# ECONOMICS OF CLIMATE CHANGE FOR SMALLHOLDER FARMERS IN NEPAL: A REVIEW

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## ABSTRACT

*Climate change is taking place. It is not clear what costs the farmers face and benefit receive as the impact of the climate change. The paper assesses the costs of climate change on agriculture using literature review and deductive logic. The farmers have to bear direct and indirect costs of climate change and costs of adaptation. The direct costs involve yield decreases in crops and livestock and increase in costs of production. It also involves the costs from the increased risks of natural hazards. The indirect costs include the change in socioeconomic conditions, lost opportunities for the improvement of the living conditions and adaptation costs. Farmers are to bear heavy costs of climate change, much higher than the benefits. The benefits emerge from shortening of crop lifecycle, increase of growing seasons and carbon fertilization that increases the crop production. The study emerges with policy measures for reducing the costs of the climate change the farmers bear.*

**Key words:** adaptation, climate change, cost benefit analysis, direst costs, indirect costs, mixed farming, small farmers

## INTRODUCTION

Literatures agree that climate changes are taking place (IPCC et al., 2007). The climate change refers to a persistent change in the mean and variability of climate parameters (temperature, rainfall, humidity and soil moisture) due to change in composition of the atmospheric gases. The change in the atmospheric composition is attributed to the anthropogenic emissions of green house gases (GHG) such as carbon dioxide ($CO_2$), methane ($NH_4$), nitrogen oxide ($N_2O$) and other gases.

The changed climate is affecting, in one or the other way, the economic activities and welfare of the people all over the world. Rule of the thumb is that more an economic activity depends on the natural processes larger is the effect of the climate change on it. The enterprise most dependent on the natural processes is the agriculture, particularly the traditional smallholder mixed farming system. Such farming system is a complex set of livelihood strategies of the poor depending heavily on the social setup and natural resource endowments. The mixed farming with crops, livestock and agroforestry as the major constituents, involves nature, culture, habit, practice and traditions relating closely to natural resource management, social status maintenance and economic achievement of the smallholder farmers. Agricultural production is the outcome of the freshwater irrigation supplies from rivers and spring and rainfall, fertile soil terraced and maintained by the farmers for generations. Similarly, the production is resultant of the balance of predators and pollinators maintained by the biological diversity and ecosystem health, suitable air temperature provided by the nature from seasons to season, suitable sunshine hours depending on the seasons and farmers painstaking management learnt for generations. Selection of the crops and their varieties, crop planting, intercultural operations and harvesting practices in several instances are guided by the culture of the farmers. Likewise, the selection of the animals and their breeds and their rearing practices are also governed by the culture. Similarly, the indigenous knowledge relating to the traditional habits of the farmers, both men and women guides many of the farm operations. Most of the farming practices among the smallholder farmers are tradition bound and tested and adjusted for

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generations. The small farmers, mostly illiterate or with low level of education depend heavily on their culture, habit and traditional practices to earn their livelihood without understanding the science behind their day to day decisions. Rapid change in the climate is, however, making such traditional practices and indigenous knowledge obsolete in no time that costs heavily to these innocent farmers. Application of modern inputs though increases the crop and livestock yields results into simplification of agroecosystems, brings losses in fertility and increases risk of exposure to new pest and disease variants (Ensor, 2009). Such simplification makes the agroecosystem vulnerable to the climate change adding the costs to the livelihood of the farmers.

The climate change is imposing heavy costs to the smallholder farmers whose livelihood is based on the structure, process and functions of the nature and market systems under which they operate. Changed temperature, rainfall pattern, humidity and soil moisture have several biophysical effects on agroecosystems most of which are still to be understood by the scientists. Such changed climate has grave impacts on socioeconomic factors. Moreover, the biophysical effects of the climate change are microclimate specific and the socioeconomic effects are household specific. There are several publications discussing biophysical effects of the climate change whereas very few are on the socioeconomic effects of the climate change. It is imperative to understand how the climate change affects the farmers' livelihood and what the farmers can do to adapt to the changed situation. This review paper discusses the potential economic impacts of the climate change on smallholder farming communities in Nepal.

The scope of the paper is limited to the costs of climate change to the farmers. Agriculture is responsible for 14 percent of global GHG emissions in the year 2000 (Stern Review 2007, Annex 7g). Similarly, the livestock play globally a considerable role in climate change in terms of their contribution to GHG emissions (Steinfeld et al., 2006). Due to rise in the income and awareness of the consumers about the benefits of animal protein, global demand for livestock products will continue to rise in the coming decades (Delgado et al., 1999) increasing the emissions. But, the emission mitigation issue is out of the scope of the paper.

