Climate Change Adaptation Technology Needs Assessment: Agriculture Sector

(Background Paper for Technology Needs Assessment for Bhutan prepared for NEC : National Green House Gas Project Phase II)

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1 INTRODUCTION

This is a background paper on “Climate Change Adaptation Technology Needs Assessment of the Agriculture Sector in Bhutan”. It was felt that there is a need to make a comprehensive review on the sensitivity of the agriculture sector to the climate change concerning impact, vulnerability, adaptation, mitigation options before making recommendations on technology needs. Chapter one provides situational analysis of the agriculture sector in Bhutan. Chapter 2 presents a review on climate change and its impact on the global and regional agriculture and food production. Chapter 3 provides a review of the adaptation options available elsewhere. Chapter 4 discusses the climate change impact on Bhutanese agriculture and proposes adaptation options and strategies including the possible technologies for adaptation and mitigation.

2 SITUATION ANALYSIS IN AGRICULTURE

2.1 Agriculture and its importance

The population in Bhutan is estimated at 678,000 (CSO 2001) with a density lowest in Asia but increasing at 3.1% of the annual growth rate. The RGoB forecasts 2.5% of population growth rate during 9th Five Year Plan (2002-2007). A majority of the nearly 79% of the total population is living in the rural areas engaged in agriculture.

The Renewable Natural Resources (RNR) sector comprising of agriculture proper, livestock and forestry remains the largest and single most sector of the Bhutanese economy, although its share in gross domestic product (GDP) is estimated to have decreased from 45% in 1988 to 35.9% in 2000**.** Its present share of GDP has increased from 35% in 1999 to 35.9% in 2000. The main contribution to growth was due to increase in production of cereal and horticultural crops (CSO 2001). The sectors’ contribution to GDP has increased from Nu. 621.4 million in 1980 to Nu 7769.1 million in 2000. Despite the rapid growth in the electricity and manufacturing sectors, agriculture including livestock and forestry remains the single biggest contributor to GDP at 35.9% in 1999 (CSO, 2001) and is the dominant industry sector with high employment ratio of labour force. There is an increasing trend on the share of the export crops, including mandarin orange, apples, potato, cardamom, and fresh vegetables.

2.2 Basic features of the Agriculture sector

Bhutan is a rugged mountainous country with wide variations in altitude from 150 m to 7,000 m in the high Himalayan zone. Climatic conditions range from wet sub-tropical in the south to

Alpine snow and ice in the north. Owing to extremely mountainous terrain, only about 7.8% of the total land is cultivable mainly consisting of wetland, dryland, tseri, pasture. Most agricultural lands are scattered around small settlements located on hills and valleys. The unique mountain terrain has led to the development of diverse agro-ecologies. Bhutanese farmers practice a subsistence-oriented mixed farming integrating crops, livestock, and forest.

Table 1. Agricultural land use (area in ha)

Land use category	Land Registration Record	RNR Statistics 2000	Land Cover map	Ratio of farm hhs (%)
Wetland	22,010	21,860	38,760	58.9
Dryland	48,310	45,640	97,720	86.9
Tseri and Pangshing	30,460	28,800	88,330	47.5
Kitchen garden	1,060	1,040		25.5
Mixed land*	-	-	84,030	-
Cultivated total	101,840	97,340	308,840	
Orchard	8,660	8,600	2,220	28.0
Plantation	-	-	3,570	
Sokshing**	7,500	7,270	-	
Tsadrok (pasture)	177,750	173,310	156,440	
Total	295,750	286,520	471,070	

*Mixed land of the above 4 landuse types

**Government owned forest land where farmers have rights to collect leaf litter for composting

The farming systems and their component cropping patterns and livestock systems are determined largely by environmental characteristics such as climate, temperature and rainfall. The country can be broadly classified into six main agro-ecological zones based on the altitude, temperature, and rainfall (Table 2).

Table 2: Agro-ecological zones of Bhutan

Agro-ecological Zone	Altitude Range (m.a.s.l)	Annual Rainfall (mm)	Air Temperature		
			Max ^{0}C	Min ^{0}C	Mean ^{0}C
Alpine	3600-4600	<650	12.0	-0.9	5.5
Cool Temperate	2600-3600	650-850	22.3	0.1	9.9
Warm Temperate	1800-2600	650-850	26.3	0.1	12.5
Dry Subtropical	1200-1800	850-1200	28.7	3.1	17.2
Humid Subtropical	600-1200	1200-2500	33.0	4.6	19.5
Wet Subtropical	150-600	2500-5500	34.6	11.6	23.6

Source: MoA, 1992

Within this broad classification, there are considerable variations in climate as a result of aspect, slopes, shading and cloud cover.

2.2.1 The Crop and livestock Production System

The production system is determined by the agro-ecological conditions and topographic features. In the alpine zone, pastoral production system dominates with yak rearing as the main source of livelihood to the semi-nomadic people living in that zone. Crop production is limited to barley, buckwheat, and few vegetables. The herders either barter or sell their yak products like butter, cheese and meat to people in lower areas from where they take cereals and essential household items.

In the cool temperate areas, livestock rearing is still dominant. Farmers rear both cattle and yaks besides other livestock types like sheep and horses. Cattle graze the pastures in summer and yaks in winter. Much more agriculture is practiced here than in the alpine zone. Buckwheat, barley and wheat are traditional crops grown in this zone and potato has become an important cash crop in more recent years. Barley, wheat and potatoes are mostly grown on *Kamshing* (dryland) which are cultivated yearly. Buckwheat and mustard are grown in *Pangshing*, land cultivated after fallow periods ranging from two to ten years. Most of these lands are used for grazing during their fallow period and some of the areas have been brought under improved pastures.

The warm temperate zone is the most productive part of the country agriculturally. A wide range of crop is grown from rice in irrigated areas to barley and potatoes on dryland. Fruit production like apples, pears and peaches have also picked up in this zone as well as cultivation of vegetables like cabbage, cauliflower, chilli, broccoli, tomatoes and many others for the market. While livestock continues to be the main source of drought power and manure, farmers in this zone are also increasingly using farm machinery and chemical fertilisers.

In the dry sub-tropical zone, maize is the most common cereal followed by millets and pulses. '*Tseri*' which is a form of slash and burn cultivation is widely practiced in this zone for growing. In more recent years, cultivation of fruits and vegetables are picking up but moisture becomes limiting for large-scale production. The harvesting of lemon grass, which is a common wild vegetation in this zone has become a very important source of income to the farmers living in this agro-ecological zone. Cattle rearing are also common with free ranching in the forest as a predominant form of herding. Farmers also rear pigs and poultry on a much larger scale than in the upper areas.

The humid and wet sub-tropical zones are very important wetland paddy production areas. Mustard, wheat, pulses and vegetables are grown in rotation with rice on some of the more fertile and warmer areas that have also easy access to markets. A number of tropical fruits like mandarin orange, mango, pineapple, banana, guava etc. are grown in this belt. The terrain is quite fragile with frequent landslides damaging roads and irrigation systems. A significant rice area is under rainfed condition. During monsoon there is too much of rain, while winters are too dry. Where irrigation is possible, vegetables are also grown in autumn or early spring.

The main source of nutrients in all the agro-ecological zones is from the farmyard manure and leaf litter from the forests. In many parts of the country, farmers still grow traditional varieties of crops and follow a traditional cropping calendar that prescribes sowing and harvesting times according to astrology. Farmers strictly subscribe to the timings as they belief that crop damage from inclement weather and pest and diseases can be averted. Very little quantities of chemical fertilisers (only about 4.3 kg of plant nutrient per ha per year) or pesticides are used.

Most agricultural lands are scattered around small settlements located on hill slopes and valley bottoms. These mountainous terrains of Bhutan are characterized by marginality, inaccessibility, heterogeneity and fragility. These features make agriculture and the farming systems complex and labour-intensive leading to high cost of production. Isolation of individual holdings and of area of production from one another and from main market makes the development of a market economy slow and difficult. This factor of mountainous terrain also limits farm mechanization. Climate variability has nevertheless maintained rich native biodiversity.

Tseri, a slash- and- burn traditional farming practice, has been followed in Bhutan, but the Royal Government and the people have decided to discontinue this system because of its negative environmental impacts. The National Assembly, beginning in 1968, discussed the matter and finally in 1994 decided to aim toward ending this system, by emphasizing permanent farming systems.

2.2.2 Land resources

Only about 7.7% of the total land area is available for agricultural purposes. Pressure on the limited irrigated land is very high due to conversion of wetland to other uses such as settlement, industrial growth, expansion of urban centres and cultivation of cash crops. Encroachment into fertile agricultural land for human settlement, model-township, and commercial enterprises will be more severe in future.

With proper care and management, land resources are renewable. However under continuous degradation, the land could ultimately become unproductive. Intensification and associated effects like declining soil fertility, enhanced soil erodability, and general drop in productivity are apparently already visible. Experience suggests that water and wind erosion accounts for the bulk of the land degradation. Hard data on degradation for Bhutan is not available. The amount of topsoil removed by runoff annually in India is around 25 billion tones (Repetto, 1994). Nutrient depletion by loss of this topsoil is estimated to be equivalent to the total quantity of chemicals used over the entire country. Erosion problems could be more severe in Bhutan due to the topography and rainfall.

2.2.3 Forest Resources

The forests of Bhutan form an integral part of the farming system, with forest products being used for fuelwood, fodder, manure and construction materials. Forest also contains plants that are used for medicinal purposes. Large percentage (72.5%) of the country’s total area is under forests. Deforestation has never been a major problem in Bhutan, mainly because of low population pressure and tight state control over forests resources. Forest cover is increasing in many areas of Bhutan due to controls on exploitation and management although there are local differences where problems of re-generation have been observed indicating decline in forest quality. The development and the increasing population are exerting pressure on the forests. Forest resources are also used extensively for grazing, fodder and organic matter collection to sustain agriculture. Sustainable harvesting and maintaining bio-diversity are issues of long-term concern. The new forest policy gives top priority to conservation. The focus, however, is shifting from conservation through government protection to conservation through people’s participation.

2.2.4 Water resources

Irrigation has been one of the crucial inputs to the national agriculture development, particularly in paddy. Its role is the quest for the national food self-sufficiency cannot be over emphasised. With assistance provided to the construction of new irrigation schemes and rehabilitation of older schemes, the irrigation sector has helped increase the overall wetland area and the agriculture production in general. The National Irrigation Policy (NIP) of 1992 has provided impetus to sustainable irrigation development in the country.

Although water is a renewable resource, the maximum amount that can be used during each season is fixed according to the geography and climate of a given location. The rainfall brought about by the South West Monsoon and its distribution in time and space has given rise to two distinct periods of dry and wet seasons. The main rivers that drain the country are not used as sources for irrigation water except in a few schemes in Paro valley. The main irrigation sources are the secondary and tertiary tributaries, which originate in small watersheds and the amount is dependent on rainfall. Due to mountainous topography, the irrigation command areas are small and scattered in nature. Long irrigation channels passing through unstable and difficult terrain connect the command areas. Overall irrigation efficiency is low due to poor conveyance efficiency. Irrigation infrastructure development and maintenance is expensive and difficult due to mountainous terrain.

In the past water was used predominantly in agriculture and, in relatively small quantities, for domestic water supply. Today an increasing demand is being made on the available water resources. In agriculture changes in household and demographic composition, as well as changes in cropping system have led to different demands and an inequitable distribution between water users. Water quantity, equitable access to water, and water quality are expected to become issues of concern in many parts of the country, particularly in small watersheds. In addition to this, an increase in demand from urban areas and the need for hydropower development has created new stakeholders in the allocation of water resources. This, together with concerns about climatic changes, increased pollution and sediment impact, points towards greater water resource management conflicts in the near future.

2.2.5 *Agricultural Inputs*

Inputs such as seeds/seedlings, fertilizers and plant protection chemicals are distributed/sold to farmers through private commission agents appointed by the Ministry. Most of the subsidies on inputs except those for promotional purposes don't exist anymore. The only subsidy is on input transports to maintain uniform cost s throughout the country.

2.2.5.1 Fertilizer

Manure is by far most important source of plant nutrients. Farmers greatly value their livestock for manure production as well as milk and milk products. Additional nutrient are added to the animal excreta, with the lavish use of litter from the forest. However, with the modernization of the agricultural system, use of synthetic fertilizers is increasing.

Farmyard manure (FYM) and artificial chemical fertilizers are two main sources of plant nutrients used by farmers. FYM continues to be the single most important source of plant nutrient with at least 139,000 mt applied to cereals and horticultural crops in year 2000 (RNR Statistics 2000). Farmers also practice tethering cattle in the field. Unlike FYM, chemical fertilizers are mainly restricted to crops with higher returns such as paddy, potato, chili and tree crops such as apples and oranges. Close to 30 percent of the households reported to have used chemical fertilizers amounting to 1800 MT. Urea, suphala and SSP comprise bulk of the amount used although MoP, CAN, bone meal and borax are also applied in minor quantities.

Wetland soils are generally low in N, low to medium in P and medium to high in K. In the wet subtropical zone, low K has been reported. At present, plant nutrients are mostly derived from organic resources. About 6-7 tons of FYM is normally applied.

The potential for yield increase due to more/better use of mineral fertilisers is enormous: local rice yields can be increased by 68-47% depending on the zone. The yield of improved rice varieties can be increased a further 30-32% if improved fertiliser practices are practised. Yield levels of up to 6 tons/ha are achievable. These data are based on a set of 66 on-farm fertiliser trials conducted in 1999n by NSSC.

