areas and in the agriculture sector, where water plays a critical role in crop and animal production (including fish), and the management of ecosystems, including forests, rangeland, and cropland.

The most immediate impact of climate change on water for agriculture will be through the increased variability of rainfall, higher temperatures, and associated extreme weather events, such as droughts and floods. In the medium to long term, climate change will affect water resources and reduce the availability or reliability of water supplies in many places already subject to water scarcity.

Water management and the efficient use of available water will be of fundamental importance in building resilient production systems and improving the management of climate change-induced risks. The efficient and equitable management of water catchments is generally only possible when done in a landscape context and combined with farm-level water management practices. Water management requires common agreements on the modalities of use. These agreements will be best achieved through participatory governance processes related to integrated land-use planning. Large catchments, such as river basins, need layers of nested planning approaches, starting at the river basin scale, with implementation activities planned in detail on the landscape scale.

Water resources management strategy is thus the key to ensuring that agricultural production can withstand the stresses caused by climate change. Improved AWM is one of the "best bets" for adapting agricultural production to climate change and variability. However, accomplishing this "Blue Revolution" is a significant challenge. The current poor performance in terms of water-use efficiency, plus competition over diminishing water resources, suggests the need for investment in better water management systems. Also, where access to irrigation is limited, farmers need to develop water conservation and rainwater harvesting systems to maximize on-farm water management.

Rainwater harvesting complements irrigation and enhances farmers' profitability. Rainwater harvesting for supplemental irrigation, for example, yielded net profits of US$ 150–600 per ha in Burkina Faso and US$ 110–500 in Kenya. Water management is also improved by having a greater diversity of options for water sources, such as small streams, shallow wells, bore wells, and rainwater storage. Other irrigation options include surface irrigation methods (furrows and small basins), pressurized systems (sprinkler and both high- and low-head drip), and water lifting technologies (gravity, manual, and pumps – motorized, wind-driven, and solar).

Another management strategy is the upgrading of rainfed agriculture through integrated rainwater harvesting systems and complementary technologies such as low-cost pumps and water application methods, such as low-head drip irrigation kits. Rainwater harvesting systems include two broad categories:

- In situ soil moisture conservation – technologies that increase rainwater infiltration and storage in the soil for crop use
- Runoff storage for supplemental irrigation using storage structures such as farm ponds, earth dams, water pans, and underground tanks

Increasing investment in AWM is one of the promising climate change adaptation strategies for farmers. AWM can contribute to agricultural growth and reduce poverty, since better management of water will translate into intensification and diversification in developed land, expansion of irrigated areas, increases in food and feed production, and environmental conservation.

Maintaining a stable water supply for agriculture requires both demand-side strategies, such as recycling and conserving water, and supply-side strategies, such as water storage (Thornton and Cramer 2012).

The identified and recommended feasible AWM interventions should be promoted by development agencies to enhance farmers' strategies for coping with climate change and variability. The following are some of the promising AWM interventions that should be considered:

- Irrigation development includes rehabilitation of existing schemes to improve water-use efficiency and productivity. This covers both gravity-fed (most preferable, where applicable, due to low operation and maintenance cost) and pumped schemes (from either groundwater or surface water sources – rivers, dams, etc.).
- Upgrading rainfed agriculture through in situ rainwater harvesting systems – farming practices that retain water in crop land (terraces, contour bunds, ridges, tied ridges, planting pits, conservation agriculture, etc.).
- Supplementary irrigation systems (farming practices that supply water to crops during critical growth stages) are appropriate where irrigation water is inadequate for full irrigation or where crops are grown under rainfed conditions and only irrigated during intra-seasonal dry spells or in case of early rainfall cessation.
- On- or off-farm water storage systems – rainwater harvesting and management systems allow the farmers to store runoff in ponds (unlined or lined). For communal land or farmers with appropriate sites, large storage

structures such as earth dams or water pans can be considered. Water can be supplied to crop land either by gravity or pumping and applied to crops either by surface irrigation (furrow or basin) or pressurized irrigation (especially low-head irrigation systems). Other rainwater harvesting structures such as sand dams, subsurface dams, and rock catchment systems fall under this category.

- Spate irrigation – flood diversion and spreading into crop land is appropriate in areas where flash floods occur, especially in lowlands adjacent to degraded or rocky catchments.
- Micro-irrigation systems – these include various technologies, among which low-head drip irrigation kits are the most appropriate. Low-head drip kits can use many different water sources. They are mainly used for irrigating high-value crops like garden vegetables and orchard fruits and for green maize production at times.
- Land drainage, wetland management, and flood recession are appropriate for areas with excess soil moisture and should therefore be considered where necessary.
- On the demand side, water-use efficiency, through, for example, recycling of water, is the main adaptation intervention. Greater use of economic incentives, including metering and pricing, can encourage water conservation and the reallocation of water to highly valued uses (IWMI 2007).
- On the supply side, more strategic water storage is a key intervention for the adaptation of agriculture to climate change. Water storage provides a buffer and can offset the risks associated with floods or droughts. Water storage options include reservoirs, ponds, tanks, aquifers, soil moisture, and natural wetlands (McCartney and Smakhtin 2010).
- The rate of glacier deposition and melting under climate change will be a major determinant of water availability for agriculture, but remains highly uncertain and under-studied. In China, for example, the best current knowledge is that runoff from glaciers may peak from 2030 to 2050, followed by a gradual decline (Piao et al. 2010).
- Irrigation will be an important adaptation option in some regions. It compensates both for long-term declines in water supply and for short-term deficits associated with increasing climate variability. This will be the key for Brazil, for example (Rosenzweig et al. 2004; Cunha et al. 2012).
- Irrigation will not work as an adaptation option everywhere. In sub-Saharan Africa, water supply reliability (ratio of water consumption to requirements) is expected to worsen and will limit the adaptation potential of irrigation. Even farming regions that are expected to have sufficient water under climate change, such as the Danube basin of Europe, may not be able to expand irrigation for adaptation strategy, as models suggest that this would increase water supply unreliability (Rosenzweig et al. 2004).
- Climate change mitigation measures, such as reforestation, can assist adaptation by increasing the capacity of soils and landscapes to hold water (Thornton and Cramer 2012).

There are several methods of applying irrigation water and the choice depends on the crop, water supply, soil characteristics, and topography. Surface irrigation methods are utilized in more than 80 % of the world's irrigated lands, yet its field-level application efficiency is often 40–50 %. To generate income and alleviate poverty of the small farmers, promotion of affordable, small-scale drip irrigation technologies are essential. Drip irrigation minimizes water losses due to runoff, and deep percolation and water savings of 50–80 % are achieved when compared to most traditional surface irrigation methods. Crop production per unit of water consumed by plant evapotranspiration is typically increased by 10–50 %. Thus, more plants can be irrigated per unit of water by drip irrigation and with less labor. The water-use efficiency by chili pepper was significantly higher in drip irrigation compared to furrow irrigation, with higher efficiencies observed with high delivery rate drip irrigation regimes (AVRDC 2005). For drought-tolerant crops like watermelon, yield differences between furrow and drip irrigated crops were not significantly different; however, the incidence of

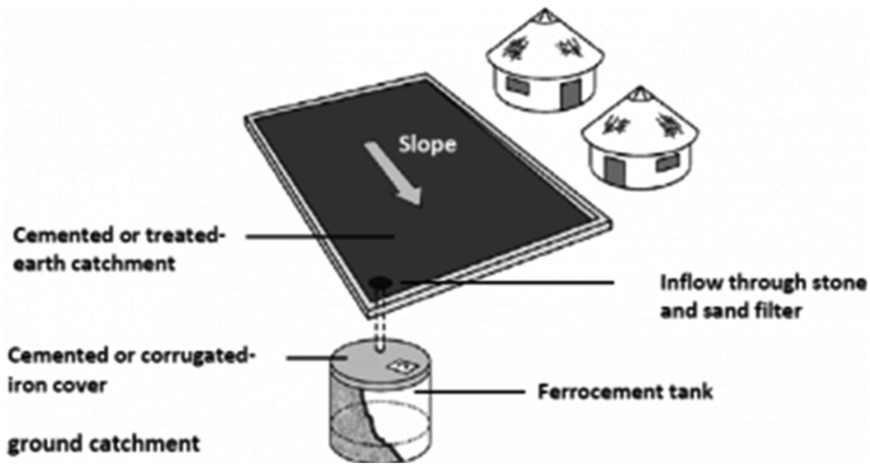

Fig. 12.7 Ground catchment system

Fusarium wilt was reduced when a lower drip irrigation rate was used. In general, the use of low-cost drip irrigation is cost-effective, labor-saving, and allows more plants to be grown per unit of water, thereby both saving water and increasing farmers' incomes at the same time. Prominent (adaptation) technologies in this area are:

- Rainwater harvesting
- Sprinkler irrigation
- Drip irrigation
- Fog harvesting

12.3.2 Rainwater Harvesting

Rainfall can provide some of the cleanest naturally occurring water that is available. There is considerable scope for the collection of rainwater when it falls, before huge losses occur due to evaporation, transpiration, and runoff and drainage – before it becomes contaminated by natural means or man-made activities. Rainwater harvesting is a particularly suitable technology for areas where there is no surface water, or where groundwater is deep or inaccessible due to hard ground conditions, or where it is too salty or acidic.

Rainwater harvesting is defined as a method for inducing, collecting, storing, and conserving local surface runoff (rain or surface water flow that occurs when soil is infiltrated to full capacity) for agriculture in arid and semiarid regions (Boers and Ben-Asher 1982). Both small- and large-scale structures are used for rainwater harvesting collection and storage including water pans, tanks, reservoirs, and dams. The catchment area is the area where the rainfall or water runoff is initially captured and is in most cases either the ground surface or rock surface.

12.3.2.1 Ground-Surface

In the ground surface method, water flowing along the ground during the rains is usually diverted towards a tank below the surface (Fig. 12.7). There is greater possibility of water loss due to infiltration into the ground. The water is generally of lower quality than that collected directly from rainfall. Techniques available for increasing runoff within ground catchment areas include (1) clearing or altering vegetation cover, (2) increasing the land slope with artificial ground cover, and (3) reducing soil permeability by soil compaction and application of chemicals (UNEP 1982). Impermeable membranes can also be used to facilitate runoff. Ground catchment is applicable for low topographic areas and is suitable for large-scale agricultural production as it allows for in situ storage and usage of fresh water for irrigation.