The next section describes the methodology followed in the study. The results of the study are presented in section three. The findings are discussed and concluded in section four.

## METHODOLOGY

The paper first summarizes the literatures available on the costs of climate change on crop production, livestock rearing and climate adaptation including the socio-economic costs. It then briefly summarizes some of the key findings from the literatures on agricultural impacts of climate change, based on the International Panel on Climate Change (IPCC) Assessment Reports (2001, 2007).

The smallholder farmers are bound to bear disproportionately high costs of climate change. What are the costs the farmers are likely to incur? What are the benefits the farmers are likely to get? The paper answers these questions based on review of the literature relating to the costs of climate change to the farmers through the increased costs of crop production and reductions in the gross revenues due to the decreased productivity. It also reviews the literature relating to the effects of the climate change that increases the costs of livestock and poultry production. Similarly, the literatures relating to the effects of the climate change on the production of the livestock and poultry are reviewed.

Though several studies use simulation models for the identification of the effects of climate change on agriculture such models are global and aggregated in nature and not much helpful for the farm level impact assessment on crops and livestock. Moreover, such global models have many limitations to simulate climate changes on crops and livestock production. Studies are very scanty on the socio economic impacts of climate change other than those on crop and livestock production. For the purpose of guiding decision makers, the costs to the smallholder farmers are identified and discussed.

Studies are sparse on the impacts of climate change on farm value, farmers' employment, farm income, home consumption and gross domestic products (GDP). Economics of climate change is still shaky, and particularly for the farm economics is still hazy. This is because the economic performance of the farm is not only affected by the climate change, but also, at the same time, by the changes in other drivers such as production technology, consumption demand and price, and governing policies. It is not easy to isolate the impacts of climate change from the hosts of other changes taking place, probably more strongly than the climate change. Therefore, the results of the review are developed logically and presented in partial analysis framework.

## RESULTS

Many studies attempt to estimate impacts of climate change on agriculture mostly by combining crop growth models with economic models (Kane et al., 1991; Parry et al., 1999; Reilly and Hohmann, 1993; Rosenzweig et al., 1993; Rosenzweig and Parry, 1994; Tsigas et al., 1997). The climate change has potential impacts on costs of production, farm revenues, farm value, employment, income, consumption and GDP. Though several reports are available on the effects of climate change on crop production mostly using crop simulation models based on different scenarios of GHG emissions, temperature rise and risks of extreme events, those on the costs to the farmers are very limited.

Logically, the farmers are to face three types of the costs from the climate change, namely, direct impact, indirect impact and adaptation costs (Table 1).

1. Direct costs from the effects of climate change on crop production, livestock production, and risks of natural hazards
2. Indirect costs from the effects of climate change on socioeconomic conditions and lost opportunities for their advancement of the living conditions
3. Costs of adaptation incurred to keep themselves away from or minimize the negative effects of the climate change.

Table 1: Potential costs of climate change falling on the smallholder farmers

| | Direct costs | Indirect costs | Costs of adaptation |
|---|---|---|---|
| 1 | Decrease in gross returns from crops | Costs of land degradation | Costs of technological adaptation |
| 2 | Additional costs of crop production | Costs of agro-biodiversity loss | Cost of behavioral adaptation |
| 3 | Decrease in gross returns from the livestock production | Costs of uncertainties | Costs of managerial adaptation |
| 4 | Additional costs of livestock and poultry production | Costs of food insecurity | Costs of compliance to policy options |
| 5 | Costs due to increasing risks of natural hazards | Costs of conflicts over scarce resources | |

Source: Author

Each of these costs deserves discussions and quantification. As the quantification of the costs is out of the scope of the paper, following paragraphs are devoted to the discussion of each of the cost headings.

### DIRECT COSTS

The direct costs are visible to the farmers who bear the costs, but may not be aware that such costs are due to the climate change. Many studies reported the direct costs of climate change on agriculture but the estimations of such costs are either not available at all or very context specific. The estimated costs are also based on several assumptions. Decreased gross returns from the crops, livestock and poultry and their increased costs of production due to changed climate are the direct costs. Increased risks of natural hazards are the most distressing direct costs to the farmers.