However, fertiliser use is in Bhutan is one of the lowest in Asia: only about 4.3 kg of plan nutrient per ha of cultivated land. In the main rice growing valleys, the adoption rate of fertiliser is about 30%. Of all fertiliser distributed in the country (about 13000 tons annually), 20-30% is applied on rice.

In short, given the levels of low fertiliser use and the demonstrated contribution of mineral fertiliser in increasing yields, the improved and increased use of fertilisers has great potential to boost rice production in Bhutan. It should be noted though, that, especially in the sub-tropics, mineral fertiliser alone will not suffice, and additional biomass has to be produced and recycled on the farm.

2.2.5.2 Plant Protection Chemicals

Consumption of plant protection chemicals has drastically reduced over the years as a result of

- Removal of subsidy on PP chemicals
- Removal of several hazardous groups of chemicals off the market for environmental concerns, and
- introduction of IPM practices for the control and management of diseases and insect pests

According to RNR Census 2000, only 30 percent of farm households have applied insecticides on cereals and horticultural crop and another 13 percent applied fungicides mainly in apples. About 22 percent of the farm households have applied herbicides on paddy.

In the recent development plans for the agriculture sector, stress is placed on improvement in the crop yield instead of increasing arable agriculture land; phasing out traditional livestock rearing with improved breeds, and permanent pasture development.

Shifting cultivation, a system of subsistence agriculture involving clearing of forests and cultivating the land for a few years, is practiced in an estimated 883 km3 (UNEP, 2001) in different parts of the country mostly on steep slope. This has also contributed significantly to the degradation of land.

Some of the natural resources like arable land and livestock are privately owned, while others such as forest areas, water, grazing are community controlled. Community involvement in managing communal land, communal pasture, and irrigation water are age-old practices. However, these systems are eroding due to commercialization of rural economy, changing institutional environment, and the increased pressure on natural resources.

2.3 Food Production

2.3.1 Cereal production

Major staple food crops of Bhutan are rice and maize, followed by wheat, barley, and buckwheat, and millet as minor crops. The production of cereal crops is given on Table ---- . Total domestic cereal production in 2000 was 158,638 mt. Of cereals, rice and maize are the principal crops, with production levels of over 68,000 and 77000 mt respectively, and jointly accounting for 91% of total cereals produced. The remainder is accounted for by wheat, buckwheat, barley and millet.

Rice continues to be the preferred staple food in Bhutan. Atleast 19,000 acres of irrigated land are known to be under paddy cultivation contributing to 42 percent of the cereal production. While area under paddy cultivation has been reduced as a result of loss to urban expansion, industries and government infrastructure developments on irrigated lands, yield per unit area has increased from **2.5 t/ha in 1997 to 3.6 t/ha in 2000.** Punakha, Sarbang, Samtse, Wangduephodrang, Paro and Tsirang are the largest paddy producers and together they contribute to 61 percent of rice production in the country.

Atleast 72 percent of the maize production comes from the six eastern Dzongkhags where maize predominates and is also the staple food of the people. With the introduction of improved varieties, overall maize yields have increased from **548kg per acre in 1990 (post Enumeration Survey 1990) to 631kg per acre in 2000.**

Wheat and Barley are generally grown on dry lands but it is also cultivated in rotation with rice. While significant part of the wheat crop is generally cut as green fodder for cattle, the remaining is harvested to supplement food consumption. Wheat and barley together contributed to 6 percent of cereal productions. Millet is grown under rain fed condition in marginal lands by about 17 percent of the population. Two different types include foxtail and finger millets. The latter is widely grown in the south and in the mid- hills partially for brewing and as a food supplement. In certain pockets of Pemagatshel and Mongar, the foxtail millet locally known as *Yangra* is a staple food.

Table 3. Cereal production and harvested area

Cereals	Harvested area (ha)	Yield kgs/ha	Production (mt)	Major producing Dzongkhags
Rice	19,148	3,581	68,573	Sarpang, Punakha, Samtse, Wangdue
Maize	31,137	2,483	77,298	Trashigang, S/jongkhar, Mongar
Wheat	4,688	928	4,352	Wangdue, Paro, Punakha
Barley	1,498	1,158	1,735	Mongar, Bumthang, Wangdue
Buckwheat	3,529	818	2,887	S/Jongkhar, Bumthang
Millet	6,167	615	3,793	Samtse, Sarpang
Total	66,167	2,398	158,638	

Source: RNR statistics 2000

Cereal dominates the Bhutanese diet composition accounting for 75% whereas, non cereals, including livestock products accounts for only 25%. Traditionally nine food crops were recognised known as "*the dru-na gu"*. These are rice, maize, wheat, barley, buckwheat, millets, amaranth, mustard and pulses.

The country is virtually self- sufficient in maize and minor cereals but only about 50% self sufficient in rice. In aggregate, the country is about **65 % self- sufficient** in cereal requirement, close to the Government self- sufficiency target of 70%. Cereal production basically remains at subsistence level. Most of the production is consumed at farm level and it is estimated that only 4.8 % of domestically produced cereals is marketed, including in the form of barter for livestock products. One major constraint to increasing marketable surplus is the difficult terrain in the country and lack of access to markets. Therefore there is very little incentive to produce more than that needed for home consumption. Crop failures through insects and other pests also appear to be localized and exceptional, although yields are regularly depressed because of depredation by wild animals. The instability of food supplies that are of emergency nature are tackled by making food supplies available from the reserve stock held by FCB. The gap between domestic cereal supply and aggregate demand, which to a great extent represents urban demand, is met by imports from India. Rice imported in 1999 was 38000 mt to a value of about Nu. **235 million**. The demand for rice is rising in both urban and rural areas.

2.3.2 Horticultural cash crop production

The RGoB is promoting development of horticulture as cash crop for income generation. Mandarin orange, apples, potato, cardamom, and vegetables are the major cash crops. The production status according to RNR statistics 2000 is given on Table .

Table 4. Production of major horticultural crops (Fruits and Nuts)

Crop	Nos of trees	Bearing trees	Production (mt)	Major producing Dzongkhags
Apple	368,388	197,000	5,133	Thimphu, Paro
Orange	1,761,005	907,000	29,616	Samtse, Chukha, Tsirang, Sarpang, S/Jongkhar
Arecanut	357,469	142,000	1,330	S/Jongkhar, Sarpang, Samtse
Walnut	36,729	6,000	235	All Dzongkhags except Samtse, Gasa, Tsirang, Trongsa

Plum	8,922	5,000	281	All Dzongkhags except Samtse
Pear	12,580	8,000	718	All Dzongkhags except Gasa
Peach	29,439	21,000	1,091	All Dzongkhags
Guava	26,927	17,000	664	All dzongkhags Ha, Paro, Gasa, Bumthang

Source: RNR statistics 2000

Table 5. Production of Vegetables/Spices

Crop	Harvest area (ha)	Production (mt)
Potato	3,122	35,436
Chilli	937	2,849
Radish	779	3,384
Turnip	349	2,615
Ginger	626	1,267
Beans		1,151
Brinjal		197
Carrot		150
Cassava		827
Peas		626
Rajma Beans		354
Sag		521
Tomato		333
Garlic		430
Onion		285
Cardamom		510

Source: RNR statistics 2000

2.3.2.1 Tree crops

Atleast 2.6 million trees of apples, oranges, walnuts, plums, pears, peaches, arecanuts and guavas exist in the country. Major commercial crops are oranges, arecanuts in the sub-tropics and apples in the temperate areas. Altogether, they account for 96 percent of the horticultural trees planted and 92 percent of the production. A total of 36,100 mt of fresh orange, apple and acrecanut have been produced in year 2000.

Mandarin orange shares 68 percent of the number of horticultural trees planted and 85 percent of the production as the leading crop. About 77 percent of the production comes from the five major orange producing dzongkhags of Sarpang, S/Jongkhar, Samtse, Tsirang and Chhukha. Production is expected to increase substantially in the next few years as 51 percent of non-bearing orange tree come into fruiting and as cultural management improves. Presently, a tree on an average, produces 33kg, which if managed better have potentials to increase further.

Apple accounts for 14 percent of all horticultural trees planted and 13 percent of all fruits produced. Apple cultivation is mainly restricted to Thimphu and Paro valleys where 86 percent of the apple trees and 89 percent of the productions are found. With only 53 percent of the trees bearing, potentials exist in the next few years to increase yield levels as non-bearing trees come into fruiting and management further improves. The current average yield per tree is 26 kg.

Arecanut is an important cash crop in the foothills with an annual production of about 1330 Mt produced from 40 percent of trees that have reached bearing stage. Major arecanut producing Dzongkhags are Samtse and Sarpang. High demand within and outside the country continue to support arecanut industry as a profitable business.

Other fruits, which are less important include guava, walnut, pear, peach and plum.

2.3.2.2 Vegetable Crops

A variety of vegetables are cultivated in the country mostly on subsistence level, contributing substantially to family's nutritional requirements. Major ones are chili, radish, turnip and potato. the latter, which is exported to neighbouring countries on large scales. Vegetables like cabbage cauliflower, peas, beans have a comparative advantage as off-season crop for the neighbouring markets in India and Bangladesh and large quantities are sold.

Potato cultivation has spread to all parts of the country and has become an important source of cash income to the farmers mainly in the west, central and in the east. Potato is dry-land crop although farmers in Paro valley do cultivate in wet lands preceding rice cultivation. Wangduephodrang, Trashigang, Chhukha, Bumthang, Paro and Monger together contributed to 79 percent of 35,437 MT potato produced in the country. Almost 70% of the produce is exported to India. The national average yield of potato is 4,593 kg acre while the highest yield level reported is 6732kg by Wangdue Dzongkhag

Chili forms an important part of the family diet and also as an important source of cash income to the farmers. Chili is cultivated in both dry and wet lands mainly in the mid hills from the west to east. Chilies popularly grown are large in size, fleshy, and mild hot good for preparation of ema datsi, an important part of Bhutanese diet. In 2000, chili harvest was severely affected by chili wilt across the country although no report of the same has been made in the year 2001. Only 2,900 MT of chili was produced on an average of about 1,230 kg fresh yield per acre.

Ginger is a sub-tropical crop cultivated mainly in the foothills. About 1600 acres of ginger was cultivated in 2000 producing 1300 MT. It is an important cash crop generally sold off to local and neighboring markets in India. Its major risk is its volatile market prices. Local consumption level is minimal and processing facilities for ginger non-existent. Garlic and Onion are grown in small quantities primarily to meet home consumption.

2.3.2.3 Export commodities

Important agricultural export commodities produced in Bhutan include mandarin oranges, apples, cardamom, potatoes, which together account **for 48% of total export** earnings. In addition to these, the country also exports a variety of fresh vegetables and processed fruits, as well as timber and wood products.

During **1999/2000, total foreign exchange earnings from these items were about Nu ------- million- a significant increase over the level in 1989 (Nu --- million) and in 1996 (Nu ----- million).**

Table 6. Import ant horticulture export commodities and earnings (in 2000)

Crop	Quantity exported (mt)	Value (Nu in million)
Apple	2,398	50.0
Orange	16,000	137.6

Potato	24,000	149.0
Cardamom	510	54.8
Ginger		
Arecanut		
Vegetables		11.0
Mushroom?		
Soyabeans?		
	Total	**402.4**

Source:

As a result of this increase in export earnings, the country continues to enjoy a positive trade balance in its agricultural trade, excluding livestock products. It also appears that the role of horticultural produce (apples, oranges, cardamom, potatoes and other fruits and vegetables) is rapidly increasing, not only as a source of foreign exchange but also as an important source of cash income for farmers.

2.3.3 Livestock production

Livestock sub-sector is essential for farm households for income source, draft power, and diet for inhabitants. Cattle husbandry is a major activity in livestock. The livestock population is given on Table------. Average number of cattle per household is around 4 heads.

Table 7. Livestock population in Bhutan

	Total nos of animals	% of households owning
Cattle	320,500	77.5
Buffalo	1,800	0.8
Yak	34,900	2.2
Horse	23,300	23.8
Mule	4,300	-
Donkey	300	-
Sheep	22,900	5.8
Goat	31,328	15.7
Pig	41,401	37.5
Poultry	230,723	65.5

Some 78% of rural households own cattle.

The productions of major livestock produces in 2000 include 4,837 MT milk, 1,316 MT butter and 2,173 MT of cheese, 1

The aggregate output in 2000 of livestock products was estimated to be roughly 25000 t of milk, 1316 t of butter and 2173 t of cheese, 700 MT of meat inclusive of beef, pork, mutton and chicken and about 17 million eggs (RNR Statistics 2000). The production is much below the level of demand for these products. While the low level of output of milk products is largely associated with the low milk yield from traditional dairy breeds, there are a number of reasons for the low level of meat supply. These include cultural and religious aversion to slaughtering animals, and the problem of establishing viable, commercial- scale production for relatively small and depressed urban markets. High transport costs and inadequate slaughtering, processing and cold storage facilities also play a part. For religious and cultural reasons, domestic cattle are seldom slaughtered, nor are households willing to sell their cattle for slaughter.