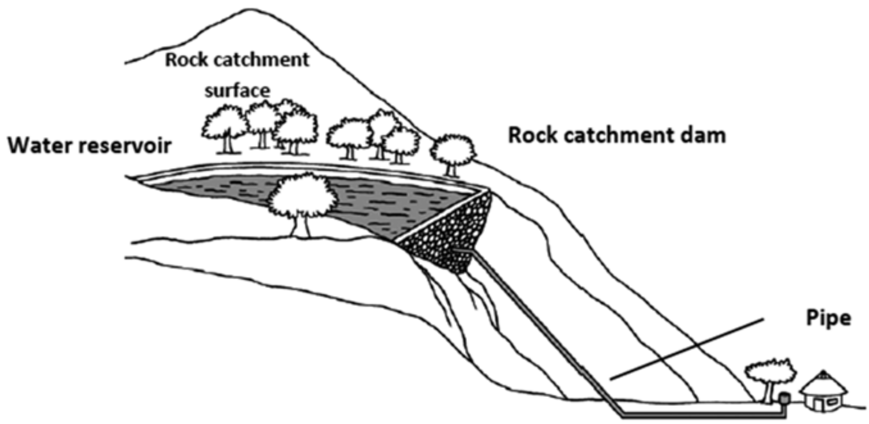

Fig. 12.8 Rock catchment dam

12.3.2.2 Rock Surface

Rock surfaces can also be used as collection catchments. Bedrock surfaces found within rocky top slopes or exposed rock outcrops in lowlands often have natural hollows or valleys which can be turned into water reservoirs by building a dam (Fig. 12.8). Developing a rock catchment area typically involves clearing and cleaning the site from vegetation and marking out the catchment area to be enclosed with gutters. Rock surfaces should not be fractured or cracked, as this may cause the water to leak away to deeper zones or underneath the dam. As with ground catchments, water is generally of lower quality than direct rainfall collection. Water quality can be improved if access to the area (e.g., by animals and children) is limited.

Several types of conveyance systems exist for transporting water from the catchment to the storage device, including gutters, pipes, glides, and surface drains or channels. Larger-scale conveyance systems may require pumps to transfer water over larger distances. These should be constructed from chemically inert materials, such as wood, bamboo, plastic, stainless steel, aluminum, or fiberglass, in order to avoid negatively affecting on water quality (UNEP 1997). In the case of rock catchments, gutters can be constructed from a stone wall built with rough stones/hardcore and joined with mortar.

Storage devices are used to store the water that is collected from the catchment areas and are classified as (1) aboveground storage tanks and (2) cisterns or underground storage vessels. These facilities can vary in size from one cubic meter to up to hundreds of cubic meters for large projects. For storing larger quantities of water, the system will usually require a bigger tank or cistern with sufficient strength and durability. Typically these tanks can be constructed out of bricks coated with cement. For water captured from a rock catchment, a dam is the more common form of storage device.

Climate change is disrupting global rainfall patterns meaning some parts of the world are suffering from a drastic drop in precipitation leading to a fall in water levels in many reservoirs and rivers. In sub-Saharan Africa where two-thirds of the region is desert and dryland, the need for improving water management in the agriculture sector is particularly critical. Rainwater harvesting represents an adaptation strategy for people living with high rainfall variability, both for domestic supply and to enhance crop, livestock, and other forms of agriculture (UNEP and SEI 2009).

Generally, the amount of water made available through rainwater harvesting is limited and should be used prudently to alleviate water stress during critical stages of crop growth. Supplemental irrigation is a key strategy and can help increase yields by more than 100 %. A small investment providing between 50 and 200 mm of extra water per hectare per season for supplemental irrigation, in combination with improved

Fig. 12.9 Farmland sprinkler system in Cajamarca, Peru (Source: Courtesy of David Dennis Rabines Alarcon)

agronomic management, can more than double water productivity and yields in small-scale rain-fed agriculture (UNEP and SEI 2009).

12.3.2.3 Advantages

Rainwater harvesting technologies are simple to install and operate. Local people can be easily trained to implement such technologies, and construction materials are usually readily available. Rainwater harvesting is convenient because it provides water at the point of use and farmers have full control of their own systems. Use of rainwater harvesting technology promotes self-sufficiency and has minimal environmental impact. Running costs are reasonably low. Construction, operation, and maintenance are not labor intensive. Water collected is of acceptable quality for agricultural purposes. Other benefits include increasing soil moisture levels and increasing the groundwater table via artificial recharge. Rainwater harvesting and its application to achieving higher crop yields can encourage farmers to diversify their enterprises, such as increasing production, upgrading their choice of crop, purchasing larger livestock animals, or investing in crop improvement inputs such as irrigation infrastructure, fertilizers, and pest management (UNEP and SEI 2009).

12.3.2.4 Disadvantages

The main disadvantage of rainwater harvesting technology is the limited supply and uncertainty of rainfall. Rainwater is not a reliable water source in dry periods or in time of prolonged drought. Low storage capacity will limit rainwater harvesting potential, whereas increasing storage capacity will add to construction and operating costs, making the technology less economically viable. The effectiveness of storage can be limited by the evaporation that occurs between rains. In water basins with limited surplus supplies, rainwater harvesting in the upstream areas may have a damaging impact downstream and can cause serious community conflict. Also, when runoff is generated from a large area and concentrated in small storage structures, there is a potential danger of water quality degradation, through introduction of agrochemicals and other impurities (UNEP and SEI 2009).

12.3.3 Sprinkler Irrigation

Systems of pressurized irrigation, sprinkler or drip, can improve water efficiency and contribute substantially to improved food production. Sprinkler irrigation is a type of pressurized irrigation that consists of applying water to the soil surface using mechanical and hydraulic devices that simulate natural rainfall (Fig. 12.9). These devices replenish the water consumed by crops or provide water required for softening the soil to make it workable for agricultural activities. The goal of irrigation is to supply each plant with just the right amount of water it needs. Sprinkler irrigation is a method by which water is distributed from overhead by high-pressure sprinklers, sprays, or guns mounted on risers or moving platforms. Today a variety of sprinkler systems ranging from simple hand-move to large self-propelled systems are used worldwide. Use of sprinkler irrigation is practiced in the Americas (13.3 million hectares (Mha)), Europe (10.1 Mha), Asia (6.8 Mha), Africa (1.9 Mha), and Oceania (0.9 Mha) (Kulkarni et al. 2006).

A sprinkler irrigation system typically consists of:

1. A pump unit which takes water from the source and provides pressure for delivery into the pipe system. The pump must be set to supply water at an adequate pressure so that the water is applied at rate and volume adequate to the crop and soil types.
2. Main pipes and secondary pipes which deliver water from the pump to the laterals. In some cases, these pipelines are permanently installed on the soil surface or buried below ground. In other cases, they are temporary and can be moved from field to field. The main pipe materials used include asbestos cement, plastic, or aluminum alloy.
3. The laterals deliver water from the pipes to the sprinklers. They can be permanent, but more often they are portable and made of aluminum alloy or plastic so that they can be moved easily.
4. Sprinklers are water-emitting devices which convert the water jet into droplets. The distribution of sprinklers should be arranged so as to wet the soil surface in the plot as evenly as possible.

A wide range of sprinkler systems is available for small- and large-scale application. Set systems operate with sprinklers in a fixed position. These sprinklers can be moved to water different areas of the field, either by hand or with machinery. Hand-move systems are more labor intensive and may be more suited where labor is available and cheap. On the other hand, mechanically operated systems require a greater capital investment in equipment. Mobile systems minimize labor inputs by operating with motorized laterals or sprinklers, which irrigate and move continuously at the same time (Savva and Frenken 2002).

Table 12.3 Farm irrigation efficiencies for sprinkler irrigation in different climates (the overall efficiency comprises conveyance efficiency, field canal efficiency, and field application efficiency) (FAO 1982)

Climate/temperature	Farm irrigation efficiency
Cool	0.80
Moderate	0.75
Hot	0.70
Desert	0.65

Sprinkler irrigation efficiency is highly dependent on climatic conditions. FAO (1982) proposed the figures of farm irrigation efficiencies provided in Table 12.3 on the basis of climate.

Sprinkler irrigation technology can support farmers to adapt to climate change by making more efficient use of their water supply. This is particularly appropriate where there is (or is expected to be) limited or irregular water supply for agricultural use. The sprinkler technology uses less water than irrigation by gravity and provides a more even application of water to the cultivated plot. Additionally, sprinkler irrigation can reduce the risk of crops freezing due to colder than usual temperatures. More frequent and intense frosts are already impacting on crops as a result of climate change. During the night, the motion of the sprinklers and the application of rain-like water droplets can reduce the stress on crops caused by a sharp decrease in temperature (Snyder and Melo-Abreu 2005).

12.3.3.1 Advantages

One of the main advantages of the sprinkler irrigation technology is more efficient use of water for irrigation in agriculture. Sprinkler systems eliminate water conveyance channels, thereby reducing water loss. Water is also distributed more evenly across crops helping to avoid wastage. The sprinkler irrigation system has also been shown to increased crop yields (Table 12.4) and is suited for most row, field, and tree crops that are grown closely together, such as cereals, pulses, wheat, sugarcane, groundnut, cotton, vegetables, fruits, flowers, spices, and condiments and for cultivating paddy crop (Kundu et al. 1998).

Sprinkler irrigation technology is well adapted to a range of topographies and is suitable in all

Table 12.4 Response of different crops to sprinkler irrigation systems (INCID 1998)

Crops	Water saving %	Yield increase %
Barley	56	16
Cabbage	40	3
Cauliflower	35	12
Chilies	33	24
Cotton	36	50
Groundnut	20	40
Maize	41	36
Onion	33	23
Potato	46	4
Wheat	35	24

types of soil, except heavy clay. Sprinkler systems can be installed as either permanent or mobile fixtures. Sprinklers provide a more even application of water to agricultural land, promoting steady crop growth. Likewise, soluble fertilizers can be channeled through the system for easy and even application. The risk of soil erosion can be reduced because the sprinkler system limits soil disturbance, which can occur when using irrigation by gravity. In addition, sprinkler irrigation can provide additional protection for plants against freezing at low temperatures. Secondary benefits from improved crop productivity include income generation, employment opportunities, and food security.

12.3.3.2 Disadvantages

The main disadvantages associated with sprinkler systems are related to climatic conditions, water resources, and cost. Even moderate winds can seriously reduce the effectiveness of sprinkler systems by altering the distribution pattern of the water droplets. Likewise, when operating under high temperatures, water can evaporate at a fast rate, reducing the effectiveness of the irrigation. Although sprinkler irrigation can help farmers to use water resources more efficiently, this technology relies on a clean source of water and therefore may not be suited to areas where rainfall is becoming less predictable. Implementation costs are higher than that of gravity-fed irrigation systems, and large labor force is needed to move pipes and sprinklers in a nonpermanent system. In some places, such labor may not be available and may also be costly. Mechanized sprinkler irrigation systems have a relatively high energy demand (Savva and Frenken 2002).

12.3.4 Drip Irrigation

Drip irrigation is based on the constant application of a specific and focused quantity of water to soil in the region of feeder roots of crops. The system uses pipes, valves, and small drippers or emitters transporting water from the sources (i.e., wells, tanks, and or reservoirs) to the root area and applying it under particular quantity and pressure specifications. The system should maintain adequate levels of soil moisture in the rooting areas, fostering the best use of available nutrients and a suitable environment for healthy plant roots systems. Managing the exact (or almost) moisture requirement for each plant, the system significantly reduces water wastage and promotes efficient use. Compared to surface irrigation, which can provide 60 % water-use efficiency and sprinkler systems which can provide 75 % efficiency, drip irrigation can provide as much as 90 % water-use efficiency (FAO 2002).