*Gross returns from crops*

Studies report that the global warming in general reduces the yield of grain crops because of accelerated plant development (Wheeler et al., 1996; Amthor, 2001). Several crop-yield models are developed to simulate the crop responses to the changing climate factors that affect crop growth and the yield. Such models are extensively used to represent management options (Rosenzweig and Iglesias, 1998). Some models are specific to some crops and some others are general covering several crops. As an example, CROPWAT is an empirical irrigation management model developed by the United Nations Food and Agriculture Organization (FAO) to calculate regional crop water and irrigation requirements from climatic and crop data (CROPWAT, 2004).

The IPCC Third Assessment Report estimates a general reduction in water availability and crop yields. The IPCC report on Impacts and Adaptation finds that climate change is likely to have both positive and negative impacts on agriculture, depending on the region of the world and the type of agriculture (Easterling et al., 2007, p. 275). Based on climate change simulations using the Commonwealth Scientific and Industrial Research Organization (CSIRO) model, Nelson et al. (2009) estimate that South Asia will experience the worst effects of climate change on cereal production by the year 2050 (Table 2). The decrease in the production due to the climate change will be greater in developing countries than that in the developed countries and greater in South Asia as compared to those in other developing countries. Agricultural production in developing countries is more nature based (depending on rainfall and atmospheric temperature) whereas those in developed countries are infrastructure based (with irrigation facilities and controlled humidity and temperature). Large proportions of farms in South Asia are small, fragmented and rainfed exposing them to the vagaries of extreme weathers resulting from the climate change.

Table 2: Effects of climate change on cereal production (no $CO_2$ fertilization)

| Production | Region | Production in 2000 (mmt) | Production in 2050, no climate change (mmt) | With climate change (% change) |
|---|---|---|---|---|
| Rice | South Asia | 119.8 | 168.9 | -14.3 |
| | Developing countries | 370.3 | 434.9 | -11.9 |
| | World | 390.7 | 455.2 | -11.9 |
| Wheat | South Asia | 96.7 | 191.3 | -43.7 |
| | Developing countries | 377.9 | 663.6 | -33.5 |
| | World | 583.1 | 917.4 | -27.4 |
| Maize | South Asia | 16.2 | 18.7 | -18.5 |
| | Developing countries | 321.3 | 556.2 | -10.0 |
| | World | 617.2 | 1061.3 | 0.2 |
| Millet | South Asia | 10.5 | 12.3 | -19.0 |
| | Developing countries | 27.3 | 66.2 | -8.5 |
| | World | 27.8 | 67.0 | -8.4 |

Note: mmt = million metric tons. Estimates based on Commonwealth Scientific and Industrial Research Organization, Australia (CSIRO) model. Source: Nelson et al. (2009)

The reduction in crop productivity due to the climate change will reduce the gross revenues of the farmers as well as the returns to the land and labour. As the effects cover wide areas, with some exceptions of colder regions, the price of the agricultural products is expected to rise. This will compensate some of the losses in the crop production for the net food selling farmers. But, large proportion of the farmers in Nepal being subsistence and even net-food buyers, such benefits of price rise will not be available to them. Such rise in price will add the costs of food buying to the food deficit farm households. It means, if the reduction in farm production is global, larger holder farmers will benefit from increased price and smallholder will lose, whereas, if the reduction in production is specific to South Asia or Nepal then the both small and large farmers in the country will suffer and those in other countries less affected by the climate change will get benefitted from increased price. As the adaptation capacity of the poor farmers in Nepal is lower than those in developed countries, the smallholder farmers in the country are bound to lose.

*Costs of crop production*

The climate change potentially increases the costs of crop production. For example, the costs of irrigation water will increase due to increased water shortage and costs of drought resistance variety seeds will be higher than those of the ordinary variety seeds. Land degradation will increase the need for fertilizer application adding the costs of production. Longer spells of drought, increased water shortage and soil degradation can aggravate the effects of climate change and force large areas of marginal agriculture land out of production (Mendelsohn et al., 2000). The farmers need to put additional efforts and buy specific inputs for the same level of crop production. The additional efforts and specification of the inputs increase the costs of production.

As the farmers are the buyers of the agricultural inputs supplied by smaller number of sellers they can not transfer the increased costs of the production to the suppliers of the inputs. Large holder farmers, who sale farm products, can transfer some of the increased costs to the consumers if the demand for the farm products such as food is inelastic (decline in demand is less than one percent for one percent rise in the price) and the costs of the production increases in all the production areas. But, for the subsistence farmers who grow the crops for self consumption there is no way to transfer the costs to others.