In addition to cattle, poultry and pigs are also kept in small numbers by nearly every household. Poultry are kept for egg production and rarely reared for meat. The production of milk and milk products is carried out as a sideline to other agricultural activities, and hence the quantity produced is very small, mainly for home consumption. In most rural areas, standards of husbandry and disease control, as well as the lack of adequate availability of suitable feed, are constraints to increasing milk yield, despite the Government’s effort to replace traditional breeds of cows by high yielding, improved breeds.

Local supply of milk, butter and cheese thus meets a small proportion of the market need in urban areas. Efforts to establish milk cooperatives have not been very successful. The requirement for meat and livestock products in Bhutan is thus met largely by imports from India. In comparison with the few hundred domestic cattle slaughtered, estimates of imported cattle amount to about **5000 head in recent years, to meet the growing demand for beef.** The cattle which are imported from India are slaughtered in the two main border town slaughter centers, Phuntshiling and Samdrup Jongkar. (**give QCRS data**)

The value of livestock and livestock product imports in 1990 were estimated to be Nu: 44.8 million, which offset the positive trade balance of about Nu: 33.2 million between agricultural exports and cereal imports.

2.4 Food insecurity issues

Food insecurity is the lack of access to sufficient food for the needs of an active and healthy life. Food insecurity may be chronic, transitory, or seasonal.

Type of food insecurity	Causes
Chronic food insecurity Constant lack of access to adequate and balanced food, manifesting itself in chronic under nutrition. Chronic food insecurity and under nutrition are mainly associated with poverty, and reflect the inability of the households to produce food in adequate quantity and variety, or the inability to earn sufficient cash income to purchase adequate food.	• Lack of insufficient land holding • Lack of alternative income generating rural activities • Lack of employment opportunities
Transitory food insecurity Temporary lack of access to adequate food, owing to adverses crop failures, marketing problems, food import problems, sudden fall in household income or high level of inflation, all of which reduce purchasing power of household cash holdings.	• Absence of food grain reserves at household, regional, or national level • Lack of adequate foreign exchange reserves at national level to import food • Lack of transport or transportation related problems
Seasonal food insecurity	• Rural households do not produce enough

Lack of access to adequate food in certain periods of the year, such as during 2-3 months before harvests	food for their annual consumption. • Rural households sell part of their production immediately after harvest for various reasons, including need for cash income. • Lack of good storage facilities

In Bhutan, prevalence of chronic food insecurity is low (MoA 9th Plan). However, transitory and seasonal shortages do occur. Farmers generally run low on their food reserves from March through June during which old stock would have been exhausted or is at minimum level while new harvest is not ready (RNR Statistics 2000). A food security survey undertaken in 1993 showed that there is high incidence of chronic and transitory food insecurity in the northern and South-eastern parts of the country (FAO 1994). This study identified the following groups as vulnerable or food insecure:

People in remote areas who depend on their own production of field crops. These groups include the subtropical maize producers, cold temperate cereal producers, the high altitude communities, and the high altitude pastoralists.

Small scale land holders, share croppers, including those with no land of their own, or only owning part of the land that they operate

The landless, including low wage workers, road maintenance and forest workers, seasonal agricultural workers, herders, petty traders.

The urban unemployed and school leavers.

The findings of the case studies show that amongst the poorest households of the less agriculturally productive zones (Thimphu and Mongar) are able to meet their minimum food needs of 2100 k cal/person/day (WFP 1999). The characteristics of the poorest households and least food secure pointed out by this study include:

Households with no assets, land or animals, who depend entirely on their labour for an income

Households who have no assets and are also labour poor

Labour poor households with limited land in isolated and low productivity areas, who because of strong traditional beliefs and attachment to their land will not leave in search of income.

2.5 Major challenges in food and cash crop production

The following major challenges confront the country's food sector (MoA 2001 9th Plan):

2.5.1 Loss of agricultural land to other forms of land use

Encroachment into fertile agricultural land for human settlement, model-township, and commercial enterprises will be more severe in future. The expansion or relocation in some cases, of the present urban centres and creation of service facilities and public amenities for the growing population will in all probability lead to encroachment of arable land

Although farm land is the most fundamental resources for agricultural production, it has been on a continual decline due ton its transfer to non-agriculture use. Farmland once lost is difficult to recover. If continued will lead to a further decline in food supply capability.

2.5.2 Shortage of farm labour

Farm households throughout the country report labour shortages as a major constraint and it is anticipated that this trend will increase in agriculture. Food production in Bhutan is labour intensive. Emphasis on increased education, off-farm employment opportunities, and changing values are leading to out migration from rural to urban areas.

The fragmented rural land holdings, limited opportunity for mechanization, and the traditional management system and wildlife guarding are the main factors that make farming in this mountain environment very labour intensive. A lack of sufficient workforce for an extended period of time in the family has also been a cause of poverty mainly due to the rural-urban migration.

2.5.3 Poor rural access and market infrastructure, and

The lack of proper road infrastructure has been identified repeatedly as the most critical obstacle for increased agricultural production due to high transportation costs that severely reduces farmers' incentives to produce and market their surplus.

2.5.4 Depredation of crops by wildlife

Wildlife depredations of crops is increasingly threatening food production and rural livelihood. According to the RNR Statistics 2000, wild animal damage ranked as the leading factor for substantial amount of food grain losses in rural areas. Results based on the farmers' own assessment reflects wild animal damage as the main problem of farming. Atleast 42 percent of farm households on an average have reported wild animal damage. Worst among all, is the wild boar damage rampant throughout the country. Bumthang, Haa, Trongsa, Zhemgang, Mongar, Yangtse, Pemagatshel and S/Jongkhar experienced maximum losses where more than 50 percent of the farm households reported wild animal damages. About 37 percent of farm households attributed damage to wild boar only. Other sources of wild animal damage include monkey, deer, elephant, bear, porcupines and birds.

The lessons learnt have been very useful to guide development of agriculture in Bhutan. Environmental concerns have always been considered important in developing strategies and programmes. Modernized farming under Bhutanese context involves use of moderate to low-level inputs for reasonable increases in production, though this may not necessarily lead to attainment of the food self-sufficiency goals.

Food security remains a key issue, and given the fragile environmental conditions, changes in production system or management can reduce or accelerate degradation of resources. The need to continue research on how to improve production while maintaining the quality of the resources is critical.

The policy of the RGoB is to ensure that the rich endowment of the country is preserved and that development remains sustainable. Thus, fortunately for Bhutan, environmental planning precedes environmental degradation; the principle of sustainability integrated in all government policies. Nevertheless, a number of environmental concerns remain apparent and appropriate measures are being adopted to address the problems. The challenge now is to balance conservation and socio-economic development of people. Conservation in the long run will need to be self-sustaining and supported by local people.

Some of the environmental concerns and issues of the agricultural sector are as follows:

- Increasing conflict between conservation and farming;
- Increasing demand for timber and wood products;
- Increasing commercialization of non-wood forest products;
- Increasing loss of forest land for industrial estates and development activities such as roads;
- Sustainability of conservation and protection measures.

2.6 Policy Objectives of the RNR Sector

Within the nation's policy framework guided by the principle objectives of self-reliance, conservation of environment, sustainability, efficiency and decentralization, the following are the RNR sector's policy objectives outlined for the 9th Plan include:

- Attainment of National Food Security
- Conservation and Management of natural resources
- Enhancement of rural income

- Generation of employment opportunities

2.6.1 Food Security

The RGoB has been consistently pursuing food security policy objective. The objective of national food security (MoA 9th Plan) has three aspects and is an essential element of national self-reliance fundamental to the enhancement of Bhutan's sovereignty and security (MoA 2001):

- Maintenance of a broad national self-sufficiency whereby the export of crops for which Bhutan has comparative advantage provides sufficient foreign exchange to cover the cost of food imports.
- Maintenance of a minimum of 70% self-sufficiency in food grain production
- Strengthening of household food security by ensuring all family members have access to adequate food at all time required for a healthy and productive life.

Self reliance built on high degree of self-sufficiency has featured strongly in the FYPs. The RGoB has always viewed self-reliance for national integrity and security. Even if market logic suggests that it is more efficient to focus on other commodities and import cheaper rice, the long-term implication of declining self-sufficiency in this strategic commodity is potentially high. Therefore, for food security reasons it is not always a matter of comparative advantage.

The Royal Government has adopted a policy of food security through a two-pronged strategy: by increasing production of cereals to achieve at least 70% self-sufficiency and by promoting exportable cash crops and use the revenue earned to offset the cost of food imports.

Food is not only indispensable to human beings but also fundamental to their physical and mental health. The stability of society and the people's peace and health heavily depend on a stable food supply. Agriculture, as the food production base has to be established as an invulnerable industry in Bhutan's free, productive economy and society. Rural communities are required not only to secure the food production base through its maintenance but also to preserve the land and the environment.

The Royal Government continued to give a high priority towards increasing food production in the past Plans. The concern over food security stems from the increasing demand due to population growth and continued reliance on the imported food grains. The domestic production should supply food as much as possible with improvements made to the productivity of agriculture because increasing dependence on imported food would further weaken the domestic food supply structure.

Therefore it is necessary to secure the food supply capability of domestic agriculture by ensuring and improving the current state of farmland and utilizing it effectively, maintaining and managing irrigation systems properly, securing and fostering workforce, and improving the agricultural technology level.

The development approach adopted during the 9th FYP will be in line with the Government's initiatives to commercialize horticulture development. Emphasis will be given on commercialization of the horticulture industry in both the existing horticulture area as well as in potential pockets that can be linked by farm roads. Attention will also be paid to private sector as well as grower groups/associations/cooperatives' initiatives in developing necessary services systems like specialized produce handlers, produce transporters and packaging.

The backyard horticulture production in the remote areas will continue to receive general services so that the policy objective of improved nutrition will be addressed but this will be treated more as complementary to the food security programmes.

The increasing pressure on land has led to the growing incidence of soil erosion and declining farm productivity. The cultivation of perennial horticultural crops on slopes will protect the soil from erosion, provide cash income and positively contribute to economic development hence minimizing rural-urban migration.

2.6.2 Enhancement of Rural Income

The sector has to play a lead role in the alleviation of poverty in the country and aims to alleviate poverty and raise the standard of living through the development and promotion of programmes related to horticulture, livestock enterprises and other income generating activities by ensuring that

- Appropriate, viable and ecologically sustainable agricultural technologies are available;
- Rural communities have access to the benefits provided by the market; and
- An enabling regulatory framework is in place, which allows economic activity to flourish while ensuring that sustainable production systems are in place.

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2.6.3 Generation of employment opportunities

With 79% of the population living in the rural areas and engaged in activities based on the natural resources, the sector will contribute towards addressing the problems of increasing unemployment and the negative impacts of rural-to-urban migration.

With the increasing trend of rural- urban migration, the employment pressure will increase on the modern sector. This is likely to exert tremendous pressure on the government to generate employment but also over stretch its resources for providing basic amenities in urban areas. It is not likely that substantial employment opportunities will be generated in the industry and service sectors. Due to its poor labour capital, difficult transport and communication systems and fragile environmental conditions, Bhutan may not be competitive at all in the manufacturing or industrial sector. Even the industries that may be viable are likely to be dependent on raw material supply from the RNR Sector, such as wood, agricultural produces, herbs and water. The absorption capacity in the service industry is limited because of the country's small consumer population.

Therefore, the objective of creating employment opportunities in rural areas has two purposes:

- to sustain current levels of employment and halt rural urban migration and thereby alleviate economic and social problems from urbanisation and unemployment;
- To generate new employment opportunities in rural areas and establish agriculture as the basic sector for sustaining the country's economy.

The MoA will continue to address the problems of increasing unemployment and rural-urban migration through:

- Making agriculture economically attractive and improving the social status and image of farming through the introduction of appropriate technologies and development of farm infrastructure.
- Creation of lucrative investment and employment opportunities through the fostering of enabling legal and financial environments.
- Provision of training in the adoption of farming technologies and farm-business skills to farmers and youth.

During the 9th FYP, the MoA will embark on the following strategies to sustain and create employment in the rural areas:

- Promote agro and wood based industries in rural areas to generate off-farm and off-farming season employment;
- Promote agro and eco-tourism to generate off-season employment and income from proving goods and services to tourists;
- Provide vocational training for educated youth in farm businesses and facilitate them with access to loan and land; and
- Establish agricultural schools to re-orientate youth to agriculture and rural life.

2.6.4 Conservation and Management of Natural Resources:

The protection of the country's mountain environment and its unique flora and fauna for future generations is an important objective of the Royal Government. This requires the utilisation of natural resources, including forest, land, biodiversity and water resources in a sustainable way and involves trade-offs between short-term economic gains and sustained long-term economic development. The protection and management of forest areas, improved land husbandry practices in agriculture are essential to achieving this objective.

The conservation of the natural environment relates directly to the long-term sustainability of the major income earners including hydro-power, tourism and other natural resource-based industries. It also means that the potential for the development of such sectors are nurtured through the conservation efforts put in by this sector. In future Bhutan's forests could also be traded off as carbon sinks with the potential to fetch attractive prices in the world market. These services continue to be rendered but are not directly compensated for right now.