In recent times, drip irrigation technology has received particular attention from farmers, as water needs for agricultural uses have increased and available resources have diminished. In particular, drip irrigation has been applied in arid and semiarid zones as well as in areas with irregular flows of water (or in zones with underground water resources that rely on seasonal patterns such as river flow or rainfall).

Drip irrigation zones can be identified based on factors such as topography, field length, soil texture, optimal tape run length, and filter capacity. Many irrigation system suppliers use computer programs to analyze these factors and design drip systems. Once the zones are assigned and the drip system is designed, it is possible to schedule irrigations to meet the unique needs of the crop in each zone. Recent automatic systems technology has been particularly useful to help control flows and pressure and to identify potential leaks, thereby reducing labor requirements. System design must take into account the effect

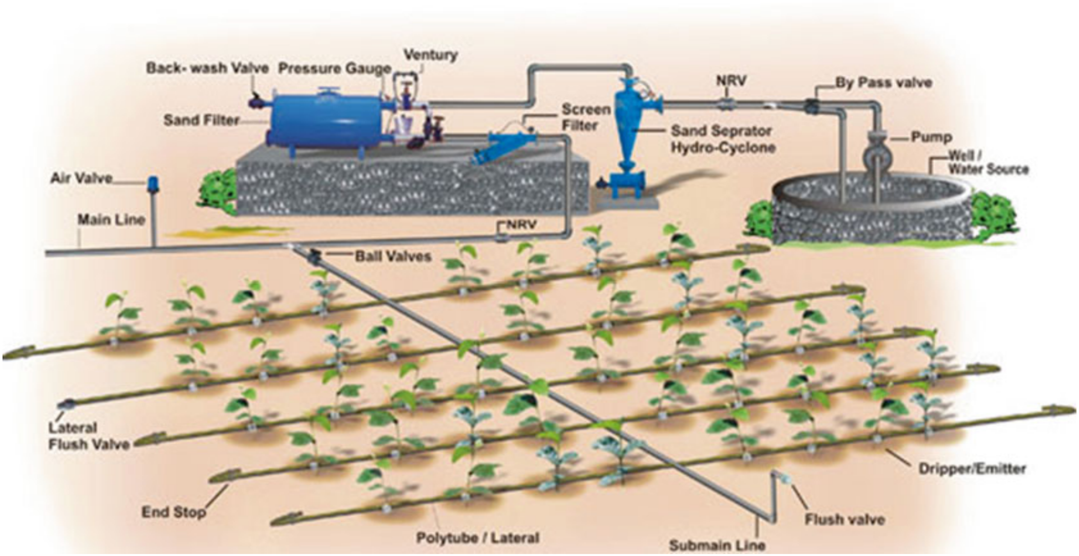

Fig. 12.10 A typical drip irrigation system

of the land topography on water pressure and flow requirements. A plan for water distribution uniformity should be made by carefully considering the tape, irrigation lengths, topography, and the need for periodic flushing of the tape. The design should also include vacuum relief valves into the system (Fig. 12.10).

Drip irrigation technology can support farmers to adapt to climate change by providing efficient use of water supply. Particularly in areas subject to climate change impacts such as seasonal droughts, drip irrigation reduces demand for water and reduces water evaporation losses (as evaporation increases at higher temperatures). Scheduled water application will provide the necessary water resources direct to the plant when required. Furthermore, fertilizer application is more efficient since it can be applied directly through the pipes.

As is the case with a sprinkler system, drip irrigation is more appropriate where there is (or is expected to be) limited or irregular water supply for agricultural use. However, the drip technology uses even less water than sprinkler irrigation, since water can be applied directly to the crops according to plant requirements. Furthermore, the drip system is not affected by wind or rain (as is the sprinkler technology).

12.3.4.1 Advantages

Drip irrigation can help use water efficiently. A well-designed drip irrigation system reduces water runoff through deep percolation or evaporation to almost zero. If water consumption is reduced, production costs are lowered. Also, conditions may be less favorable for the onset of diseases including fungus. Irrigation scheduling can be managed precisely to meet crop demands, holding the promise of increased yield and quality.

Agricultural chemicals can be applied more efficiently and precisely with drip irrigation. Since only the crop root zone is irrigated, nitrogen that is already in the soil is less subject to leaching losses. In the case of insecticides, fewer products might be needed. Fertilizer costs and nitrate losses can be reduced. Nutrient applications can be better timed to meet plants' needs.

The drip system technology is adaptable to terrains where other systems cannot work well due to climatic or soil conditions. Drip irrigation technology can be adapted to lands with different topographies and crops growing in a wide range of soil characteristics (including salty soils). It has been particularly efficient in sandy areas with permanent crops such as citrus, olives, apples, and vegetables. A drip irrigation system can be automated to reduce the requirement for labor.

Fig. 12.11 Fog harvesting

12.3.4.2 Disadvantages

The initial cost of drip irrigation systems can be higher than other systems. Final costs will depend on terrain characteristics, soil structure, crops, and water source. Higher costs are generally associated with the costs of pumps, pipes, tubes, emitters, and installation. Unexpected rainfall can affect drip systems either by flooding emitters, moving pipes, or affecting the flow of soil salt content. Drip systems are also exposed to damage by rodents or other animals. It can be difficult to combine drip irrigation with mechanized production as tractors and other farm machinery can damage pipes, tubes, or emitters.

12.3.5 Fog Harvesting

Fogs have the potential to provide an alternative source of fresh water in dry regions and can be harvested through the use of simple and low-cost collection systems. Captured water can then be used for agricultural irrigation and domestic use. Research suggests that fog collectors work best in locations with frequent fog periods, such as coastal areas where water can be harvested as fog moves inland driven by the wind. However, the technology could also potentially supply water in mountainous areas if the water is present in stratocumulus clouds, at altitudes of approximately 400–1,200 m (UNEP 1997). In addition to Chile, Peru, and Ecuador, the areas with the most potential to benefit include the Atlantic coast of southern Africa (Angola, Namibia), South Africa, Cape Verde, China, Eastern Yemen, Oman, Mexico, Kenya, and Sri Lanka.

Fog harvesting technology consists of a single or double layer mesh net supported by two posts rising from the ground. Mesh panels can vary in size. The ones used by the University of South Africa in a fog harvesting research project measured 70 m^2 (UNISA 2008), whereas in Yemen, a set of 26 small Standard Fog Collectors (SFC) of 1 m^2 were constructed. The material used for the mesh is usually nylon, polyethylene, or polypropylene netting (also known as "shade cloth") which can be produced to various densities capable of capturing different quantities of water from the fog that passes through it (UNEP 1997). The collectors are positioned on ridgelines perpendicular to prevailing wind and capture and collect water when fog sweeps through (Fig. 12.11). The number and size of meshes chosen will depend on the local topography, demand for water, and availability of financial resources and materials. According to FogQuest, the optimal allocation is single mesh units with spacing between them of at least 5 m with additional fog collectors placed upstream at a distance of at least ten times higher than the other fog collector. In South Africa, the university research project arranged several mesh panels together in order to expand the water catchment area and provide greater stability to the structure in windy conditions (UNISA 2008).

The collector and conveyance system functions due to gravity. Water droplets that collect on

Table 12.5 Water collection rates from fog collectors

Project	Total collecting surface (m^2)	Water collected (liters/day)
University of South Africa	70	3,800
Yemen	40	4,500
Cape Verde	200	4,000
Dominican Republic	40	4,000
Eritrea	1,600	12,000

Sources: UNISA (2008), Schemenauer et al. (2004), Wash technology, FogQuest

the mesh run downwards and drip into a gutter at the bottom of the net from where they are channeled via pipes to a storage tank or cistern. Typical water production rates from a fog collector range from 200 to 1,000 l per day, with variability occurring on a daily and seasonal basis (FogQuest). Efficiency of collection improves with larger fog droplets, higher wind speeds, and narrower collection fibers/mesh width. In addition, the mesh should have good drainage characteristics. Water collection rates from fog collectors are shown in Table 12.5.

The dimensions of the conveyance system and storage device will depend on the scale of the scheme. Storage facilities should be provided for at least 50 % of the expected maximum daily volume of water consumed. For agricultural purposes, water is collected in a regulating tank, transferred to a reservoir, and then finally into an irrigation system that farmers can use to water their crops (UNEP 1997).

Drought caused by climate change is leading to reductions in the availability of fresh water supplies in some regions. This is having an impact on agricultural production by limiting opportunities for planting and irrigation. Fog harvesting provides a way of capturing vital water supplies to support farming in these areas. Furthermore, when used for irrigation to increase forested areas or vegetation coverage, water supplies from fog harvesting can help to counteract the desertification process. If the higher hills in the area are planted with trees, they too will collect fog water and contribute to the aquifers. The forests can then sustain themselves and contribute water to the ecosystem, helping to build resilience against drier conditions.

12.3.5.1 Advantages

Atmospheric water is generally clean, does not contain harmful microorganisms, and is immediately suitable for irrigation purposes. In a number of cases, water collected with fog harvesting technology has been shown to meet World Health Organization standards (UNISA 2008). The environmental impact of installing and maintaining the technology is minimal. Once the component parts and technical supervision have been secured, construction of fog harvesting technology is relatively straightforward and can be undertaken on site. The construction process is not labor intensive, only basic skills are required, and, once installed, the system does not require any energy for operation. Given that fog harvesting is particularly suitable for mountainous areas where communities often live in remote condition, capital investment and other costs are generally found to be low in comparison with conventional sources of water supply (UNEP 1997).

12.3.5.2 Disadvantages

Fog harvesting technologies depend on a water source that is not always reliable, because the occurrence of fogs is uncertain. However, certain areas do have a propensity for fog development, particularly, mountainous coastal areas on the western continental margin of South America. Further, calculation of even an approximate quantity of water that can be obtained at a particular location is difficult (Schemenauer and Cereceda 1994). This technology might represent an investment risk unless a pilot project is first carried out to quantify the potential water rate yield that can be anticipated in the area under consideration.

12.3.6 Interventions

12.3.6.1 Research and Development

- Development of crop variants with high water-use efficiency levels such as those capable of regulating stomata closure and opening, etc.
- Exploring structural and technological measures to enhance water-use efficiency with reference to various types of crops, soils, agroclimatic zones, etc.