*Gross returns from the livestock and poultry production*

There is a debate about the effects of the climate change on livestock production. Dixon et al. (2003) note that there are likely to be smaller impacts on livestock yields per se, compared with grassland biomass, because of the ability of livestock to adjust consumption in response to the changes. There is still another type of reporting that the net revenues from livestock for small farmers will be up by 25 percent, and that for large farms goes down by 22 percent (Seo and Mendelsohn, 2006). This is due to increased market price to all the farmers and increased costs of production to the large farmers. On contrary, several studies show that the climate change adversely affects livestock and poultry production. Livestock production is highly sensitive to climate change and that there is a non-linear relationship between climate change and livestock productivity (Kabubo-Mariara, 2009). The explanation is that the pasture species composition plays greater role in Nepalese range-based livestock farming. Increased temperature increases lignification of plant tissues and reduce the digestibility (Minson, 1990) reducing meat and milk production in range-based livestock production system. Increased heat stress is another pathway affecting the livestock production. The increased heat alters heat exchange between animal and environment affecting the feed intake and metabolism (SCA, 1990; Mader and Davis, 2004). Such stresses will affect growth and productivity of the animals. But, effects vary from species to species. For example, water buffaloes need frequent bath for heat exchange. Drying of ponds due to drought will deprive the buffaloes for taking baths affecting adversely the productivity of the buffaloes. Similarly, the increased energy deficits may decrease cow fertility, fitness and longevity (King et al., 2006). Increased temperature and humidity will increase the risks of mortality and morbidity among the livestock and poultry. Amundson et al. (2005) also report a decline in conception rates of cattle (Bos Taurus) for temperatures above 23.4 0C. But, Rotter and van de Geijn (1999) suggest that impacts of heat stress may be relatively minor for the more intensive livestock production systems where some control can be exercised over the exposure of animals to climate change. It means that the loss in the livestock production will depend on the degree of control of the shed. As the developed countries can control the livestock production conditions minimizing the losses from the climate change, the global price for the livestock products will not increase much due to the climate change. Thus, Nepalese livestock farmers who can not control the production conditions of the livestock are bound to suffer from both the sides, the reduced production and inadequate rise of the price. Moreover, the subsistence farmers almost always lose. However, the loss in the gross revenues from the livestock is expected to be smaller than those from the crops. Climate change also increases mortality and morbidity of animals particularly from the climate sensitive infectious diseases (Patz et al., 2005b). Increases in zoonotic diseases among the animals also increase the risks of transmission of such diseases in the human being. In summary, as a result of the climate change Nepalese farmers have to bear loss from the livestock production.

*Costs of livestock and poultry production*

Studies show that the climate change will have major impacts on the more than 600 million people who depend on livestock for their livelihoods (Thornton et al., 2002). These impacts will include reduction in the productivity of rainfed crops used for livestock and poultry feed, reduction in productivity of forage crops, reduced water availability and more widespread water shortages, and changing severity and distribution of important human, livestock and crop diseases. Major changes can, thus, be anticipated in livestock systems, related to livestock species mixes, crops grown and feed resources and feeding strategies (Thornton et al. 2009). Such changes increase the costs of livestock production. The climate change is feared to have impacts on feed crops and grazing systems, for example, greater incidences of droughts can decrease fodder production and rise in temperate can change the species-mix in the pasture (Hopkins and Del Prado, 2007). Increase in the temperature changes the rangeland species distribution, composition, patterns and biome distribution (Hanson et al., 1993) increasing the need for feed supplements.

With the climate change, the cost of water for the livestock farming will increase. The livestock need water daily and frequently and also for animal feed production. But, the literatures on the added water costs for livestock production are not readily available.

The climate changes also increases the costs of veterinary medicines in livestock and poultry production. Though the impacts of the climate change on animal diseases and their vectors depend on the ecosystems and their changes, nature of the pathogen and the susceptibility of the livestock (Patz et al., 2005a) the costs of the treatment is feared to rise. The effects of climate change on the health of livestock and poultry are reported by many studies (Cook, 1992; Harvell et al., 1999, 2002; Baylis and Githeko, 2006). Increased temperature and relative humidity also increases the risks on aflatoxin development in feed stuffs increasing the risks of poisoning among the animals. Thus, the climate change will increase the costs of livestock and poultry production.