2.7 Priority areas for the 9th Plan

Based on the situation analysis discussed above, following priority areas have been identified for the 9th Plan for the Ministry of Agriculture:

- Enhancing household and national food security
- Enhancement of rural livelihood and income
- Development of farm infrastructure
- Development and organization of farm-business and wood-based industries
- Conservation and utilization of natural resources
- Development of internal and external markets for farm produce and products

2.8 Strategies for the 9th Plan

The priority programmes identified will be implemented through adoption of the following strategies:

- Creation of enabling policy and legal framework
- Improving planning and management of programmes
- Improving monitoring and evaluation of programmes
- Generation of appropriate technology
- Delivery of extension services
- Creation of enabling financial environment
- Delivery of inputs to the farmers
- Mechanization of farms
- Enhancing markets for primary products
- Developing adequate level of vital infrastructure

- Diversifying the economic base of the sector
- Enhancing the integrity of the natural resources
- Promotion of economic growth and development
- Strengthening human resources and capacity building
- Introduction and adoption of information technology
- Mobilization of financial resources
- Strengthening administrative and financial management of Programmes

3 REVIEWS ON CLIMATE CHANGE IMPACT, ADAPTATION AND VULNERABILITY

3.1 Agriculture and food security

Agriculture is the world's food and fiber-producing industry. It includes both traditional farming and intensive livestock and crop production. Agriculture also covers enterprises concerned with the development, manufacture and distribution of commodities such as animal feeds, crop seeds, fertilizers, agricultural chemicals, veterinary products and machinery. Among the most frequently cited human systems likely to be affected by climatic change are agriculture. It is especially sensitive to the consequences of global warming as it relies heavily on the weather and climate. Climate change presents a challenge for research the impact on agriculture, due to the global scale of likely impacts, the diversity of agricultural systems, and the decades-long time scale.

One of the foremost goals for global agricultural in coming decades will be expansion of the global capacity of food and fiber in step with expansion of global demand (Reilly et al. 1996). Agricultural production and trade policies also affect food availability and food security. There is a widespread tendency for high-income countries to maintain policies that effectively subsidize agricultural production, whereas low-income countries generally have policies that tax or discourage agricultural production (Schiff and Valdez, 1996). Many low-income countries also purse policies that promote food self-sufficiency. Although all of these policies tend to reduce agriculture resource utilization, they have not changed long run trends in global supply and demand (Antle, 1996a).

Degradation of natural resources—taken here as soils, forests, marine fisheries, air, and water—diminishes agricultural production capacity (Pinstrup-Andersen and Pandya-Lorch, 1998). Soil degradation emerges as one of the major challenges for global agriculture. It is induced via erosion, chemical depletion, water saturation, and solute accumulation. In the post-World War II period, approximately 23% of the world's agricultural land, permanent pastures, forests, and woodland were degraded as defined by the United Nations Environment Programme (UNEP) (Oldeman et al., 1991). Various estimates put the annual loss of land at 5-10 Mha yr^{-1} (Scherr and Yadav, 1997). Although irrigated land accounts for only 16% of the world's cropland, it produces 40% of the world's food. There are signs of a slowing in the rate of expansion of irrigation: 10-15% of irrigated land is degraded to some extent by water logging and salinization (Alexandratos, 1995). Degradation of natural resources is likely to hinder increases in agricultural productivity and could dim optimistic assessments of the prospects of satisfying growing world food demand at acceptable environmental cost. Multiple pressures are being exerted on the agricultural sector, including the need to meet rising demand for food and fiber, resource degradation, and a variety of environmental changes.

Food insecurity appears to be the primary concern for Asia. The vision for a sustainable agriculture sector firstly aims at increasing the productivity so that agriculture remains a key source of economic development, and employment. Crops would be diversified to become less vulnerable to changes in market conditions and climate.

3.2 Climate Change

The changes in climate of earth during the past few decades have become the focus of scientific and social attention. The Inter-Governmental Panel on Climate Change (IPCC) of the United Nations in its recent report has again confirmed the global warming trend and projected that the globally averaged temperature of the air above the earth's surface would rise by 1.4 – 5.8^{0}C over the next 100 years (IPCC, 2001). This change would be much larger than any climate change experienced over at least 10,000 years. Although forecasts of regional global warming are still far from precise, the warming expected by 2050, without any deliberate mitigation, is estimated to be 1.4^0 C above the 1961-1990 average (IPPC 1996). About 0.25^{0}C has already occurred by the 1990s. Observations in Europe have revealed that the average annual growing season (changes in phenology) of plant crop has lengthened by 10.8 days since the 1960s, these shifts can be attributed to changes in air temperature (Menzel and Fabian 1999).

Over the past century, the average annual temperature in the Temperate Asia increased by more than 1°c. This increase has been most evident since the 1970's; seasonally, the warming is evident mainly in winter. Subregionally, over the past 100 years, there has been a 2-4 oc temperature increase in eastern and north eastern temperate Asia and a 1-2oc emperature secrease in some parts of southeastern China, except for the coastal area. These trends also are reflected in corresponding seasonal temperature distributions, except that summer temperatures in central Siberia actually are decreasing.

The most imminent of the climatic change of the earth in recent times is the increase in the atmospheric temperatures due to the increased levels of carbon dioxide (CO_2) and other greenhouse gases. The quantity of rainfall and its events has also become more uncertain. In certain places, climatic extremes such as droughts, floods, timing of rainfall and snowmelt have also increased. All these changes have been ascribed primarily to the combustion of fossil fuel and land use changes. The magnitude of projected changes in temperature, rainfall and carbon dioxide in future for different parts of the world, including South Asia, as simulated by various general circulation models has been compiled by the IPCC (Watson et. al., 1998). According to this, by 2010 CO_2 level will increase to 397 - 416 ppm from the current (2000) level of approximately 368 ppm. This will further increase to 605 - 755 ppm by 2070. There is considerable uncertainty in the projected magnitude of change in rainfall and temperature.

3.2.1 Mountain and upland regions

Scenarios of climate change in the mountainous regions of the world are highly uncertain; they are poorly resolved even in the highest-resolution GCM's (IPCC 1996, WGII, section 5.2). A few impact studies have been carried out in the mountain regions of tropical Asia, where topography and elevation also have an important influence on the regional climate.

In Nepal, Bhutan, and northern India, for instance, mountains provide food, fuel, and fresh water- which are needed for human survival and are fundamental resources for tourism and economic development. Tourism contributes about 24% of Nepal's foreign-exchange earnings (HMGN, 1992). Seasonal variations in the water resources of Nepal's Himalaya region are very high: the maximum-to-minimum discharge ratios for the Karnali, Sapt Gandaki, and Sapt Kosi Rivers are 120:1, 180:1, and 105:1, respectively. This variation is due to mainly to heavy and concentrated rainfall during a short time period; steep topography, which encourages higher surface runoff; and the high rate of deforestation in the watersheds **(Uprety, 1988).**

At high elevations in the Himalayas, an increase in temperature could result in faster recession of glaciers and an increase in the number and extent of glacial lakes-many of which according to **Watanabe et al (1994),** have formed in the past several decades.

Damage from floods takes several forms, including the destruction of footbridges that often provide the only link between remote mountain villages; demolition of irrigation diversions; mass-wasting by undercutting of steep, stream- adjacent slopes; and damage to floodplain agricultural land by erosion and sedimentation **(Marston et al,1996).**

The effects of climate change on soil erosion and sedimentation in mountain regions of Tropical Asia may be indirect but could be significant. An erosion rate in the range of 1-43 tons/ha-with an average of 18 tons/ha- was calculated in three small experimental plots in central Nepal. Over the 3- years period of the experiment, 40-96% of the annual losses occurred during two storms **(Carver and Nakarmi, 1985)** Part of the generated sediment may be deposited on agricultural lands or in irrigation canals and streams, which will contribute to a deterioration in crop production and in the quality of agricultural lands (IPCC 2001 Ch 11).

Climate change will impose significant stress on resources throughout the Asian region. Asia has more than 60% of the world's population; natural resources already are under stress, and the resilience of most sectors in Asia to climate change is poor. Many countries are socio-economically dependent on natural resources such as water, forests, grassland and rangeland, and fisheries. The magnitude of changes in climate variables would differ significantly across Asian sub regions and countries. The region's vulnerability to climate change is given below for selected categories of regions/issues.

	Central Asia	Tibetan Plateau	Temperate Asia	Tropical Asia (South Asia)
Food and Fibre	Highly Vulnerable	Slightly or not Vulnerable	Highly Vulnerable	Highly Vulnerable
Biodiversity	Moderately Vulnerable	Highly Vulnerable	Moderately Vulnerable	Highly Vulnerable
Water resources	Highly Vulnerable	Moderately Vulnerable	Highly Vulnerable	Highly Vulnerable
Coastal Ecosystems	Moderately Vulnerable	Not Applicable	Highly Vulnerable	Highly Vulnerable
Human Health	Moderately Vulnerable	No information	Highly Vulnerable	Moderately Vulnerable
Settlements	Moderately Vulnerable	No information	Highly Vulnerable	Highly Vulnerable

The impacts of global warming on mountain regions in temperate Asia are summarized below

- Significant increase in frequency of strong winds and torrential rains (Nakashizuka and Iida, 1995; IPCC 1996, WG II, (chapters 1 and 12).
- Warm and dry spring and summer, causing increased fire risk (Nakashizuka and Iida, 1995; IPCC 1996, WG II, chapters 1 and 12
- change of main species of mountain plants and animals, causing increased stress on mountain ecosystems
- easier upward shift of main species of mountain plants, due to short shift distance and less stress of adaptation to light condition within shift elevation
- Effects of changing snow accumulation on plants and animals. (Mooney et al 1995, IPCC 1995, WG II, Ch 5)
- Mountain agriculture: decrease in existing crops (IPCC 1996, WG II) change of cultivation calendar along mountain slopes (Ch 5 and 13)
- change of economically predominant forest species
- increased damage by wildfire, pests, virus, disease, etc..

3.2.2 Tropical Asia

The 16 countries of tropical Asia range in size from about 61,000 ha (Singapore) to 300 million ha (India). The region is physiographically diverse and ecologically rich in natural and crop-related biodiversity.

Climate in tropical Asia is characterized by seasonal weather patterns associated with the two monsoons and the occurrence of tropical cyclones in the two core areas of cyclogenesis 9 the northern Indian ocean and the north western pacific ocean). Over the past 100 years, mean surface temperatures across the region have increased in he range of 0.3-0.8oc.

Substantial elevation shifts of ecosystems in the mountains and uplands of Tropical Asia tree projected. At high elevations, weedy species can be expected to displace tree species, although the rates of vegetation change could be slow and constrained by increased erosion in the greater Himalayas.

The Himalayas play a critical role in the provision of water to continental monsoon Asia. Increased temperature and increased seasonal variability in perception are expected to result in accelerated recession of glaciers and increasing danger from glacial lake outburst floods.

The sensitivity of major cereal and tree crops to changes in temperature, moisture, and carbon dioxide (CO2) concentration of the magnitudes projected for the region has been demonstrated in many studies. For instance, projected impacts on rice, wheat, and sorghum yields suggests that any increase in production associated with CO2 fertilization will be more than offset by reductions in yield resulting from temperature and/or moisture changes. Although climate change impacts could result in significant changes in crop yields, production, storage, and distribution, the net effect of he changes region wide is uncertain because of vertical differences and local differences in growing season, crop management, and so forth; non inclusion of possible disease, pests, and microorganisms in crop model simulations; and the vulnerability of agricultural areas to episodic environmental hazards, including floods, droughts, and cyclones. Low- income rural populations that depend on traditional agricultural systems or marginal lands are particularly vulnerable.

3.3 Potential Impacts of Climate Change on Agriculture and Food Supply

Considerable study has gone into questions of just how farming might be affected in different regions, and by how much; and whether the net result may be harmful or beneficial, and to whom. The problem of predicting the future course of agriculture in a changing world is compounded by the fundamental complexity of natural agriculture systems, and of socioeconomic systems governing world food supply and demand.

The poverty impacts of climate change: The third IPCC Assessment Report of the IPCC 2001 confirmed that the poorest (countries and people) are most at risk. The IPCC report identified a range of poverty-related climate change impacts, including:

- Reduction in crop yields in most tropical and sub- tropical regions due to flooding, temperature changes, and decreases water availability and new/changed insect pest incidence. Falls in agricultural productivity of up to 30% over the 21st century are projected; marine life and the fishing industry will be severely affected in some places;
- Such change will have a major impact on food security, employment, incomes and economic growth; e.g. one study has predicted a 9% - 25% fall in net farm revenue in India from a temperature rise of 2^{o}- 3.5^{o}C.

Assessments of agricultural vulnerability to climate change calls attention to populations, regions, and sectors that may lose the means to satisfy basic needs (food security, progress toward development, a healthy environment). Although no single measure of agricultural vulnerability exists, several indices together provide a sketch of vulnerability, including crop yields, crop prices, production, income, number of people at risk of hunger, rates of erosion, and irrigational demand (IPCC 2001 Ch 5).

Climate change can impact agricultural sustainability in two interrelated ways: first, by diminishing the long term ability of agro-ecosystem to provide food and fiber for the world's population; and second by including shifts in agricultural regions that may encroach upon natural habitats, at the expense of floral and faunal diversity. Global warming may encourage the expansion of agricultural activities into regions now occupied by natural ecosystems such as forests, particularly at mid- and high- latitudes. Forced encroachments of this sort may thwart the processes of natural selection of climatically- adapted native crops and other species. While the overall, global impact of climate change on agricultural production may be small, regional vulnerabilities to food deficits may increase, due to problems of distributing and marketing food to specific regions and groups of people. For subsistence farmers, and more so for people who now face a shortage of food, lower yields may result not only in measurable economic losses, but also in malnutrition and even famine (Rosenzweig and Daniel Hillel, 1995).