12.3.6.2 Technologies and Good Practices

- Augmentation of water resources through extensive rainwater harvesting, artificial recharge of groundwater, etc.
- Use of prefabricated water conveyance systems and adoption of ridge and furrow method of irrigation, raised bed method of farming, field bunding, leveling, etc.
- Development of storage structures for off-season use
- Wastewater treatment and its utilization
- Promotion of watershed development and management practices
- Improvement of irrigation efficiency by promoting drip and sprinkler irrigation techniques in place of channel irrigation
- Growing of less water-demanding crops and adopting resource conservation technologies (RCTs) to economize water use
- Adopting mixed cropping and agro-forestry practices for retaining soil moisture and reducing dependency on irrigation
- Intermittent flooding during rice cultivation for aeration of the fields

12.4 Agro-forestry (Adaptation)

Agro-forestry is an integrated approach to the production of trees and of non-tree crops or animals on the same piece of land. The crops can be grown together at the same time, in rotation, or in separate plots when materials from one are used to benefit another. Agro-forestry systems take advantage of trees for many uses: to hold the soil, to increase fertility through nitrogen fixation or through bringing minerals from deep in the soil and depositing them by leaf fall, and to provide shade, construction materials, foods, and fuel. In agro-forestry systems, every part of the land is considered suitable for the cultivation of plants. Perennial, multiple purpose crops that are planted once but yield benefits over a long period of time are given priority. The design of agro-forestry systems prioritizes the beneficial interactions between crops, for example, trees can provide shade and reduce wind erosion. According to the World Agro-forestry Centre, "agro-forestry is uniquely suited to address both the need for improved food security and increased resources for energy, as well as the need to sustainably manage agricultural landscapes for the critical ecosystem services they provide." Agro-forestry is already widely practiced on all continents. Using a 10 % tree cover as threshold, agro-forestry is most important in Central America, South America, and Southeast Asia but also occupies a large amount of land area in Africa.

Generally agro-forestry systems can be categorized into three broad types: agrosilviculture (trees with crops), agrisilvipasture (trees with crops and livestocks), and silvopastoral (trees with pasture and livestock) systems.

Agro-forestry is appropriate for all land types and is especially important for hillside farming where agriculture may lead to rapid loss of soil. The most important trees for incorporating into an agro-forestry system are legumes because of their ability to fix nitrogen and make it available to other plants. Nitrogen improves the fertility and quality of the soil and can improve crop growth. Some of the most common uses of trees in agro-forestry systems are:

- Alley cropping: growing annual crops between rows of trees
- Boundary plantings/living fences: trees planted along boundaries or property lines to mark them well
- Multi-strata: including home gardens and agroforests that combine multiple species and are particularly common in humid tropics such as in Southeast Asia
- Scattered farm trees: increasing number of trees, shrubs, or shaded perennial crops (such as coffee and cocoa) scattered among crops or pastures and along farm boundaries

Any crop plant can be used in an agro-forestry system. When selecting crops, the following criteria should be prioritized:

- Potential for production
- Can be used for animal feed
- Already produced in the region, preferably native to the zone

- Good nutritional content for human consumption
- Can protect the soil
- A lack of competition between the trees and crops

Five stages to the design and implementation of an agro-forestry system are presented in Table 12.6.

Agro-forestry can improve the resilience of agricultural production to current climate variability as well as long-term climate change through the use of trees for intensification, diversification, and buffering of farming systems. Trees have an important role in reducing vulnerability, increasing resilience of farming systems, and buffering agricultural production against climate-related risks. Trees are deep rooted and have large reserves and are less susceptible than annual crops to interannual variability or short-lived extreme events like droughts or floods. Thus, tree-based systems have advantages for maintaining production during wetter and drier years. Second, trees improve soil quality and fertility by contributing to water retention and by reducing water stress during low rainfall years. Tree-based systems also have higher evapotranspiration rates than row crops or pastures and can thus maintain aerated soil conditions by pumping excess water out of the soil profile more rapidly than other production systems if there is sufficient rainfall/soil moisture (Martin and Sherman 1992).

Trees can reduce the impacts of weather extremes such as droughts or torrential rain. For example, a combination of Napier grass and leguminous shrubs in contour hedgerows reduced erosion by up to 70 % on slopes above 10 % inclination without affecting maize yield in central Kenya (Mutegi et al. 2008). Research has also demonstrated that the tree components of agro-forestry systems stabilize the soil against landslides and raise infiltration rates (Ma et al. 2009). This limits surface flow during the rainy season and increases groundwater release during the dry season.

Agro-forestry can also play a vital role in improving food security through providing a means for diversifying production systems. By integrating trees in their farms and rangelands, farmers reduce their dependency on a single staple crop or having sufficient grass for their animals. For example, if a drought destroys the annual crop, trees will still provide fruits, fodder, firewood, timber, and other products that often achieve high commercial value. A study of 1,000 farmers from 15 districts in Kenya found that fruit trees contributed 18 % of crop revenue and tea and coffee contributed an additional 29 % of revenue. A study in Zimbabwe concluded that indigenous fruits provided higher returns to labor than annual crop production (Mithoefer and Waibel 2003). A study from Nepal on the impact of agro-forestry on soil fertility and farm income showed that agro-forestry intervention nearly doubled farm productivity and income (Neufeldt et al. 2009).

12.4.1 Advantages

Agro-forestry has a broad application potential and provides a range of advantages, including:

- Agro-forestry systems make maximum use of the land and increase land-use efficiency.
- The productivity of the land can be enhanced as the trees provide forage, firewood, and other organic materials that are recycled and used as natural fertilizers.
- Increased yields. For example, millet and sorghum may increase their yields by 50–100 % when planted directly under *Acacia albida* (FAO 1991).
- Agro-forestry promotes year-round and long-term production.
- Employment creation. Longer production periods require year-round use of labor.
- Protection and improvement of soils (especially when legumes are included) and of water sources.
- Livelihood diversification.
- Provides construction materials and cheaper and more accessible fuel wood.
- Agro-forestry practices can reduce needs for purchased inputs such as fertilizers.

Table 12.6 Five stages to the design and implementation of an agroforestry system

Stage	Basic tasks
Diagnostic	Definition of the land-use system and site selection
	Physical characteristics (including altitude, rainfall, slopes, water supplies, soil condition, visible erosion). This is basic background for evaluating the need for agro-forestry and the local suitability of various techniques
	Current uses of trees and shrubbery. This suggests the kind of subsistence products that an agro-forestry system would be expected to provide
	Sales and purchases of agro-forestry products (including poles, fruit, firewood, fodder, etc.). This provides data for economic analysis and indicates opportunities to replace purchased items or to expand sales by raising agro-forestry products
	Current tree planting (including species, source of seedlings, and intended use). This shows the present state of silvicultural knowledge
	Farmers' perceptions of deforestation and erosion (including any perceived impact on crop yields). This gives a sense of how critical farmers think their problems are and indicates current awareness of agro-forestry relationships
	Land and tree tenure. This shows whether farmers have a right to their trees and therefore whether they have an incentive to plant
	Current yields
	Limiting constraints access to technology and finance, farmer capacities, and markets
	Survey of local knowledge and scope for domestication of wild food and medicinal plants
Design and evaluation	How to improve the system?
	List potential benefits of an agro-forestry system
	List agricultural production needs (meet food security, increase production to meet market demands, and so on)
	Adoptability considerations: social and cultural acceptance; importance of local knowledge, practice, and capacity; as well as equity and gender issues
	Characterize the crops desired by minimum space requirements, water and fertilizer needs, and shade tolerance
	Select the trees, shrubs, or grasses to be used
Planning	If the system is temporary:
	Plan the features of soil erosion control, earthworks, and gully maintenance
	Plan spacing of fruit trees according to final spacing requirements
	Plan a succession of annual or short-lived perennials beginning with the most shade tolerant for the final years of intercropping
	If the system is permanent:
	Plan the proportion of the permanent fruit and lumber trees on the basis of relative importance to the farmer
	Plan the spacing of long-term trees on the basis of final space requirements times 0.5
	Plan succession of annual and perennial understory crops, including crops for soil protection and enrichment
	As large permanent trees grow, adjust planting plan to place shade-tolerant crops in most shady areas
Implementation	On-farm trials of proposed agro-forestry models to analyze impacts of trees on crops, testing harvesting regimes
Monitoring	Ongoing study and analysis of soil nutrition, moisture, and so on
	Watershed design study
	Measure the inputs and outputs of the system (including yields of trees and crops, and labor requirements)
	Survey of land use
	Socioeconomic benefit assessment

Source: Martin and Sherman (1992) and FAO (1991)

12.4.2 Disadvantages

Agro-forestry systems require substantial management. Incorporating trees and crops into one system can create competition for space, light, water, and nutrients and can impede the mechanization of agricultural production. Management is necessary to reduce the competition for resources and maximize the ecological and productive benefits. Yields of cultivated crops can also be smaller than in alternative production system; however, agro-forestry can reduce the risk of harvest failure.

12.4.3 Integrated Crop–Livestock Systems

The annual crops may be rotated with pasture without the destructive intervention of soil tillage (FAO 2011). Practical innovations have harnessed synergies between crop, livestock, and agro-forestry production to improve the economic and ecological sustainability of agricultural systems and at the same time provide a flow of valued ecosystem services. Through increased biological diversity, efficient nutrient recycling, improved soil health, and forest conservation, integrated systems increase environmental resilience and contribute to climate change adaptation and mitigation. They also enhance livelihood diversification and efficiency by optimizing production inputs, including labor. In this way, integrated systems also increase producers' resilience to economic stresses (FAO 2011).

Integrated crop–livestock systems imply a diverse range of integrated ecological, biophysical, and socioeconomic conditions (FAO 2010). They aim to increase profits and sustain production levels while minimizing the negative effects of intensification and preserving natural resources (IFAD 2009). They also have environmental, social, and economic benefits. These systems, which enhance the natural biological processes above and below the ground, represent a synergistic combination that (a) reduces erosion; (b) increases crop yields, soil biological activity, and nutrient recycling; (c) intensifies land use and improving profits; and (d) can therefore help reduce poverty and malnutrition and strengthen environmental sustainability (IFAD 2009).

As climate changes, the resilience and adaptive capacity of agricultural production systems and agricultural landscapes will become more important. To become more resilient and better able to adapt to changing conditions, crop production systems will need to rely more on ecological processes that produce positive feedbacks on sustainability and production and ensure improved provision of all ecosystem services (FAO-PAR 2011). Progress in this area could be made by adopting existing agricultural practices that have already been proven to have multiple benefits for food security and environmental health.

12.5 Ecological Pest Management

12.5.1 Key Issues

- Efficient, safe, and environmentally sound methods of pest management
- Incentivizing research, commercial production, and marketing of biopesticides
- Developing insect forecasting models
- Decision and information support systems for pest and disease surveillance
- Institutional mechanism for quick response in case of disaster

Ecological Pest Management (EPM) is an approach to increasing the strengths of natural systems to reinforce the natural processes of pest regulation and improve agricultural production. Also known as Integrated Pest Management (IPM), this practice can be

> defined as the use of multiple tactics in a compatible manner to maintain pest populations at levels below those causing economic injury while providing protection against hazards to humans, animals, plants and the environment. IPM is thus ecologically-based pest management that makes full use of natural and cultural processes and methods, including host resistance and biological control. IPM emphasizes the growth of a healthy crop with the least possible disruption of agro-ecosystems, thereby encouraging natural pest control mechanisms. Chemical pesticides are used only where and when these natural methods fail to keep pests below damaging levels.