Aggarawal and Sinha (1994) showed that in North India, a 1^{o}C rise in mean temperature would have no significant effect on wheat yields, while a 2^{o}C increase would reduce yields in most places. In a recent study, Kumar and Parikh (1998) have examined the adaptation options while estimating the agricultural impacts. The study showed that even with adaptation by farmers of their cropping patterns and inputs, in response to climate change, the losses would remain significant. Ravindranath and Sukumar (1998) discuss the impacts of two climate change scenarios on tropical forests in India -one involving greenhouse gas forcing and the other incorporating the effects of sulphate aerosols. The first scenario, associated with increased temperature and rainfall, could result in increased productivity, migration of forest types to higher elevations, and transformation of drier forest types to moister types. The second scenario, involving a more modest increase in temperature and a decrease in precipitation in central and northern India, could have adverse effects on forests. Results indicate that under the climate scenarios generated by ECHAM3 climate model, the soil moisture is likely to decline and, in turn reduce teak productivity from 5.40 m^3/ha to 5.07m^3/ha. The study also shows that the productivity of moist deciduous forests could decline from 1.8m3/ha to 1.5m3/ha (Achanta and Kanetkar 1996).

Large negative impacts on rice production could occur in China as a result of climate change, and would increase the pressure to feed China's large population (IPCC 1998). Guo (1995) predicts that the present forests of *Pinus tabulaeformis*, a key temperate species of northern China, will be reduced by an additional 9.4% under a doubled carbon dioxide concentration scenario.

The onset of summer monsoon over India is projected to be delayed and often uncertain. This will have a direct effect not only on the rainfed crops, but also water storage will be affected putting stress on irrigation water availability. Since availability of water for agriculture would have to face tremendous competition for other uses of water, agriculture in future would come under greater strain. Simulation studies indicate that the direct effects of climate change on Indian agriculture would be small in short-run provided pests could be controlled. However, in the long run, the production of rabi crops such as wheat particularly in central India and southern India may be more seriously effected. The indirect effects of climate change through projected increased incidence of uncertainties of rainfall onset, duration and frequencies of drought and floods, availability of irrigation, soil transformations, crop-pests competition, and submergence of some coastal land due to sea level rise may be more serious than the direct effects on crop growth (Aggarwal et al 2002).

Crop production and aquaculture would be threatened by thermal and water stresses, sea-level rise, increased flooding, and strong winds associated with intense tropical cyclones (high confidence). It is expected that areas in mid- and high latitudes will experience increases in crop yield; yields in lower latitudes generally will decrease. A longer duration of the summer season should lead to a northward shift of the agro ecosystem boundary in boreal Asia and favor an overall increase in agriculture productivity (medium confidence).

Climate variability and change also will affect scheduling of the cropping season, as well as the duration of the growing period of the crop. In China, yields of several major crops are expected to decline as a result of climate change. Acute water shortages combined with thermal stress should adversely affect wheat and, more severely, rice productivity in India even under the positive effects of elevated CO_2 in the future. Crop diseases such as wheat scab, rice blast, and sheath and culm blight of rice also could become more widespread in temperate and tropical regions of Asia if the climate becomes warmer and wetter.

Climate change presents crop production with prospects for both benefits and drawbacks. The changes will affect agriculture through their direct and indirect effects on crops, soils, livestock and pests. Some observers believe that climate change will exert its influence so slowly (a fraction of a degree per decade) that the effects will be barely noticeable. Others emphasize the need to study the potential for what is called "threshold effects" i.e shifts in production when critical levels of certain factors are surpassed. Unexpected consequences or "surprises" may well accompany the build up of greenhouse gases. Even if climate changes gradually, it will affect the range of options available for agriculture in a given region. Under changing climate conditions, farmers' past experience will be a less reliable predictor of what is to come. Global warming is a real phenomenon that is likely to endanger serious consequences on agricultural systems (Rosenzweig and Hillel1995).

Increase in atmospheric carbon dioxide could promote growth and productivity of plants with C3 pathway. Increase in temperature, depending upon the current ambient temperature, on the other hand, can reduce crop duration, increase crop respiration rates, alter photosynthate partitioning to economic products, effect the survival and distributions of pest populations, hasten nutrient mineralization in soils, decrease fertilizer use efficiencies, and increase evapotranspiration. Indirectly, there may be considerable effects on land use due to snow melt, availability of irrigation, frequency and intensity of inter- and intra-seasonal droughts and floods, soil organic matter transformations, soil erosion, changes in pest profiles, decline in arable areas due to submergence of coastal lands, and availability of energy. All these can have tremendous impact on agricultural production and hence food security of any region.

3.3.1 Anticipated responses of agroecosystems (Cynthia)

Effect of enhanced CO2 on crop growth.

Plant grow through the well known process of photosynthesis, utilizing the energy of sunlight to convert water from the soil and carbon dioxide from the air into sugar, starches, and cellulose the carbohydrates that are the foundation of the entire food chain. CO2 enters a plant through its leaves. Greater atmospheric concentrations tend to increase the difference in partial pressure between the air outside and inside the plant leaves, and as a result more CO2 is absorbed and converted to carbohydrates. Crops species vary in their response to CO2. Wheat, rice and soybeans belong to a physiological class (called C3 plants) that respond readily to increased CO2 levels. Corn, sorghum, sugarcane, and millet are C4 plants that follow a different pathway. The latter, through more efficient photosynthetically than C3 crops at present levels of CO2, tend to be less responsive to enriched concentrations. Thus far, these effects have been demonstrated mainly in controlled environments such as growth chambers, greenhouses, and plastic enclosures. Experimental studies of the long- term effects of CO2 in more realistic field settings have not yet been done on a comprehensive scale.

Effects of higher temperature

In middle and higher latitudes, global warming will extend the length of the potential growing season, allowing earlier planting of crops in the spring, earlier maturation and harvesting, and the possibility of completing two or more cropping cycles during the season. Crop-producing areas may expand poleward in countries such as Canada and Russia, although yields in higher latitudes will likely be lower due to the less fertile soils that lie there. Many crops have become adapted to the growing- season daylengths of the middle and lower latitudes and may not respond well to the much longer days of the high latitude summers. In warmer, lower latitude regions, increased temperatures may accelerate the rate at which plants release CO2 in the process of respiration, resulting in less than optimal conditions for net growth. When temperatures exceed the optimal for biological processes, crops often respond negatively with a steep drop in net growth and yield. If nighttime temperature minima rise more than do daytime maxima- as is expected from greenhouse warming projections- heat stress during the day may be less severe than otherwise, but increased nighttime respiration may also reduce potential yields. Another important effect of high temperature is accelerated physiological development, resulting in hastened maturation and reduced yield.

Available water

Agriculture of any kind…..

Soil fertility and erosion

Higher air temperatures will also be felt in the soil, where warmer conditions are likely to speed the natural decomposition of organic matter and to increase the rates of other soil processes that affect fertility. Additional application of fertilizer may be needed to counteract these processes and to take advantage of the potential for enhanced crop growth that can result from increased atmospheric CO2. This can come at the cost of environmental risk, for additional use of chemicals may impact water and air quality. The continual cycling of plant nutrients- carbon, nitrogen, phosphorus, potassium, and sulfur-in the soil-plant-atmosphere system is also likely to accelerate in warmer conditions, enhancing CO2 and N2O greenhouse gas emissions.

Nitrogen is made available to plants in a biologically usable form through the action of bacteria in the soil. The process of nitrogen fixation, associated with greater root development, is also predicted to increase in warmer conditions and with higher CO2, if soil moisture is not limiting.

Where they occur, drier soil conditions will suppress both root growth and decomposition of organic matter, and will increase vulnerability to wind erosion, especially if winds intensify. An expected increase in convective rainfall-cause by stronger gradients of temperature and pressure and more atmospheric moisture- may result in heavier rainfall when and where it does occur. Such “extreme precipitation events” can cause increased soil erosion.

Pests and diseases

Conditions are more favorable for the proliferation of insect pests in warmer climates. Longer growing seasons will enable insects such as grasshoppers to complete a greater number of reproductive cycles during the spring, and autumn. Warmer winter temperature may also allow larvae to winter-over in areas where they are now limited by cold, thus causing greater infestation during the following crop season. Altered wind patterns may change the spread of both wind- borne pests and of the bacteria and fungi that are the agents of crop disease. Crop-pest interactions may shift as the timing of development stages in both hosts and pests is altered.

Livestock diseases may be similarly affected. The possible increases in pest infestations may bring about greater use of chemical pesticides to control them, a situation that will require the further development and application of integrated pest management techniques.

The results of a large number of experiments have confirmed a beneficial effect of elevated CO_2 on crops [69]. CO_2 fertilization effects have been considered in some studies [43,46,70] and shown that the effects of potential CO_2 fertilization are dramatic. However, scientific controversy remains concerning this effect. Scientists studying the physiological effects of CO_2 have raised a number of questions. Such as field responses may be different from the experimental response. The assessment of the relative contributions of the direct effects of CO_2 (parameter value changes in some models) remains a crucial research question **(from You and Takahashi…..)**

3.3.2 *Agriculture as a greenhouse gas contributor*

The role of climate as a determinant of agriculture has long been recognized. It is only in the last decade, however, that the reciprocal effect has come to light: the role of agriculture as a potential contributor to climate change. Clearing forests for fields, burning crop residues, submerging land in rice paddies, raising large herds of cattle and other ruminants and fertilizing with nitrogen, all release greenhouse gases to the atmosphere. The main gas emitted are CO2, CH4, and N2O.

From about 1700 to 1900, the clearing of northern hemisphere forests for agriculture was the largest agent of change in the carbon cycle. Emissions from agricultural sources are believed to account for some 15% of today’s anthropogenic greenhouse gas emissions. Land use changes, often made for agricultural purposes, contribute another 8% or so to the total. As a result, agriculture ranks third after energy consumption (which is also in part agricultural) and chlorofluorocarbon production as a contributor to the enhanced greenhouse effect.

4 AGRICULTURE ADAPTATION TO CLIMATE CHANGE: A REVIEW

4.1 Adaptation

Vulnerability can be defined as “the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity (IPCC, 2001)

Adaptation refers to the adjustments in ecological, social, or economic systems in response to actual or expected climatic stimuli and their effects or impacts. Adaptation refers to efforts to reduce system’s vulnerabilities to climate. Adaptation is concerned with responses to both the negative and positive effects of climate change (IPCC 1996). It refers to any adjustments – whether passive, reactive, or anticipatory – that can respond to anticipated or actual consequences associated with climate change. Thus it implicitly recognizes that future climate change will occur and must be accommodated in policy.

Adaptation can be spontaneous or planned, and can be carried out in response to or in anticipation of changes in conditions. IPCC technical guidelines distinguish difference between autonomous adjustments and adaptation strategies. Autonomous adjustments are natural or spontaneous adjustments that will probably occur in response to climate change. In addition to autonomous adjustments, a wide range of responses can be implemented exogenously by management or policy decisions at the regional or national level. These adjustments are adaptation strategies (Carter 1996). Many scientists and policy makers see adaptation as a powerful option by which to reduce the negative impacts of climate change or take advantage of the positive effects.

Adaptation to climate change has the potential to substantially reduce many of the adverse impacts of climate change and enhance beneficial impacts, though neither without cost nor without leaving residual damage. The capacity to adapt varies considerably among regions, countries, and socioeconomic groups and will vary over time. The ability to adapt and cope with climate change impacts is a function of wealth, scientific and technical knowledge, information, skills, infrastructure, institutions, and equity. Countries with limited economic resources, low levels of technology, poor information and skills, poor infrastructure, unstable or weak institutions, and inequitable empowerment and access to resources have little capacity to adapt and are highly vulnerable (IPCC 2001). Adapting to climatic variability will have a substantially greater effect in reducing impact than will mitigation. Reducing water demand by just 5% has four times as great an effect as reducing emissions by 30 per cent (Parry et al 1998).

There are six reasons to adapt to climate change (Burton 1996):

Climate change cannot be totally avoided.

Anticipatory and precautionary adaptation is more effective and less costly than forced, last-minute, emergency adaptation or retrofitting.

Climate change may be more rapid and more pronounced than current estimates suggest. Unexpected events are possible.

Immediate benefits can be gained from better adaptation to climate variability and extreme atmospheric events.

Immediate benefits can also be gained by removing maladaptive policies and practices.

Climate change brings opportunities as well as threats. Future benefits can result from climate change.

The following are the key findings on adaptation and capacity in Asia (Climate Change 2001: Chapters 10 through 17):

- Early signs of climate change already have been observed and may become more prominent over 1 or 2 decades. If this time is not used to design and implement adaptations, it may be too late to avoid upheavals. Long- term adaptation requires anticipatory actions.
- Priority areas for adaptation are land and water resources, food productivity, and disaster preparedness and planning, particularly for poorer, resource- dependent countries.
- For many developing countries in Asia, climate change is only one of a host of problems to deal with, including nearer term needs such as hunger, water supply and pollution, and energy. Resources available for adaptation to climate change are limited. Adaptation responses are closely linked to development activities, which would be considered in evaluating adaptation options.
- Adaptive capacities vary between countries, depending on social structure, culture, economic capacity, and level of environmental disruptions. Limiting factors include poor resource and infrastructure bases, poverty and disparities in income, weak institutions, and limited technology.
- The challenge in Asia lies in identifying opportunities to facilitate sustainable development with strategies that make climate- sensitive sectors resilient to climate variability.
- Adaptation strategies would benefit from taking a more systems- oriented approach, emphasizing multiple interactive stresses, with less dependence on climate scenarios.
- A wide range of precautionary measures are available at the regional and national level to reduce economic and social impacts of disasters. These strategies include awareness building and expansion of the insurance industry.
- Development of effective adaptation strategies requires local involvement, inclusions of community perceptions, and recognition of multiple stresses on sustainable management of resources.
- Adaptation strategies would benefit from taking a more systems oriented approach, emphasizing multiple interactive stresses, with less dependence on climate scenarios.