EPM is a biotechnology belonging to the denominated "clean" technologies which combines the life cycle of crops, insects, and implicated fungi, with natural external inputs (i.e., biopesticides) that allows a better guarantee of good harvesting even in difficult conditions of pests and diseases that emerge with the temperature and water level changes (increase of relative atmospheric humidity and runoff) typical of climate change. Thus, it is a biotechnology for facing uncertainty caused by climate change.

EPM contributes to climate change adaptation by providing a healthy and balanced ecosystem in which the vulnerability of plants to pests and diseases is decreased. By promoting a diversified farming system, the practice of EPM builds farmers' resilience to potential risks posed by climate change, such as damage to crop yields caused by newly emerging pests and diseases.

The basis of this natural method of controlling pests is the biodiversity of the agroecological system. This is because the greater the diversity of natural enemy species, the lower the density of the pest population, and as diversity of natural enemy species decreases, pest population increases.

The key components of an EPM approach are:

12.5.2 Crop Management

Selecting appropriate crops for local climate and soil conditions. Practices include:

- Selection of pest-resistant, local, native varieties and well-adapted cultivars
- Use of legume-based crop rotations to increase soil nitrate availability, thereby improving soil fertility and favorable conditions for robust plants that better face pests and diseases
- Use of cover crops, such as green manure to reduce weed infestation, disease, and pest attacks
- Integration of intercropping and agro-forestry systems
- Use of crop spacing, intercropping, and pruning to create conditions unfavorable to the pests

12.5.3 Soil Management

Maintaining soil nutrition and pH levels to provide the best possible chemical, physical, and biological soil habitat for crops. Practices include:

- Building a healthy soil structure according to the soil requirements of the different plants (such as deep/shallow soil levels or different mineral contents).
- Using longer crop rotations to enhance soil microbial populations and break disease, insect, and weed cycles.
- Applying organic manures to help maintain balanced pH and nutrient levels. Adding earthworm castings, colloidal minerals, and soil inoculants will supplement this. Microbes in the compost will improve water absorption and air exchange.
- Soil nutrients can be reactivated by alleviating soil compaction.
- Reducing soil disturbance (tillage) – undisturbed soil with sufficient supply of organic matter provides a good habitat for soil fauna.
- Keeping soil covered with crop residue or living plants.

12.5.4 Pest Management

Using beneficial organisms that behave as parasitoids and predators. Practices include:

- Releasing beneficial insects (predators) and providing them with a suitable habitat
- Managing plant density and structure so as to deter diseases
- Cultivating for weed control based on knowledge of the critical competition period
- Managing field boundaries and in-field habitats to attract beneficial insects and trap or confuse insect pests

IPM strategies can exist at various levels of integration. Note that integration at all four levels is not common:

- Control of a single pest on a particular crop
- Control of several pests on the same crop
- Several crops (and non-crop species) within a single production unit (farm)

- Several farms in a region (area-wide pest management)

These practices, if well implemented, result in systems that are:

- Self-regulating, maintaining populations of pests within acceptable boundaries
- Self-sufficient, with minimal need for "reactive" interventions
- Resistant to stresses such as drought, soil compaction, and pest invasions
- Capable of recuperating from stresses

Worldwide public attention has been focused on the importance of EPM since the United Nations Conference on Environment and Development held in Rio de Janeiro in June 1992. The blueprint for action prepared by the Conference (Agenda 21) recognized pesticide pollution as a major threat to human health and the environment worldwide and identified IPM as a key element in sustainable agricultural development.

Pesticide consumption in India has increased over time, and its injudicious use has created problems like development of resistant strains in insects and plant pathogens; resurgence of pest species; direct exposure to the applicator; destruction of parasites, predators, and other beneficial organisms; and accumulation of pesticide residues in agricultural commodities, water, air and soil, etc. Pesticide residues in feed and water affect livestock health due to direct and indirect exposure in the course of pest control measures. Strategies suggested under this intervention have to primarily focus on the establishment of decision and information support systems for pest and disease surveillance, demonstration of best practices, and quick response mechanism that are at par with the norms to deal with other disasters or natural calamities.

12.5.5 Advantages

With the EPM approach, farmers can avoid the costs of pesticides as well as the fuel, equipment, and labor used to apply them. A 22-year trial comparing conventional and organic corn/soybean systems found that organic farming approaches for these crops use an average of 30 % less fossil energy (Pimentel et al. 2005). Although this can cause a slight drop in productive performance, the risk of losing an entire crop is reduced dramatically.

There are also reports that production levels have increased when there has been a reduction in the use of pesticides. This is the case when there are specific controllers for a determined pest, for example, in West Africa the introduction of the wasp has been a spectacular control of the slug of cassava, thus saving the staple food crop for millions of Africans.

12.5.6 Disadvantages

There are very strong pests for which the "biological control" has not yet been identified (i.e., an insect that destroys it). When these pests emerge, it is common for producers to turn to pesticides. EPM is not easy to implement and requires substantial knowledge and monitoring for the combined components of the system to produce success. Perhaps the biggest drawback to the EPM approach is that biological control is not a "quick fix." In most cases, biological control will take several years to successfully establish a population and begin making a significant contribution. In addition, no single biological control works in every situation. A control that works well in one soil type, for example, may not work at all in another soil type. In the long run, more than one type of biological control may have to be used to achieve uniform control across a variety of different situations and land types.

12.5.7 Interventions

12.5.7.1 Research and Development

- Providing site-specific weather data to help researchers run predictive pest models and for farmers to make informed decisions on pest management.
- Research on pest/insect–crop–weather interactions for developing simple operational and

predictive models that can be used in agro-advisory services.

- Integrate biotechnology with traditional agricultural practices and metabolomic and bioinformatics systems to design novel insecticide molecules for studying interactions with the DNA and protein models.
- Develop new biopesticides and technologies on pest management through sterile insect techniques, new botanical, semiochemicals (repellents, pheromones, allomones, etc.), and endophytic microbial metabolites for pest control, transgenic insects, pests, and disease forecasting.

12.5.7.2 Technologies and Practices

- Develop effective surveillance systems for invasive species based on semiochemicals.
- Streamlining the flow of information of pest surveillance and livestock diseases to reduce response time between detection and action to manage and prevent pests and diseases.
- Promotion of bio-intensive integrated pest management at large scale.
- Strengthening the existing network of veterinary health support services with particular emphasis on preventive healthcare services including immunization.
- Plant protection measures to be tailored to meet the threat to crops and farm animals arising from the outbreak of vector-borne diseases.

12.6 Livestock Adaptation

Adaptation for pasture-grazing livestock includes changes in the use and maintenance of pastures and in the mix of livestock breeds (Easterling et al. 2007).

Climate change is having substantial effects on ecosystems and the natural resources upon which the livestock sector depends. Climate change will affect the sector directly, through increased temperature, changes in the amount of rainfall, and shifts in precipitation patterns. Indirect impacts will be experienced through modifications in ecosystems, changes in the yields, quality and type of feed crops, possible increases in animal diseases, and increased competition for resources.

12.6.1 Sector Trends

Global production of meat, milk, and eggs has rapidly expanded during the last decades in response to growing demand for livestock products. This increase in demand, which has been particularly strong in developing regions, has largely been driven by expanding populations and increasing incomes. For example, between 1960 and 2005, annual per capita consumption of meat has more than tripled, consumption of milk almost doubled, and per capita consumption of eggs increased fivefold in the developing world (Fig. 12.12).

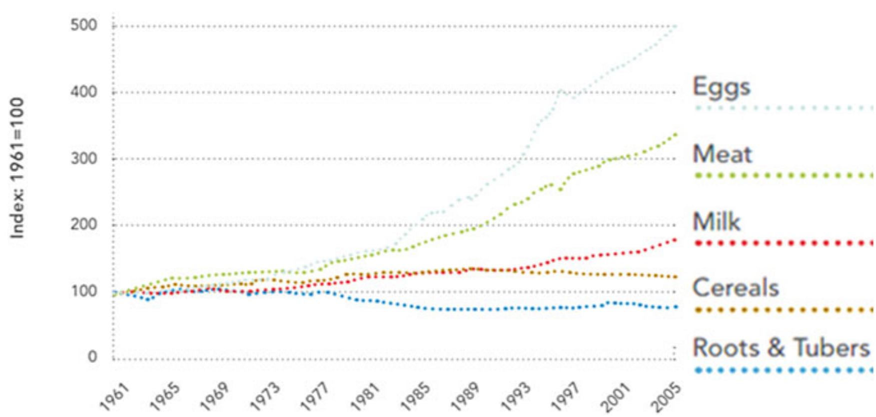

Fig. 12.12 Per capita consumption of major food items in developing countries (FAO 2009)

Excluding Brazil and China, per capita meat consumption in developing countries is expected to increase to 26 kg in 2030 and 32 kg in 2050. In terms of future consumption, it is projected that a marked gap will continue to exist between developed and developing countries. This gap indicates that there is scope for further growth in the livestock sector. Driven by demand, global production of meat is projected to more than double, from 229 million tons in 1999/2001 to 465 million tons in 2050. Milk production is expected to increase from 580 to 1,043 million tons (FAO 2006).

Livestock make a necessary and important contribution to global calorie and protein supplies. However, livestock need to be managed carefully to maximize this contribution. While livestock products are not absolutely essential to human diets, they are valued and they will continue to be consumed in increasing amounts. Meat, milk, and eggs in appropriate amounts are valuable sources of complete and easily digestible protein and essential micronutrients.

12.6.2 Adaptation Needs: Climate-Resilient Livestock

Climate-resilient adaptation options deemed suitable for land-based systems, along with their capacities to satisfy multiple climate-resilient objectives, are listed in Table 12.7.

Table 12.7 Summary of CRA practices and technologies for land-based systems

Practices and technologies	Impact on food security	Effectiveness of adaptation
Grazing management	+/−	+
Pasture management	+	
Animal breeding	+	++
Animal and herd management	+	++
Animal disease and health	++	++
Supplementary feeding	+	+
Vaccines against rumen archaea	++	
Warning systems	++	+
Weather-indexed insurance		+
Agro-forestry practices	++	++

Adaptation potential: + = low; ++ = medium

12.6.3 Livestock Disease Management

Livestock systems in developing countries are characterized by rapid change, driven by factors such as population growth, increases in the demand for livestock products as incomes rise, and urbanization. Climate change is adding to the considerable developmental challenges posed by these drivers of change. The increasing frequency of heat stress, drought, and flooding events could translate into the increased spread of existing vector-borne diseases and macro-parasites, along with the emergence of new diseases and transmission models (IFAD 2002). Appropriate sustainable livestock management practices are required so that livestock keepers can take advantage of the increasing demand for livestock products (where this is feasible) and protect their livestock assets in the face of changing and increasingly variable climates.

Livestock diseases contribute to an important set of problems within livestock production systems. These include animal welfare, productivity losses, uncertain food security, loss of income, and negative impacts on human health. Livestock disease management can reduce disease through improved animal husbandry practices. These include: controlled breeding, controlling entry to farm lots, and quarantining sick animals and through developing and improving antibiotics, vaccines and diagnostic tools, evaluation of ethno-therapeutic options, and vector control techniques.