Historically, farming systems have adapted to changing economic conditions, technology, and resource availability and have kept pace with a growing population. Examples of technological options for the adaptation by agriculture include seasonal change in sowing dates; different crops varieties or species; new crop varieties; water supply and irrigation systems; management adjustments with fertilizer; tillage, and so forth; and improved short- term climate prediction (IPCC 1996, WG II, Section 13.9.1; Darwin et al.,1995).

Socioeconomic options for adaptation include improved training and general education of populations dependent on agriculture; assessment of currently successful strategies for responding to climate variability; improved agriculture research to increase the robustness of new farming strategies; interactive communication to bring research results to farmers and farmers' problems to researchers; improved preservation and maintenance of genetic material critical to adaptation; and food programs to buffer against local supply changes. Transportation, distribution, and market integration provide additional flexibility for regions to respond to climate variability, and changes in policies could increase the adaptive capacity of agriculture (IPCC 1996, WGII, Section 13.9.2).

Activities required for enhancement of adaptive capacity are essentially equivalent to those promoting sustainable development. Enhancement of adaptive capacity is a necessary condition for reducing vulnerability, particularly for the most vulnerable regions, nations, and socio-economic groups. Many sectors and regions that are vulnerable to climate change also are under pressure from forces such as population growth and resource depletion (IPCC 2001 Ch. 6))

Success in adapting to possible future climate change will depend on a better definition of what changes will occur where, and on prudent investments, made in timely fashion, in adaptation strategies.

4.2 Adaptation strategies

Rapid change of climate may seriously inhibit the ability of some crops to survive or to achieve desired yields in their current region without intervention. Adaptation Strategies are deliberate actions taken by “governments” to adjust to climate change.

Therefore, a wide range of measures that would affect agricultural production systems should be implemented exogenously. Tremendous agricultural adaptation measures have been stated in previous studies and report (IPCC 1996, IPCC 1998, Smit et al 1996, Jodha 1989, Rosenberg 1992, Toman and Bierbaum 1996). Carter 1996 has summarized adaptation strategies for agricultural sector as given below:

a) Change topography of land
b) Use artificial systems to improve water use/availability and protect against soil erosion
c) Change farming practices
d) Change timing of farm operation
e) Use different crop varieties
f) Governmental and institutional policies and program
g) Research into new technologies

Findings from studies on agricultural adaptation to climate change impacts can be summarized in following catalogues……..

IPCC technical guidelines distinguish between autonomous adjustments and adaptation strategies (IPCC 1996). Autonomous adjustments are natural or spontaneous adjustments that will probably occur in response to climate change. In addition to autonomous adjustments, a wide range of responses can be implemented exogenously by management or policy decisions at the regional or national level. These adjustments are adaptation strategies. Tol *et a*l 1998 grouped adaptation further into four categories: no adaptation, arbitrary adaptation, observed adaptation (analogues) and modeled adaptation (optimization). Schimmelpfennig *et a*l 1996 distinguished agricultural adaptation to climate change at three levels: (1) farm-level adjustments to climate change; (2) national adjustments to climate change; and (3) global adjustments to climate change. Fischer *et a*l 1994 group the adaptation measures at the farm level further into two levels. Level 1 implies little change to existing agricultural systems, reflecting relatively easy and low-cost farmer response to a changing climate. Level 2 implies more substantial changes to agricultural systems, possibly requiring resources beyond the farmer's means.

Agricultural adaptation to climate change at the farm level depends on the technological potential (different varieties of crops, irrigation technologies); basic soil, water, and biological response; and the capability of farmers to detect climate change and undertake any necessary actions. Climatic variability is a feature of current climate in most geographic areas. This variability may make it difficult for farmers to readily detect climate change and respond appropriately.

At the national level, government policies and programs, ranging from crop insurance and disaster assistance to acreage reduction programs, tariffs and quotas, and the level of agricultural research, will affect the farm sector's response to climate change by affecting the economic incentives for farmers (and others) to adapt and the technological options with which they can adapt.

The effects of adaptation strategies have been estimated based on assumptions or calculated based on field experiment in many studies. In most cases, the adaptation strategies can offset the negative effects of climate change. Many studies agree that adaptation to climate change is more likely in areas where are currently less climatically stressed. The best way to adapt to some uncertain future climate is to improve adaptation to present day climate variability and reduce vulnerability to extreme events. The extent of their adaptation depends on the affordability of adaptive measures, accessing to technology, and biophysical constraints such as land and water resource availability, soil characteristics and genetic diversity for crop breeding (e.g. crucial development of a heat-resistance rice cultivar), and topography. Therefore, study on agricultural adaptation to climatic change must be based on the country level rather than the global or regional level, in which the negative effects in some countries may be overlooked (You and Takahashi 19_______). You and Takahashi observe that some measures have been identified for agricultural adaptation to climate impact, but few of them have been actually evaluated and combined into strategies to meet given goals and objectives. Some major categories of adaptation, such as insurance, disaster assistance, and changes in land use and location, receive little or no attention in the adaptation options described in IPCC reports. Competition for resources from other sectors and other resources changes are not well considered in adaptation study.

4.3 Adaptation options

A wide variety of adaptive actions may be taken to lessen or overcome adverse effects of climate change on agriculture. At the level of farms, adjustments may include the introduction of later-maturing crop varieties or species, switching cropping sequences, sowing earlier, adjusting timing of field operations, conserving soil moisture through appropriate tillage methods, and improving irrigation efficiency. Some options such as switching crop varieties may be inexpensive while others, such as introducing irrigation (especially high-efficiency, water- conserving technologies), involve major investments (Rosenzweig and Daniel Hillel, 1995).

Adaptation measures to reduce the negative effects of climatic variability may include changing the cropping calendar to take advantage of the wet period and to avoid the extreme weather events (e.g. typhoons and strong winds) during the growing season.

Rice the second most important crop in the world after wheat, with about 585 million tones being produced from about 151 million hectares in 2001. The largest production of rice is from Asia, which produces about 94% of the total world production. However to meet the demands of its rapidly expanding population, an estimated 70% increase in rice production is required over the coming decades. In 1989, a major research project was initiated at the International Rice Research Institute (IRRI) in the Philippines to investigate the likely impact of climate change on rice production. The study showed that, in currently cooler areas, modification of sowing date to take advantage of longer growing season under the higher temperatures expected in future climates permitted a possible transition from single- cropping to double-cropping at some locations. This adaptation could potentially have a large positive impact on national rice production in some countries. Selection for varieties with a higher tolerance of spikelet fertility to temperature was shown to be capable of restoring yield levels to those predicted for current climates. The use of longer-maturing varieties to take advantage of longer growing seasons in the currently cooler areas may instead result in lower yields, due to the grain formation and ripening period being pushed to less favourable conditions later in the season. A better strategy might be to select for shorter- maturing varieties to allow a second crop to be grown in these regions (Matthews ________)

Adaptation options including changed varieties, planting windows, fertilizer regimes and cropping mixes have been investigated for the wheat industry. Result show that such adaptations can offset negative impacts under the problematic 100-year co2 and climate change scenarios and substantially improve industry viability in more positive scenarios (**Ref …**

5 ADAPTATION TECHNOLOGY NEEDS ASSESSMENT

5.1 Appropriate technologies

Development of so called appropriate technologies could lead to environmental protection and economic security in developing countries. The label "appropriate technologies " is used because they build upon the indigenous knowledge and capabilities of local communities; produce locally needed materials, use natural resources in a sustainable fashion, and help to regenerate the natural resource base. They may enable developing countries to keep an acceptable environmental quality within a controlled cost (Hou 1988). Low cost, but resource efficient technologies are of particular importance for the rural and urban poor. There is a latent demand for low-input organic agriculture, small agro-based rural enterprises, and biomass-based small industries. Sustainable agriculture can benefit both the environment and food production. Indeed, intermediate performance levels are often desirable because of their higher employment impact, lower investment cost, local adaptability, and potential for decentralization. For this reason, technologies that combine high eco-efficiency with appropriate performance levels hold an enormous potential for improving people's living containing the use of natural resources and GHG emissions (IPCC 2001 Working Group III Mitigation).

Adding to the list of available technological options can, of course, lower the cost of implementing a specific policy designed to accomplish a specific objective, but the additions must be more socially acceptable than the existing alternatives, as well as structurally, politically, and culturally feasible. If not, they will not be adopted.

5.2 Adaptation technologies

Adaptations – such as changes in crops and crop varieties, improve water management and irrigation systems, and changes in planting schedules and tillage practices- will be important in limiting negative effects and taking advantage of beneficial changes in climate. The extent of adaptation depends on the affordability of such measures, particularly in developing countries: access to know-how and technology, the rate of climate change and biophysical constraints such as water availability, soil characteristics and crop genetics. (SPM, SAR of IPCC WGII, 1996)

Many adaptation opportunities suitable for climate change have already been applied by farmers. Table 11 provides a list of currently available adaptation opportunities that can be applied at the farm or farmer community level. Most available options take advantage of the general flexibility of agricultural systems related with the short management cycles involved. It is likely that autonomous adjustment by farmers will continue to be important as climate changes, provided that farmers have access to the right information and tools. However, some agricultural systems are less flexible, for example because they are constrained by soil quality or water availability, or because they face economic, technological, institutional or cultural barriers. In such cases, autonomous adjustments may not be implemented in time because of lack of awareness(of both problems and solutions), and anticipatory planned adaptation would be required to provide the right conditions (i.e. information and tools) to farmers for autonomous adjustment (Klein and Tol, 1997)

Increasing the variety of crops may require the introduction of new knowledge and machinery to a farming community. However, as climates changes, the technologies listed in Table 11.1 may not be sufficient, and the need may arise for the development of new technologies to allow farmers to cope better with anticipated climate-change impacts, and to reduce the costs of adaptation (Klein and Tol, 1997).

Table 11 Examples of adaptation opportunities to climate change impacts on agricultural systems (Smit, 1993).

Response strategy	**Adaptation options**
Use different crops or varieties to match changing water supply and temperature conditions	• Conduct research to develop new crop varieties • Improve distribution networks
Change land topography to reduce runoff, improve water uptake and reduce wind erosion	• Subdivide large fields • Grass waterways • Land leveling • Waterway-leveled pans • Bench terracing • Tied ridges • Deep plowing • Roughen land surface • Use windbreaks
Introduce systems to improve water use and availability and control soil erosion	• Low-cost pumps and water supplies • Dormant season irrigation • Line canals or install pipes • Use brackish water where possible • Concentrate irrigation water during peak-growth period • Level fields, recycle tail-water, irrigate alternate furrows • Drip-irrigation systems • Diversions
Change farming practices to conserve soil moisture and nutrients, reduce runoff and control soil erosion	• Conventional bare fallow • Stubble/straw mulching • Minimum tillage • Crop rotation • Contour cropping to slope • Avoid mono-cropping • Chisel up soil clods • Use lower planting densities
Change timing of farm operations to better fit new climatic conditions	• Advance sowing dates to offset moisture stress during warm period

5.2.1 Genetic improvements critical to climate change adaptation

While yields growth accounted for over 90 per cent of recent agricultural output growth, scholar credit genetic improvements in crop varieties with half of this yield growth (**Duvick, 1992**; **Byerlee, 1996**; Wright 1996). The remainder of the growth is attributed to improved management practices, irrigation and increased use of fertilizers and other inputs. In the future, genetic improvements are likely to play an even greater role. This is particularly true given other environmental considerations that limit the extent to which higher yields can come from more intensive use of chemical fertilizers and pesticides. The efficient conservation, exchange and use of agricultural genetic resources will be critical for future agricultural technology development and transfer (Would Bank 1992).

Because the performance of crop varieties is sensitive to agro-climatic conditions, much of the technology transfer of improved crop varieties has been North-North between temperate regions and South- South across tropical or sub-tropical regions. The advances of the green Revolution may be thought of as “North-assisted” South- South technology transfer. The semi-dwarf wheat varieties now widely adopted in India’s Punjab where originally developed in Mexico, while Indian rice yields are substantially higher thanks to infusions of germ-plasm collected by the International Rice Research Institute (IRRI) from other parts of Asia. In the future, biotechnology may offer significant opportunities to address the need for crop adaptation to changing climate across all countries (IPCC 2001).

Developing countries must look for more efficient operations and for economics of scale through collaboration with breeding programme in other countries or the IARCs. For the past 20 years, great hopes have been placed on the benefit to plant breeding from biotechnology. Biotechnology aids to plant breeding often will be used first in the industrialized nations, but will be available for use in developing countries with very little delay. In some cases the improvements will be publicly available; in other cases, the products will be available on a commercial basis.