Livestock disease management is made up of two key components:

- Prevention (biosecurity) measures in susceptible herds
- Control measures taken once infection occurs

The probability of infection from a given disease depends on existing farm practices (prevention) as well as the prevalence rate in host populations in the relevant area. As the prevalence in the area increases, the probability of infection increases.

12.6.3.1 Prevention Measures

Preventing diseases entering and spreading in livestock populations is the most efficient and cost-effective way of managing disease. While many approaches to management are disease specific, improved regulation of movements of livestock can provide broader protection. A standard disease prevention program that can apply in all contexts does not exist. But there are some basic principles that should always be observed. The following practices aid in disease prevention:

- Elaboration of an animal health program.
- Selection of a well-known, reliable source from which to purchase animals, one that can supply healthy stock, inherently vigorous and developed for a specific purpose. New animals should be monitored for disease before being introduced into the main flock.
- Good hygiene including clean water and feed supplies.
- Precise vaccination schedule for each herd or flock.
- Observe animals frequently for signs of disease, and if a disease problem develops, obtain an early, reliable diagnosis and apply the best treatment, control, and eradication measures for that specific disease.
- Dispose of all dead animals by burning, deep burying, or disposal pit.
- Maintain good records relative to flock or herd health. These should include vaccination history, disease problems, and medication.

12.6.3.2 Surveillance and Control Measures

Disease surveillance allows the identification of new infections and changes to existing ones. This involves disease reporting and specimen submission by livestock owners, village veterinary staff, and district and provincial veterinary officers. The method used to combat a disease outbreak depends on the severity of the outbreak. In the event of a disease outbreak, the precise location of all livestock is essential for effective measures to control and eradicate contagious viruses. Restrictions on animal movements may be required as well as quarantine and, in extreme cases, slaughter.

The major impacts of climate change on livestock diseases have been on diseases that are vector-borne. Increasing temperatures have supported the expansion of vector populations into cooler areas. Such cooler areas can be either higher altitude systems (e.g., livestock tick-borne diseases) or more temperate zones (e.g., the outbreak of bluetongue disease in Northern Europe). Changes in rainfall pattern can also influence an expansion of vectors during wetter years and can lead to large outbreaks. Climate changes could also influence disease distribution indirectly through changes in the distribution of livestock. Improving livestock disease control is therefore an effective technology for climate change adaptation.

12.6.3.3 Advantages

Benefits of livestock disease prevention and control include: higher production (as morbidity is lowered and mortality or early culling is reduced) and avoided future control costs. When farmers mitigate disease through prevention or control, they benefit not just themselves but any others at risk of adverse outcomes from the presence of disease on that operation. At-risk populations include residents, visitors, and consumers. The beneficiaries might also include at-risk wildlife populations surrounding the farm that may have direct or indirect contact with livestock or livestock-related material.

12.6.3.4 Disadvantages

Management options may interact, so the use of one option may diminish the effectiveness of another. Another critical issue is the long-term sustainability of currently used strategies. Chemical intervention strategies such as antibiotics or vaccines are not biologically sustainable. Animals develop resistance to drugs used to control certain viruses, and with each new generation of vaccine, a new and more virulent strain of the virus can arise (FAO 2003). Small-scale producers may be negatively affected by livestock disease management if the full cost of the disease management program is directly passed onto them with no subsidy from the government (FAO 2003).

Modeling disease outbreaks and spread can provide valuable information for the development of management strategies. Modeling involves studying disease distribution and patterns of spread to determine the scale of a problem. This information is used to develop a model that can predict the spread of disease. Disease modeling requires prior knowledge of animal population distributions and ecology, diseases present, and methods of disease transmission. Modeling can be used to assess potential disease impacts and develop contingency plans.

Geographic Information System (GIS) software can play a key role in livestock disease management. The main advantage of GIS software is not just that the user can see how a disease is distributed geographically, but also that an animal disease can be viewed against other information (e.g., maps that show the possible impacts of climate change on rainfall patterns, crop yields, and flooding). The disease presence can then be related to these factors and more easily appreciated visually. This is important in relation to managing and responding to the changes in distribution of diseases due to changing climate. The role of indigenous knowledge in livestock disease management under climate change has been shown, in certain cases, to be cost-effective, sustainable, environmental friendly, and practical. Practices include:

- Utilization of local plant remedies for prevention and cure of diseases.
- Avoiding certain pastures at particular times of the year and not staying too long in one place to avoid parasite buildup.
- Lighting smoke fires to repel insects, especially tsetse flies.
- Mixing species in the herd to avoid the spread of disease.
- Avoiding infected areas or moving upwind of them, spreading livestock among different herds to minimize risks, and quarantining sick animals.
- Selective breeding. As an example from the arid south of Zambia, restocking and promoting the rearing of drought-tolerant goat breeds are adaptive measures already being undertaken.

12.6.4 Selective Breeding via Controlled Mating

Genetic makeup influences fitness and adaptation and determines an animal's tolerance to shocks such as temperature extremes, drought, flooding, pests, and diseases. Adaptation to harsh environments includes heat tolerance and an animal's ability to survive, grow, and reproduce in the presence of poor seasonal nutrition as well as parasites and diseases. Selective breeding is a technology that aims to improve the value of animal genetic diversity. This technology can be applied to all types of livestock, including cattle, sheep, and goats. As developments have been made over time in improving measurement techniques and methods for estimating an animal's genetic potential, the power and effectiveness of selective breeding as a tool has also increased. Over the last half century, it has helped achieve dramatic improvements in the productivity of livestock species as well as improvements in the health and welfare of livestock and other animals.

Selective livestock breeding is the systematic breeding of animals in order to improve productivity and other key characteristics. Various methods for selective breeding exist, from high-tech and costly processes such as in vitro fertilization or genetic engineering to more simple low-cost techniques that rely on the selection and controlled mating of animals based on observable characteristics. Key breeding traits associated with climate change resilience and adaptation include thermal tolerance, low-quality feed, high kid survival rate, disease resistance, good body condition, and animal morphology. In general, developing countries have a weak capacity for high-tech breeding programs to increase livestock adaptation (IFAD 2002). Therefore, programs based on controlled mating methods are likely to be more appropriate. These programs usually do not produce immediate improvements. Improvements are usually not seen for at least one growing season, so a livestock producer must be able to incorporate long-term planning into production management strategies. Such measures could include

(1) identifying and strengthening local breeds that have adapted to local climatic stress and feed sources and (2) improving local genetics through cross-breeding with heat- and disease-tolerant breeds.

There are three main approaches to selective breeding:

12.6.4.1 Outcrossing

Mating two animals that are unrelated for at least 4–6 generations back is called an outcross. This method works best when the genetic variation for a trait is high. When dominant genes are the desirable ones, outcrossing works perfectly well. One of the best advantages of outcrossing is that it hides detrimental traits by keeping them recessive. Outcrossing improves fitness traits such as reproductive ability, milk production, kid survivability, and longevity.

12.6.4.2 Linebreeding

Linebreeding involves mating-related animals like half brother/half sister, cousins, aunt/nephew, and other more distant relationships. This is usually done to capitalize on a common outstanding ancestor who appears in recent generations of the pedigree. There is a higher degree of uniformity with linebreeding than in outcrossing and a reduced possibility of harmful genetic defects than inbreeding.

12.6.4.3 Inbreeding

This breeding method involved mating directly related animals, like mother/son, father/daughter, and full brother/full sister (full siblings). This method is used generally to create uniformity and prepotency (the ability of this process to continue) and to force out latent weaknesses from the gene pool. However, recessive genes are more of a factor than dominant genes in genetic faults, so there is a high risk producing kids with problems. Inbreeding reduces the pool of available genes and can cause some lines to become extinct. Fitness traits are especially at risk with this breeding scheme.

Selective breeding through controlled mating enables farmers to breed animals that are more resistant to the impacts of climate change, such as sudden changes in temperature, prolonged droughts, or the appearance of new diseases. It can reduce mortality rates, increase fertility rates, and can also be used to improve the quality of livestock products such as milk and fiber. As a result, livestock producers are at a lower risk from losing animals to climate change impacts, and they are also able to diversify their income-generating activities by capitalizing on higher-quality dairy or fiber production.

12.6.4.4 Advantages

The specific advantages of selective breeding through controlled mating include low input and maintenance costs once the strategy is established and permanence and consistency of effect. In addition, controlled mating can preserve local and rare breeds that could be lost as a result of climate change-related disease epidemics.

12.6.4.5 Disadvantages

One of the main limitations of this technology is that selective breeding of certain genes can run the risk of reducing or removing other genes from the overall pool, a process which is irreversible. This can create new weaknesses among animals, particularly with the emergence of a new pest or disease. Depending on the animal traits chosen, selective breeding may not always lead to higher productivity rates.

12.6.5 Early Warning Systems and Insurance

The use of weather information to assist rural communities in managing the risks associated with rainfall variability is a potentially effective (preventative) option for climate change adaptation. Livestock insurance schemes that are weather indexed (i.e., policy holders are paid in response to “trigger events” such as abnormal rainfall or high local animal mortality rates) may also be effective where preventative measures fail (Skees and Enkh-Amgala 2002).

12.7 Energy Adaptation

The adaptation strategies in energy sector include:

- Exploiting new and renewable energy sources, especially solar energy. Solar power (photovoltaic or solar heaters) (Fig. 12.13), wind, and geothermal energy are all sources of energy that are available today for both large and small applications. They are particularly suitable for remote rural areas.
- Initiating and developing projects that promote the use of alternative and or non-wood energy sources (e.g., biogas and fuel-saving stoves).
- Increasing awareness of the effect of pollution on the environment through information, education, and communication (IEC), with a focus on energy use and environmental education.
- Improvement and increase in clean thermal power generation.
- Protection of hydropower water catchments.
- Increase in availability of biomass resources. Improvement of biomass to increase energy conversion efficiency.
- End-use energy efficiency programs.
- Integrated approach to renewable energy for farming systems.

Non-food crops such as biofuels present opportunities for crop diversification and increased income should also be considered, albeit with caution since they compete with food crops for land, nutrients, and water. Biofuels produce low greenhouse gas emissions by recycling carbon dioxide extracted from the atmosphere. Besides mitigating the impacts of climate change, biofuels have the economic and strategic advantage of replacing fossil fuels (Raswant et al. 2008). Due to their high economic returns with minimum investment, biofuels are seen by smallholder farmers as a viable alternative to labor-intensive and low-yielding cereals. Plants such as jatropha are becoming popular among smallholder farmers in eastern Africa (e.g., Ethiopia) and West Africa (e.g., Mali). However, little information on the productivity of biofuels in water-stressed conditions is available, and more research is needed.