5.3 Transferable technologies for adaptation and mitigation

Mitigation options are available that could result in a significant decrease in GHG emissions or increase carbon sequestration into agricultural soils. If implemented, most of them are more likely to increase rather than decrease crop and animal productivity. Considerable progress has been made in evaluating the potential effects of climate change on global agriculture, but significant uncertainties remain, so agricultural policies are specifically appropriate for adapting to climate change. A range of adaptation options can be employed to increase the flexibility and adaptability of vulnerable systems, and reverse trends that increase vulnerability. Many of these attempts to abate climate change will be of immediate benefit, and can therefore be considered “no-regret” technologies.

In order to achieve these objectives, technology transfer must occur more rapidly, and with more intense focus on those technologies that further sustainable development. Table 12 summarizes some key technology examples, catalogued by objectives:

Table 12 Examples of transferable technologies catalogued by objectives and specific technology

Oblectives	Technology	Mitigation	Adaptation	Potential Impact	Relative Cost
CO2 Sequestering in soils	Conservation tillage	Yes	Yes	M	H
Higher Yields	Improve irrigation	Yes	Yes	H	H
	Yield improvement	Yes	Yes	M	M
	Genetics	Yes	Yes	H	M
	Improve inputs	Yes	Yes	M	M
	Pest Control	Yes	Yes	M	M

Reducing Emissions	Improve animal agriculture	Yes	Yes	H	M
	Lower GHGs	Yes	Yes	H	Not sure
	Improve feed efficiency	Yes	Yes	M	M
	Concentrating on best lands	Yes	Yes	M	M
	Improve nitrogen efficiency	Yes	Yes	M	M

There are many barriers that may be encountered (Table 13). Some of these options require more labour and some need more capital investment, which may represent the main constraints slowing adoption of the technologies.

Table 13. Barriers for adoption of the selected mitigation technologies

No	Options	Constraints
1	Irrigation efficiency	• Requires large investments and national technology and assessment commitment • Requires technology transfer to the farm level • Requires cooperative community action
2	Direct seeding of rice	• Requires intensive weed control
3	Substitution of traditional varieties by improved varieties	• Less preferred grain quality • New pest problems in certain areas • Changed management
4	Conservation tillage	• Risk of reduction of yield • Different machinery needs, crop varieties, soil moisture and temperature conditions • Required intensive weed control
5	Ammoniation of straw for animal feed	Ammoniation sulphate is more expensive than urea
6	Large scale biogas digester	More investments, more complex to operate and maintain

In most cases the transfer of technologies needs to take into account, e.g., the link between technology adoption and diffusion and enhancing income in technology receiving countries. This will be critical in achieving adoption and wide-scale diffusion of alternative technologies in these countries. The lack of financial incentives will be a major obstacle to the adoption of some of these practices. Otherwise, the system depends on subsidies of some sort (e.g. cost shares) to speed adoption and diffusion, and when the subsidy runs out, the practice is dropped.

5.4 Transferred Technologies

Technology transfer and diffusion of new technologies could in particular focus on improvement of irrigation technology and alternative species and varieties.

5.4.1 Improving irrigation technology

Rind et al (1990) use GCM results to calculate that for many mid- latitude locations (e.g. USA) the incidence of severe droughts that currently occur only 5% of the time could rise to a 50% frequency by 2050, based on the difference between precipitation and potential evapotranspiration. Such a change would constitute a severe natural disaster for agricultural production.

About 253 million hectares, 17% of the world's crop land, are irrigated. This land produces more than one-third of the world's food (Geijer et al, 1996). Irrigation is therefore increasingly important for adapting to the effects of climate change on agricultural production. Almost three quarters of the world's irrigated area is in developing countries. To mitigate the negative effects of climate on agriculture, developing countries should improve their existing irrigation efficiency through adoption of drip irrigation systems and other water-conserving technologies (FAO1990). An alternative is to import technologies and equipment from developed countries that have advanced irrigation technologies. See Box 1 for a discussion of the main barriers involved.

> Box. <u>Irrigation Technology Transfer between Countries and across Barriers.</u>
>
> The main flow of irrigation technology transfer is from developed to developing countries. The primary barrier encountered by the importing developing countries is that they cannot afford the high cost of patents and equipment. The second barrier is that the importers do not have enough money to build the auxiliary equipment for the introduced technology, because developing countries, in many cases, only buy key equipment due to their limited financial resources. The third barrier for irrigation technology transfer between countries is that the importing developing countries are not clearly aware of what technologies fit their conditions and where they can find the suitable ones. The importers do not always receive satisfactory service when there are problems with their imported equipment or scientific instrument.

5.4.2 New species and varieties adapted to changing climate.

For most major crops, varieties exist with a wide range of maturities and climatic tolerances. For example, **Matthews et al. (1994**) identified wide genetic variability among rice varieties as a reasonably uncomplicated response to spikelet sterility in rice that occurred in simulations for South and Southeast Asia. Studies in Australia showed that responses to climate change are strongly cultivar dependent (Wang et al., 1992). The genetic base is broad for most crops but limited for some (e.g. kiwi fruit). A study by Easterling et al. (1993) explored how hypothetical new varieties would respond to climate change (also reported in McKenney et al., 1992) Heat, drought, and pest resistance, salt tolerance, and general improvements in crop yield and quality would be beneficial for crop adaptation (Smit, 1993). See Box 2.

> Box 2 <u>New rice in Sierra Leone</u>
>
> The development of a new mangrove rice variety in Africa is an important case study of technology development and transfer. Much of the success of this effort

hinged on the accident of a critical mass of researchers at the government rice research station in Rokupr Sierra Leone and the interest of the West African Rice Research Development Association (WARDA) in this effort. WARDA provided additional resources to the station at Rokupr to carry out the development of a new rice variety to meet the changed climate conditions, and improve yields above those previously achieved. The Sierra Leone agricultural research establishment was able to demonstrate the value of their rice research effort to the food supply of the nation and WARDA was able to demonstrate to their financial supporters their value in contributing to this new technology and its transfer. There was a German seed distribution project that helped with some seed distribution, but farmers themselves undertook most of the technology transfer to other farmers once the success of the new variety became apparent (Prahah- Asante et al., 1982, 1986; Spencer, 1975; Spencer et al., 1979; Tre et al., 1998; WARDA, 1987; Zinnah, 1992; Zinnah et al., 1993).

5.5 Mitigation

Most developing countries depend heavily on agriculture. Developing countries are barely able to adopt the mitigation technologies mentioned in Table 11.3 to mitigate the GHG emissions in agricultural systems, because of barriers mentioned in Table 11.4. If advanced technologies are transferred to them with demonstration projects, as well as technical assistance and financial support, GHG emissions will be reduced.

5.5.1 Improvement of the efficiency of nitrogen fertiliser

Nitrogen fertilizer efficiency decreased with increased nitrogen fertilizer inputs. So, farmers need additional information such as soil testing data, as well as educational support to interpret the data. They can also gain experience by participating in demonstration projects. Extension personnel are needed to provide on- farm technical assistance with new practices to increase N efficiency. Availability of application machinery and technologies must be transferred simultaneously to be effective.

5.5.2 Reducing methane emission from rice fields

Feasible mitigation strategies that have been verified to significantly reduce methane emission from rice fields are temporary midseason aeration of the soil, using fermented instead of fresh organic manure, applying sulfate containing fertilizer, and planting/breeding rice cultivars with low emission capacity.

5.5.3 Reducing methane from animal waste

Biogas digesters can provide clean energy and high quality fertilizer, and can be an important option for reducing methane emission from livestock manure. This technology is widely recognized as an EST and has been widely accepted all over the world, especially in China and India.

5.6 Barriers to Technology Transfer between Countries

5.6.1 Constraints of supply of new technologies

5.6.1.1 Shortage of technological information.

Because the developing countries lack access to information, they are not aware of what technologies fit their conditions and where they can find the suitable ones. International technology exchanges are helpful for overcoming this obstacle.

5.6.1.2 Shortage of capital

Due to the long-term aspects of climate change, financial capital may also be a constraint to new technology.

5.6.1.3 Growth of agricultural research funding is slowing

Agriculture is heavily dependent on climate in developing countries, so technology transfer is crucial for climate change adaptation and mitigation. The growth of agricultural research funding is slowing down. This will impede the generation and transfer of technology. Funding trends for international research centres under the auspices of the CGIAR have shown a similar decline.

5.7 Special problems of technology transfer among developing countries

The main floe of technology transfer to deal with climate change is from developed to developing countries, as emphasized by UNFCCC and The Kyoto Protocol. Some cases of the existing technology transfer between developing countries are beneficial to climate. International organizations and relevant developed countries could encourage the existing technology transfer among developing countries.

Institutional capacity on agricultural research is limited in developing countries. A matter of great concern is the state of the national agricultural systems (NARSs) in developing countries. Many of which have declined in capacity over the past decade or two.

- Operational budgets per researcher in many developing countries have been declining in recent years
- The biggest barrier for technology transfer among developing countries may be the shortage of financial support. Technology recipients need new investments to adopt new technology.

The main flow of technology transfer is from developed to developing countries dealing with climate change, as was emphasized by the UNFCCC and The Kyoto Protocol. Some cases of existing agricultural technology transfer among developing countries, such as CGIAR and other multilateral systems, can be most helpful in assisting countries dealing with climate change if their capacities are strengthened. International organisations and relevant developed countries can make great contributions by encouraging and supporting technology transfer among developing countries

Climate change requires extra effort to transfer technologies that;

- Increase crop output per liter of irrigation water drawn;
- Increase demand for appropriate technology with incentives if needed, and ensure the provision of reliable supplies and equipment that meet local situations and needs;
- Increase soil carbon and reduce methane emissions;
- Assure that intellectual property rights help and do not hinder technology transfer, especially to small farmers and developing countries; and
- Provide crops suited to warmer temperatures

At minimum, this extra effort calls for a restored CGIAR and linked NARSs.

5.8 Farm level Adoption Barriers/Constraints

For farm-level adoption, the barriers include small farm size, credit constraints, risk aversion, lack of access to information, lack of human capital, inappropriate transportation infrastructure, inadequate incentives associated with tenurial arrangements, and unreliable supplies of complementary inputs. Because strategies for new technologies are often imposed from the top down, implementation fails when local people are not consulted or are treated as laborers only, or when local research and extension staff are not sufficiently trained in the specific techniques. Consequently, positive measures to improve soil and water productivity, for example, both through individual and communal action, should receive higher priority for research, extension, and training in the future. Some agricultural measures should also form part of an integrated biotechnical approach that provides appropriate expertise and equipment, seeds of improved cultivars, plant nutrients, and pest management, with strong social and economic incentives.

6 CLIMATE CHANGE IMPACT AND ADAPTATION IN BHUTANESE AGRICULTURE

6.1 Impact of climate change in Bhutan

Climate change will have significant impacts on Bhutan's mountainous ecosystems. These include increased threat of landslides and glacier lake outbursts, adverse impacts on agriculture, biodiversity, and water resources.

In Bhutan the entire northern upper land has glacial/snow-fed lake in the mountain tops. Increased temperature and greater seasonal variability in precipitation will lead to accelerated recession of glaciers and result in increase in the volume of these lakes (IPCC 1998). This might result in fresh floods when the barriers and dams created by glacier debris give way, causing severe damages in terms of loss of lives, economy and infrastructure in the valley. In 1994, a glacier lake out burst in the Lunana region flooded and damaged everything in the lower valley of Punakha and below, illustrating the high degree of Bhutan's vulnerability to such extreme events.

The availability of water in Bhutan is heavily dependent on heavy rainfall, glacier or snow, land use practices, and user demand. A reduction in the average flow of snow-fed rivers, combined with an increase in peak flows and sediments yields, would have major impact on hydro-power generation, urban water supply, and agriculture. An increase in rainfall intensity may increase may increase run off enhance soil erosion and accelerate sedimentation in the existing water supplies or reservoirs.

Methane (CH_4) from livestock has been the main greenhouse gas from the agriculture sector. CH_4 emissions amounting to 19.17 Giga grams (Gg) have been estimated from enteric fermentation and manure management. Because of the very small rice cultivation area, the emission of methane from rice cultivation is negligible[1].

Climate change has emerged as a critical global environmental and development issue. Scientists have indicated that mountain ecosystems or transitional countries are more vulnerable to the effects of such change. Impacts could include threats related to glacier melting, decline in agricultural production, forest degradation, bio-diversity losses and perturbation in the natural water resources. For Bhutan, where 79% of the population depends on agriculture and natural resources, and where hydroelectric power generation is a critical source of revenue, the highlighted negative impacts would be severe. Indeed, under adverse climatic change, the policy of sustainable and environmentally sound social development advocated by the Royal Government of Bhutan will be undermined.

Although Bhutan's contribution to global emissions is negligible, it is one of the most vulnerable countries. Bhutan is not only a country with a fragile mountainous ecosystem, but is also a Least Developed Country, that lacks the resources for adapting to the adverse impacts of climate change.

Although, the country does not contribute to the negative changes in the climate system, climate change can place additional stress on the already fragile mountain environment and expose Bhutan's rich concentration of species and ecosystems to the threat of extinction. In the Himalayas, the changes are manifested in natural disasters, modifications in natural systems in forests, increased health risks from malaria, lung disorders and other diseases, and noticeable alterations in crop growing seasons.

Development of a national policy framework to facilitate implementation of appropriate and effective mitigation measures and adaptation strategies is important. This will require institutional strengthening, community participation, development of national capacity and local

[1] First Greenhouse Gas inventory (NEC, RBoB September 2000)

and regional expertise. It also will include developing locally appropriate methodologies for analyzing these effects and increasing understanding of current interactions of climate and environmental and socioeconomic effects and changes.

6.2 Impact on Agriculture

Agriculture is inherently sensitive to climatic conditions. Upland crop production, practiced close to the margin viable production can be highly sensitive to variation in climate. A temperature increase of 2^0C would shift the cultivating zone further into higher elevation. This means that crops that are sensitive to low temperatures can be introduced into higher elevations with this temperature rise although this may seem a useful aspect, a closer examination indicates that the land forms at this altitudes are mainly steep slopes, appropriate only for protection forest, and unsuitable for agriculture. The related cropping patterns would be affected. Warming may have positive impacts on crop yields if moisture is not a constraint. But increase in the occurrence of extreme events or pest may offset any potential benefits. Both crops and livestock would be affected by increased incidence of alien/invasive pest and diseases (IPCC 1998).

Climate change is expected to increase the severity and frequency of monsoonal storms and flooding in the Himalayas, which could aggravate the occurrence of land slides. In addition to the danger to life and property some of the generated sediments may be deposited in the agricultural lands or in irrigation canals and streams, which will contribute to deterioration in crop production and in the quality of agricultural lands.

In Bhutan, an important dimension in dealing with the impacts of climate change on agriculture is the wide range of conditions for agricultural production. The impacts of climate change on agriculture have not been established. Agriculture is also influenced by other climatic sensitive variables, such as pests, insects, and plant diseases, which are not as yet captured in impact scenarios.

The anticipated impacts of climate change on agriculture in Bhutan include:

- Shifts in vegetation zones and agriculture
- Biodiversity threats
- Northern expansion of agricultural potential. Warmer climate at the temperate and alpine zones (2500 -3500 m) could shorten the growth duration of crops.
- Rice cultivation could extend up to 3000 m from the present altitude limit of 2400 m
- Decreased crop production in the southern foothills due to moisture stress
- Soil erosion and loss of agricultural land
- Occurrence of new diseases and pests

Climatic variation, particularly deviations from ‘normal’ conditions, represents significant and recurring risk to agricultural producers and the viability of rural communities.

6.3 Agriculture Adaptation

The Initial National Communication of Bhutan on Climate Change (NEC 2000) suggests that Bhutan’s adaptation strategies take a “no-regret approach” approach. These strategies should increase the ability of ecosystems and communities to cope with on-going environmental stresses and climate variability. In addition, “no-regrets” strategies benefit both the society and the environment in the long run, in spite of initial economic costs.

The Initial National Communication suggests the following basic measures related to agriculture sector to be undertaken not only to meet the climate change, but also in the country’s development process:

Agricultural Activities

1. There is a need to develop varieties of crops and livestock with greater resilience to limited arable land arable land and extreme temperature events.
2. Quarantine surveillance should be increased against alien/invasive species with higher temperature optima and others, which may be adapted to higher elevations.
3. Agro-forestry or agro-silvo-pastoral systems may be utilized to reduce erosion and run-off on steep slopes. This could also be used to mitigate heat stress and respiration problems, as well as soil fertility loss.

Forests and Biodiversity

1. Community based forest management and afforestation projects should be encouraged in areas where ther is rich bio-diversity. Forest Management approaches should consider and contribute to national land conservation, water resource conservation, nature conservation, wood production and human living environment conservation, as well as prevention of the global warming
2. Research in developing a sustainable socio-economic system, which can ensure that society is in harmony with the natural environment, should be initiated.
3. Research in tree species that are fast growing and more resistant to insect damages, natural phenomena and forest fire should be initiated.
4. Improvement to an appropriate database for natural resources such as forests – not only in the context of climate change but also support to other development strategy frameworks – is urgently required.
5. Banning of export of raw timber products by RGoB in the recent years was one good example of adaptation measures for sustainability of forest cover.

Water resources

4. Community involvement and awareness are very important in using water resources more sustainably.
5. Land use planning should be improved to promote afforestation in degraded water cathment areas.
6. There is a need to extend, improve and maintain water supply infrastructure, including water tanks, pipes and so forth.

6.3.1 Potential adaptation measures

Diversifying crop and livestock types and varieties to reduce economic vulnerability

Changing location of crop and livestock production areas

Changing farm practices to encourage soil moisture retention

Diversifying household agricultural incomes

Developing new crop varieties tolerant to temperature and moisture stress

Developing early warning systems to inform farmers about the variability and probability of extreme climatic events

Developing or enhancing irrigation and other water management systems

Modifying subsidy, support, and incentive programmes to influence farm level production and management practices

- It will be necessary to first determine the sensitivity of forests to climate change and then identify the degree of change that would have serious impacts (IPCC 1998a). Adaptation strategy may include:

- Adjusting replanting behavior, including planting species more tolerant to variable climates
- Protecting existing forests by enhancing fire and pest prevention programmes

- Management techniques, particularly those of integrated water resources management, can be applied to adapt to the hydrologic impacts of climate change and thus lessen vulnerabilities. Adaptive responses include both supply side (changes in water supply) and demand side (differential pricing, public awareness campaigns etc) approaches and would offset some, nut not all, of the impacts on water users.
- Physical adaptation measures to reduce drought impacts on agriculture should mainly focus on improved irrigation efficiency and crop diversification. Improved irrigation efficiency will become an important adaptation too. Crop diversification with an emphasis on more drought resistant crops in drought sensitive areas should help to reduce vulnerability to climate change. For example, wheat requires significantly less irrigation water compared to rice. Institutionally, measures to reduce drought vulnerability may consider development of drought tolerant crop varieties and training and extension. Emphasis should be given on community- based adaptations rather than regulation, i,e. the community deciding on how to share a limited common resource.

6.4 Adaptation Strategies and Technologies

Adaptation to climate risks and opportunities could involve innovations in farm management practices, crop breeding, weather forecasting, farm financing, crop insurance, and government relief programs. These impacts and adaptation issues are not well addressed in current research programs and little information exists on their implications for the agri- food sector. The adaptive capacity of farmers is severely restricted by heavy reliance on natural factors and lack of complementary inputs and institutional support systems.

Impacts of climate change(especially variations from year to year and extreme events) are not experienced in isolation from other stresses on a farming system (for instance depressed market prices and increased input cost) which has an impact on the ability of producers to deal effectively with climate change risks and opportunities. Research directed at understanding the multiple factors influencing decisions and support programs is lacking.

6.4.1 Building Adaptation Capacity

- create awareness among farmers and other stakeholders
- better provision of crop-climate/ weather information
- farm-level adaptations- changes in inputs, timing, crops grown, cultivar traits, etc.
- Increased productivity on intensively managed lands, through increased research and development
- increased and more effective extension activities
- more efficient marketing systems and increased storage capacity

6.4.2 Priority areas for adaptation

- improving availability of appropriate High Yielding Varieties seeds
- expanding areas under different crops and commodities through diversification of agriculture
- improving productivity of crops, existing plantations, and livestock
- developing infrastructure for post-harvest management, marketing, and agribusiness
- transfer of technological inputs
- develop and implement insect pest and diseases surveillance system

6.4.3 'No-regrets' policy options

- breeding and development of new crop varieties and species (heat- tolerant crops, low-water use crops)
- maintenance of seed banks, flexibility of commodity support programs, agricultural drought management
- promotion of efficiency of irrigation and water use and dissemination of conservation management practices. Water conservation measures by all users
- More efforts at water quality protection from agricultural, industrial, and human wastes
- rehabilitation of degraded forest and watersheds
- Greater emphasis on planning and preparedness for droughts and severe floods
- strengthening of biophysical and socioeconomic resource use related databases, and focused research to improve our understanding of climate-ecosystem-social system interaction at the macro-and micro- levels.
- Increasing genetic enhancement and base-broadening efforts: Broadening the genetic base of crops can contribute to increasing stability and performance in crops.
- Promoting sustainable agriculture through diversification of crop-production and broader-diversity in crops. The future agriculture system will need to incorporate a broader range of crops including inter alias crops, which produce raw material or are sources of energy. Actions are warranted now to encourage and facilitate the use of more diversity in breeding programmes for the varieties and species used on-farms.
- Innovation approaches in plant breeding for the purposes of domesticating new crops, the development of new plant varieties and the promotion of higher levels of genetic diversity in crops. On farms, use of crop mixtures of adapted varieties, are recognized as means for adding stability in agricultural systems and promoting agricultural production and food security.
- Pursue the present efforts on IPM
- Increase efficiency of fertilizer use
- Develop and adopt proper land and soil management system

6.4.4 Planning for Adaptation in Agriculture

1. Embark on the development of a national framework for adaptation in agriculture. The framework should identify the goals for adaptation, priority areas for action, factors that need to be addressed in adaptation strategy development and mechanisms that exist or will be needed for adaptation strategy development.
2. Conduct research to better determine Bhutan's vulnerability in the agriculture sector to climate change and to contribute to the development of adaptation strategies
3. Mainstreaming climate change issues in land use planning, natural resources management, energy, transport, and coastal management agendas;
4. Integrating climate change management in the economic planning and budget process, by engaging Ministries of Finance or Planning:
5. Incorporate climate change in long- term research planning for agriculture. The potential impacts of climate change on agriculture should give directions to the RNR Research System.
6. Developing and promoting resource conserving technologies – zero tillage, reduced tillage, surface seeding, direct seeding in rice instead of transplanting, soil amendments etc..
7. Improving dissemination of good practice tools and methodologies;
8. Implement research and development on new crops suitable for impacts of climate change. Research and development efforts should include crops better suited to grow under climate

change conditions. Crop varieties that are more resistant to extreme weather events will be needed under climate change.

9. Improve the outreach and information dissemination network, and corresponding extension services. Agriculture is a relatively flexible economic sector because farmer can change crops and practices on an annual or more frequent basis.
10. Expand access to credit and crop insurance: farmers need ready access to credit for financing the purchase of new equipment, adopting new technologies and for investment in alternative crops.
11. Integrated farming Systems Approach. Promote and encourage the present integrated farming through a combination of diversified and mixed farming consisting of crop husbandry, agro-forestry, dry-land horticulture, silvi pastures and livestock farming.
12. Integrated Watershed Development as an Adaptation Strategy and Mitigation Option. Mainstreaming of the approach to strengthen and build on the progress made so far. Need to identify critical watersheds and develop management programmes. Strengthen national level coordination to involve all the stakeholders.

6.5 Information gaps

The National Communication on Climate Change has identified the following information gaps in preparing the vulnerability and adaptation assessment for Bhutan (NEC 2000):

- Future climate change scenarios for Bhutan
- Status and health of mountain ecosystems and their sensitivity to climate change and non-climate stresses
- Land evaluation and land at risk from flooding and inundation
- Erosion processes, sediment transport dynamics and areas at risk from erosion, specially in already erosion prone areas
- Effect of climate change on water resources
- Possible risk of damage from floods to housing and infrastructure
- Present cross-sectoral interactions and the possible effect of climate changes on these interactions
- Cumulative effects and indirect impacts of climate change effects
- Cost in environmental and social consequences, particularly, and effectiveness of adaptation opportunities, including mitigating measures and policy strategies

Farmers will adjust to climate change only if they have reliable information about how climate is changing, how it affects their yields and management opportunities, and how climate change affects demands in markets in which they compete.

6.5.1 Research needs and questions

Applied research in the field of impacts and adaptation of agriculture to climate change is needed. The list of information gaps and research need is given below

1. How will the frequency and intensity of agriculturally significant climatic conditions change?
2. What climate parameters have the most impact on agriculture in Bhutan (heat, frosts, drought, precipitation patterns, etc.) and how does the agri-food sector currently deal with them?
3. How do agricultural producers adapt now to variability and extremes?
4. Will the detrimental effects of climate change on other regions in the world have positive or negative effects on Bhutanese agriculture?

5. How can climate change be recognized and exploited for new opportunities and possibilities?
6. What are the climate change related pest and disease risks for agriculture including frequency and intensity? What are the proposed adaptation strategies for climate related pest and disease risks and what impact could these strategies have environmentally and economically?
7. What adaptation options are technically feasible and economically viable?
8. How can climate change adaptation issues be integrated into other agriculturally related research programmes?

6.5.2 Technologies (Agriculture Working Group)

	Technology identified (hardware & knowledge including local technologies)	What national or Sectoral policies and goals does this technology meet?	What environmental benefits do they have? Does this technology aid in mitigation or adaptation to climate change?	What local situations need to be considered for this technology with regard to sustainability, suitability and local capacity
1	Genetic improvement of crops	Food security	Adaptation	Limited arable land
2	Irrigation water management	Conservation	Mitigation	Capacity and skills
3	Mechanization of agriculture	Increased income	Adaptation	Landforms
4	Integrated Pest Management	Food security	Mitigation	Capacity and skills
5	Improved soil management	Food security	Mitigation/adaptation	Traditional practices
6	Appropriate land use system	Food/conservation	Mitigation/adaptation	Sectoral demands
7	Increased efficiency of fertilizer use	Food security	Mitigation	Local resources
8	Improved cropping system	Food security	Mitigation/adaptation	Access to market
9	Introduction of improved animal breeds	Conservation/food	Mitigation	Local resources
10	Develop data base system	Capacity building	adaptation	Not accessible
11	Early warning system	Food security	Adaptation/mitigation	Poor infrastructure

9.

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