Other crops such as sugarcane, soybean, and maize can also be used as biofuels, but the current global food crisis and escalating prices discourage conversion of food crops to biofuel. Concern over the diversion of food crops to biofuel has placed the issue at the center of debate concerning future options for biofuel (Connor and Hernández 2009). An important consideration, however, is that some biofuel crops are drought resistant and can even be grown on degraded land, hence offering another advantage. The rehabilitation of degraded lands, especially on the vast semiarid environ-

Fig. 12.13 Field filled with solar panels

ments of Sub-Saharan Africa (SSA), could be a boon to many smallholder farmers. The combination of modern breeding and transgenic techniques could result in greater achievements in biofuel crops than those of the green revolution in food crops and in far less time (Ragauskas et al. 2006). There exists some doubt, however, about the long-term negative impact of these crops on soils and human health. Countries such as Burkina Faso are already growing transgenic cotton, vegetables, and potatoes, but the jury is still out on this sensitive issue. One advantage of developing transgenic crops is that they can produce in a very short time and hence cope with low rainfall conditions.

12.8 Early Warning Systems

An Early Warning System (EWS) is a set of coordinated procedures through which information on foreseeable hazards is collected and processed to warn of the possible occurrence of a natural phenomenon that could cause disasters. These systems are acquiring more importance in view of increased climate variability and the ability to implement them has become fundamental for improving capacity to adapt to climate change.

There are two types of EWS:

- Centralized systems implemented by national government bodies. The ministry of defense or another appropriate government entity is responsible for implementing hazard warning and response activities.
- Decentralized community systems, usually operated by a network of volunteers employing simple equipment to monitor meteorological conditions and operate radio communication networks.

Operators of decentralized community meteorological stations report the information to a local forecasting center where the data is analyzed and then communicated back to the community network. The demand for community-led systems is increasing due to lower operational costs and the need for local forecasting and monitoring of climate variability and potential disasters.

The following are the main implementation stages of a decentralized community system:

- Establishing an organizing committee (leaders of the community and civil society, NGOs, representatives of local authorities, and the private sector)
- Creating and analyzing information: building and installing measuring instruments, carrying out forecasts
- Producing a participatory emergency and contingency plan
- Implementing a communication system: early warnings, dissemination of prevention, mitigation and adaptation measures

Increased frequency and intensity of extreme weather events, prolonged drought and processes of desertification, longer periods of heavy rainfall, and increased risk of flooding are just some of the impacts of climate change affecting the world's poorest populations (IPCC 2007). EWS technology designed as a climate change adaptation strategy must therefore be capable of forecasting a number of climatic events that correspond to different time scales:

- Three to four months of advance warning of a drought
- Two to three weeks of advance warning of freezing weather conditions and monsoons
- A few hours of advance warning of torrential rain, hail, and floods

This technology contributes to the climate change adaptation and risk reduction process by improving the capacity of communities to forecast, prepare for, and respond to extreme weather events and thereby minimize damage to infrastructure and social and economic impacts, such as loss of livelihoods.

12.8.1 Advantages

- Introduction of hazard-related and disaster management concepts into community-level planning processes
- Exchange of information of a social or legal nature, in addition to climatic information, through the established communication network

- Facilitation of decision-making in political organizations
- Creation and improvement of a structure that incorporates different stakeholders involved in drawing up specific action plans

12.8.2 Disadvantages

The majority of EWSs were established to prevent or reduce the impacts of climate-related disasters (such as floods and hurricanes). By comparison, the capability of these systems to forecast droughts, extreme colds, and Indian summers has been less effective. Droughts are particularly distinguishable from other extreme weather events in that they begin slowly and gradually and are less "obvious" at the outset. In addition, drought can last extended periods of time and affect extensive areas. Given these complexities, EWSs should be complemented with historical data on droughts, along with available climatological, hydrological, physical, biological, and socioeconomic statistics. Only by combining these data can the complex causes of droughts be better understood and different scenarios modeled with the aim of developing prognoses (such as the probable start date of the rainy season or possible variations in rainy and dry seasons) to be disseminated via appropriate communication channels.

12.9 Crop Insurance Schemes

12.9.1 Key Issues

- Developing various models for risk assessment
- Designing user-friendly decision support systems to help assess risks and develop region-specific contingency plans
- Strengthening existing risk cover mechanism under NAIS and weather-based crop insurance scheme
- Implementing region-specific contingency plans based on vulnerability and risk scenarios

Agricultural insurance is an important mechanism by which risks to agricultural output and income can be addressed. Crop insurance incentivizes farmers to adopt innovative options by spreading the risks over space and time. It also stabilizes farm incomes, thereby enabling farmers to repay debts, which not only preserve the viability of formal financial institutions but also save huge government expenditures incurred in writing-off agricultural loans. Deficiencies in the existing framework of assessment of crop damage and prompt settlement of claims need to be addressed so that a disaster mode of operational efficiency is institutionalized. Research and development activities for developing new insurance products in the light of new risks emerging from climate change also need to be taken up as a medium- to long-term strategy. An effective design and efficient implementation mechanism is required to ensure timely benefits especially to the small and marginalized farmers.

Over the last 40 years, natural catastrophes have caused a sevenfold increase in economic losses (Dlugolecki 2004). Therefore, to address such risks, an effective insurance system is needed that meets the following criteria:

- Affordable and accessible to all rural people
- Compensation for income losses to protect consumption and debt repayment capacity
- Practical to implement, given potential limits on data availability
- Can be provided by the private sector with little or no government subsidies
- Avoids the problems of moral hazard and adverse selection

Effective crop insurance schemes should be evolved to help the farmers in reducing the risk of crop failure due to these events. Both formal and informal, as well as private and public, insurance programs need to be put in place to help reduce income losses as a result of climate-related impacts. However, information is needed to frame out policies that encourage effective insurance opportunities. Micro-finance has been a success among rural poor, including women. Low-cost access to financial services could be a boon for vulnerable farmers. Growing network of mobile telephony could further speed up SMS-based banking services and help the farmers in having better integration with financial institutions. However, compared to micro-finance, micro-insurance innovations and availability are limited. There is a need to develop sustainable insurance system, while the rural poor are to be educated about availing such opportunities.

12.9.2 Interventions

12.9.2.1 Research and Development

- Developing various models for risk assessment to assess the magnitude of risk exposure and availability of supportive infrastructure including resources in case of climate variability and extreme events
- Developing innovative and new generation agricultural insurance products, such as weather index-based insurance, livestock insurance, etc.
- Developing strategies to deal with emerging risks due to climate change such as high intensity rain, heat waves, depletion of groundwater, water contamination, etc.
- Designing user-friendly decision support systems to help assessing risks and develop region-specific contingency plans

12.9.2.2 Technologies and Practices

- Assessing availability of appropriate technologies and their backstopping support system that has long-term effect on reduction of risk mitigation
- Use of crop-weather forecast models to aid field-based planning and operational activities by both farmers and governing bodies

12.10 Livelihood Diversification

12.10.1 Key Issues

- Mitigating risks by supplementing income from off-farm activities
- Crop diversification
- Crop–livestock–fisheries farming system

Livelihood diversification plays a major role in providing options of supplementing income from core agricultural activities through on-farm or off-farm activities, mitigating risks by providing additional support to agricultural income under conditions of climatic and non-climatic stresses, supporting farm-based investments for better productivity, and through income generated by alternate livelihood options. The strategies under this dimension would aim to promote diversification of agriculture into other high-value crops and horticulture; research, development, and extension of crop–livestock farming systems; and increasing focus and development of approaches like sericulture, agro-forestry, crop-fish farming, etc.

12.10.2 Interventions

12.10.2.1 Research and Development

- Development of high productive horticultural crops, namely, fruits, vegetables, aromatic and medicinal plants, and spices and plantation crops (e.g., coconut, areca nut, cashew, cocoa, etc.)
- Conducting research on risks to specific livelihoods for understanding the changing nature of risk due to climatic and non-climatic stresses (e.g., changes in climatic variables, trade patterns, market prices, etc., can guide farmers regarding investments in specific crops)
- Development of decision support system for integrating market information to improve production and trade of horticultural/dairying/fisheries products
- Extending research on resource-conserving technologies (RCT) in the domain of crop production and livestock management

12.10.2.2 Technologies and Practices

- Penetration of technologies such as micropropagation; integrated nutrient, water, and pest management; organic farming; and immunodiagnostic techniques for detection of diseases and to improve the productivity of horticultural crops
- Strengthening technologies and practices that assist in food processing such as value addition and cold storage for horticulture/dairying/fisheries products

- Adopting region-specific silvicultural and farming practices to optimize food production, carbon sequestration, and biodiversity conservation
- Refining package of practices for crop-fish farming using locally available resources and resource-efficient practices that reduce input requirements supported by appropriate policy instrument to reduce investments and cost input in terms of feed, manpower, and infrastructure
- Developing and strengthening low tunnel/polyhouse farming under controlled condition to sustain livelihood from small landholdings

12.11 Access to Information

12.11.1 Key Issues

- Minimizing information asymmetry through ICT-based systems
- Public–private partnership to develop technology-based solution for providing farmers with information on price discovery, commodity arrivals, mandi prices, etc.
- Building an ICT-enabled knowledge management network
- To create, manage, and develop national resource portal

Effective communication approaches are critical to help farmers adapt to climate change as weather becomes more erratic and less predictable. Fresh strategies for management of information may be required to sustain production levels. This dimension is crosscutting in nature, having implications at all levels in the agricultural production system as well as for all the other key dimensions. At the crop level, the focus needs to be on upscaling the efforts to link the public and private partners with the research institutions so that the laboratory results can get commercialized quickly. At the level of the farm, focus needs to be on enhancing awareness of farmers as well as the developmental agencies with the latest scientific research, market information, and policy initiatives so that they are empowered to take informed decisions for maximizing farm productivity. At a larger scale, at the food system level, technological and infrastructural research along with interventions required to enhance the adaptive capacity for ensuring food security in the wake of climate change must be investigated.

12.11.2 Interventions

12.11.2.1 Research and Development

- Minimizing information asymmetry through focused attention on developing ICT-based systems and methodologies for quick and timely dissemination of information to rural and remote end users

12.11.2.2 Technologies and Practices

- Forging public–private partnership to develop technology-based solutions for providing farmers with information on price discovery, commodity arrivals, mandi prices, etc.
- Partnering with civil society organizations for large-scale deployment of technology for communicating climate change risks to bring about behavioral changes for adopting good agricultural practices
- Preparation of crop-/commodity-specific advisories for different soil and climatic characteristics for the use of farmers to adopt specific packages suitable to weather conditions

12.12 Credit Support

12.12.1 Key Issues

- Developing new forms of credit assessment and risk management systems
- Promoting micro-finance
- Developing mechanisms to enhance the flow of credit to critical infrastructure
- Upscaling the Kisan Credit Card Scheme (KCCS)
- Designing customized credit policies and programs to mitigate risks

Free, untied, and timely credit support to farmers is essential for sustaining farm productivity, especially when it comes to small and marginal farmers. Easy and timely financial incentives and credit (and insurance) packages provided to farmers can help in adoption of improved management practices including resource conservation technologies, agro-diversification, postharvest value addition processes, etc., which would contribute to reducing risks and enhancing farm incomes. This dimension emphasizes efforts to augment the flow of credit to agriculture, alongside exploring new innovations in product design and methods of delivery, through better use of technology and related processes. Facilitating delivery through processors, input dealers, NGOs, self-help groups (SHGs), etc., would help in providing access to credit to the resource poor farmers, especially the small and marginalized farmers, to help them to manage the additional risks from climate change in a sustainable manner.

12.12.2 Interventions

12.12.2.1 Research and Development

- Research on credit assessment and risk management systems.
- Designing customized credit plans and programs to mitigate risks and support higher productivity and production in drought- and flood-prone areas.
- Designing innovative schemes and products which recognize the varied nature of agribusiness and supply chains for different farming systems, food systems, and communities.

12.12.2.2 Technologies and Practices

- Adoption of a customized approach by financial institutions to cater to specific agricultural credit risks and needs of different agricultural sectors and regions
- Creating credit flow for conservation farming, agricultural diversification, and value-added activities
- Developing credit plans with higher component of direct finance and with a special thrust on small and marginal farmers so as to reduce their dependence on informal credit institutions and money lenders
- Providing financial support/incentives to farmers to enable investment/adoption of relevant technologies to overcome climate-related stress
- Upscaling the Kisan Credit Card Scheme (KCCS) to cover all eligible farmers

12.13 Markets

12.13.1 Key Issues

- To formulate market-aligned research and development programs
- Improving supply chain efficiency
- Creation of new market infrastructure
- Supporting community partnerships in developing food and forage banks
- Strengthening access to quality and timely inputs by farmers for mitigating risks

Inadequate marketing infrastructure, presence of large number of intermediaries, lack of market information and intelligence, and inadequate storage facilities result in huge postharvest losses in the food supply chain. Some of the major initiatives that are to be taken up under this dimension include reducing quantitative as well as qualitative losses across the supply chain; creating market-aligned production systems; strengthening climate-resilient postharvest management, storage, and marketing and distribution system; strengthening timely access to farmers to quality inputs; strong farmer–institution–industry interface; and encouraging food processing industries and greater exports.

12.13.2 Interventions

12.13.2.1 Research and Development

- To formulate market-aligned research and development programs for developing higher shelf-life varieties, increasing shelf-life through improved packaging technologies, etc.
- To improve food safety and quality standard through developing domestic standards and/or adopting global standards, strengthening food testing network, etc.

- Developing customized market information, intelligence, and forecasting system for farmers

12.13.2.2 Technologies and Practices

- Improving supply chain efficiency to avoid postharvest and transition losses
- To align production systems with market demand for mitigating the risks
- Strengthening of local market for improving the access of farmers to quality and timely inputs such as seeds, pesticides, fertilizers, credit, insurance, and information

12.14 Adaptation Priorities and Opportunities

The objectives are to outline the approach for identification of potential adaptation options for agriculture and prioritize the potential adaptation options to respond to the climate change. The whole exercise can be undertaken through a workshop in which experts with wide experience on adaptation participate. Experts may be invited from the scientific, technical, and farming communities besides policymakers and youths. The ranking and prioritization of the adaptation options are carried out using the following four steps:

- First, various potential adaptation options based on literature survey are identified and listed for the experts. Additional options are sought from the experts based on their experience and a composite list is prepared.
- Second, the experts are asked to rank (1–5 scale) those options based on the qualitative assessment of each priority. Scores are attached for each of the options and for each of the criteria, ranging from 1 to 5, indicating very low priority (1) to very high priority (5). The number of experts giving a particular rank (1–5) to each option is counted which is multiplied by 1, 2, 3, 4, and 5, respectively, to get the total score. The 10 most relevant options are short-listed based on this total score and subjected to further ranking and prioritization.
- Third, ranking of the options is done based on such characteristics as importance, urgency, no-regret, co-benefits for other domains, and mitigation effect as judged by the experts. The importance (i.e., effectiveness in avoiding damages) of an option reflects the level of necessity to implement that option in order to avoid negative impacts. These options can reduce major damages related to climate change and could generate substantial gross benefits. The urgency of the option relates to the need of implementing the adaptation option immediately or whether it is possible to defer action to a later point in time. "No-regret" options are the adaptation options for which non-climate-related benefits, such as improved air quality, will exceed the costs of implementation; hence, they will be beneficial irrespective of future climate change taking place. The criterion "co-benefit" has been specifically designed to reduce the climate change-related vulnerability while producing corollary benefits that are not related to climate change (Abramovitz et al. 2002). In the effect on mitigation, the adaptation options will also induce a reduction of greenhouse gas emissions and thus score very high on mitigation effect. The ranking is based on a weighted summation of the scores on the criteria (1) importance (weight 40 %), (2) urgency (weight 20 %), (3) no-regret characteristics (weight 15 %), (4) co-benefits (weight 15 %), and (5) mitigation effect (weight 10 %) (de Bruin et al. 2009).
- Fourth, ranking of the options is done according to the feasibility criteria. The feasibility is scored based on the technical, societal, and institutional complexities that accompany the implementation of proposed measures. The following criteria of weightaging are used: technical complexity (20 %), societal complexity (40 %), and institutional complexity (40 %) (de Bruin et al. 2009). Technical complexity refers to the technical difficulties and challenges which accompany the realization of the adaptation option, such as the technical facilities that have to be realized or mobilized; the technological uncertainties which accompany the implementation; and the uniqueness

of the operation and its risks. Social complexity involves the diversity of values which are at stake when the option will be implemented, the changes which are necessary in the perceptions of stakeholders, the necessity of their cooperation, etc. As the institutional complexity of implementing an adaptation grows, there are more adjustments of the official, bureaucratic organizations, existing procedures and arrangements necessary, and more cooperation between institutional separated domains, thus resulting in a bigger tension with existing practices and structures. Scores are attached on 1–5 scale, ranging from very low (1) to very high (5) complexities.

12.14.1 Potential Adaptation Options in Indian Agriculture

A case study from literature and consultations with the stakeholders, 27 adaptation options were identified. A brief description of these options, which potentially can reduce the vulnerability of the Indian agriculture to the effects of climate change, has been provided in Table 12.8. As the options have been taken from the literature or have been suggested by a wide range of stakeholders, they include a large variety.

Out of these 27 potential options, the 10 adaptation options having the highest priority were identified. These options were climate-ready

Table 12.8 Climate change adaptation technologies in Indian agriculture based on literature survey and stakeholder consultation

Adaptation option	Description of the option
1. Climate-ready crop varieties	Crop varieties tolerant to drought, flood, and heat, giving higher yield even under extreme climatic conditions
2. Water-saving technologies	Drip, sprinkler, and laser-aided land leveling to increase water-use efficiency
3. Changing planting date	Changing planting date (early or late sowing) to avoid heat stress during flowering and maturity of crop
4. Integrated farming system	Inclusion of crop, livestock, and fishery in farming system to sustain livelihood, particularly of poor farmers
5. Growing different crops	Growing tolerant/resistant crops to withstand the adverse impacts of climate change
6. Integrated pest management	Combining physical, chemical, and biological methods of pest management
7. Crop insurance	Incentives to farmers for covering risks of climatic extremes
8. Organic farming	Use of organic sources of nutrients, avoiding the use of chemical pesticides
9. Conservation agriculture	Zero tillage, crop rotation, residue cover of soil
10. Precision farming	Precise management of water, nutrients, and pest
11. Improved nutrient management	Site-specific demand-driven and balanced use of nutrients
12. Use of efficient microbes	Use of microbes for enhancing soil fertility and crop productivity
13. Rainwater harvesting	To reduce runoff loss and recharge groundwater
14. Waste land management	Developing wastelands through water and nutrient management for forestry, agro-forestry, grassland, and crop production
15. Improved weather-based agro-advisory	Forecasting of weather, particularly extreme agro-advisory events, for crop management planning
16. Growing crops in polyhouse	Protected cultivation of crops in polyhouse for control of temperature, moisture, pests, etc.
17. Increasing irrigation facilities	Bringing more area under irrigation through minor irrigation schemes, check dams, shallow tube wells
18. Intercropping/mixed cropping	Growing more than one crop to increase productivity and avoid crop failure
19. Creation of seed bank	To provide quality seed to poor farmers, especially useful in case of late onset of monsoon or failure of germination of first sowing
20. Intensifying crop production	Increasing crop production through intensive use of fertilizer and irrigation. This would provide enough food for the years of low production

(continued)

Table 12.8 (continued)

Adaptation option	Description of the option
21. Agro-horticulture, agro-forestry	Agro-horticulture and agro-forestry are more tolerant to drought and flood compared to food crops
22. Cooperative farming	Useful for poor farmers with small landholdings. Farmers joining together can adopt new technologies and bear more risks
23. Use of nanotechnology	To increase nutrient- and water-use efficiency
24. Use of nonconventional energy	Use of solar and wind energy to substitute fossil fuel-based conventional energy sources
25. Use of biofuel	Use of biofuel, particularly from nonedible crops and crop residues, in conjunction with fossil fuel
26. Relocating crops into alternate areas	Identifying the crops and regions that are more sensitive to climate changes/variability and relocate them in more suitable areas
27. Indigenous technical knowledge	Harnessing indigenous technical knowledge of farmers for weather forecasting and crop management

crop varieties, water-saving technologies, changing planting dates, integrated farming system, growing different crops, integrated pest management, crop insurance, conservation agriculture, improved weather-based agro-advisory, and improved nutrient management.

12.15 Conclusions

As climate change unfolds through the early decades of the twenty-first century, adaptation will become the pivotal response to maintain food security and self-sufficiency, to retain vibrant rural communities, and to sustain globally important agricultural exports.

Much needs to be done to enable society to adapt to conditions that are already changing, and to further change, which may now be largely unavoidable. Early preparation to adapt is both sound practice and likely to confer national benefit and competitive advantage under almost any likely climatic outcome. Furthermore, it is highly likely that many of the adaptations developed in one country will have great value in helping other countries and societies to stabilize food production and to offset or avoid some of the more serious consequences of climate change. This is a role for which past contributions and current expertise equip it well to contribute solutions to this global challenge.

Adaptation alone cannot absorb all the projected impacts of climate change, especially over the long term. Some of these can be further avoided, reduced, or delayed by effective reduction in global net greenhouse gas emissions. Agriculture and forestry hold great potential for mitigating greenhouse gas emissions through afforestation, soil carbon management, and better management of livestock and cropping emissions. Making the right energy choices for the future from among our abundant resources and technologies will often be an issue of which energy source, or combination of sources, best suits a particular context. World's greatest need is for low emission technologies that are competitively priced, resilient, and flexible enough to cope with a range of possible future energy challenges and demands. All options are still in the mix for a future energy system with many niches and opportunities.

To adapt to climate change, farmers will need to broaden their crop genetic base and use new cultivars and crop varieties. They will need to adopt sustainable agronomic practices such as shift in sowing/planting dates, use of cover crop, live mulch and efficient management of irrigation, and reduce the vulnerability of soil-based agricultural production systems through the management of soil fertility, reduced tillage practices, and management of the cycle of soil organic carbon more efficiently in grasslands and cropping systems. There will be a need to monitor pathogens, vectors, and pests and assess how well natural population control is working.

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