*Costs from the risks of natural hazards*

The increased global temperature increases the risks of natural extreme events causing loss of natural and man-made capital. The farmers whose main capitals are the land and immobile irrigation structures will have higher risks of suffering from such hazards. Crops, fruit trees, livestock and poultry are also vulnerable to the natural calamities making the farmers more vulnerable to such hazards than the other households.

INDIRECT COSTS

*Costs of land degradation*

Price of agricultural land depends on the productivity of the land. Decrease in the productivity of the land due to the climate change will reduce the price of land asset. Long-term decline in rainfall have increased the spread of deserts in southern and western Africa, resulting in shifting sand dunes and loss of flora and fauna (IPCC et al., 2007). Though, such effects are not visible in Nepal, many farmers in mountain areas, particularly those who can afford for alternative livelihood, are found to abandon their farm land due to declining productivity. Such decline in the value of the land is not straight away visible to the farmers but it is actually happening.

*Costs of agro-biodiversity loss*

Farmers in Nepal heavily rely on agrobiodiversity to produce food, fuel and fibre. Biodiversity also helps the farmers by regulating the climate, diseases and flooding, recycling water and plant nutrients and providing them cultural and educational opportunities (FAO, 1999). Climate change and resultant loss of agrobiodiversity is really a cost to the farmers in Nepal. The mountainous ecosystems are feared to change further, resulting in loss of species adapted to the cold climate. Many species will become extinct, primarily due to loss of habitat and vegetation (Malcolm, 2006). Loss in the agrobiodiversity reduces the genetic base putting the farmers in increased risks of pest spread and other climate related risks.

*Costs of uncertainties*

Identifying effects of climate change on agricultural production is difficult given the complex interactions between climate and current natural resource management issues (Howden and Meinke, 2003). Climate-induced alterations in availability of land and water and their socio-economic impacts are not well understood. A major source of uncertainty is our inability to accurately project future changes in economic activity, emissions and climate (Darwin, 2004).

But, substantial uncertainties remain about actual and potential impacts of climate change on agriculture and its economic consequences (Antle, 2008). Such uncertainty reduces the visions of the farmers and also of the government for long term production and infrastructural planning. The uncertainties increase the insurance premium to the crops and livestock. Faced with a series of catastrophic losses, several property insurers have reached the conclusion that climate change and its economic implications have already arrived (Tucker, 1997). When crop changes occur due to localized changes in climate both the farmers and insurers incur losses (Fosse and Stanley, 1993). In addition, the increased uncertainty and increased costs of insurance increases the rate of discount in the agricultural investment reducing the potential investment. Such reduced investment is the costs to the agricultural sector in general and to the farmer specifically.

Costs of food insecurity

Decrease of grain yield due to the climate change is predicted by many simulation models particularly in tropical and subtropical climate. As the Terai plain, falling in sub-tropical areas is the main food production area in the country. It is likely that food production decreases in this area. The decreased in food production diminishes food security in Nepal. This is true for other small food-importing countries too (IPCC, 2001). The increased food insecurity increases the costs to food deficit farm households. This is particularly problematic to those smallholder farmers who are food deficit and have no secure alternative source of income. Climate change will affect the food quality because of the increasing temperature and decreasing crop growth period. It is necessary to integrate climate, energy, food, environment and population together to analyse future food security

(Kang, 2009). The study reported that the food availability and food quality still are the big challenges for scientists due to changing climate.

*Costs of conflicts over scarce resources*

The climate change is feared to degrade the natural resources like land, water, pasture and forest. The degradation of the natural resources increases the competition for acquiring or getting access to such resources. In a country like Nepal, where most of the healthy competitions fails, conflicts may arise for the use of the scarce resources. For example, conflicts may arise over the apportioning of the irrigation water or the use of pasture land. Such conflicts increase the cost to the farmers.

ADAPTATION COSTS

Wide array of options are being recommended for climate change adaptation, each option increases the costs. Improvement in the supply of ecosystem services like carbon sequestration and water quality increases the crop yield (Pretty et al., 2006). The ecosystem services can be augmented promoting ecosystem resilience and diversity. Diversity helps to control pests, diseases and weeds. Controlling erosion helps reduce nutrient losses. Conservation tillage, agroforestry practices and water harvesting techniques are other adaptation measures (TEEB, 2009). There are barriers, limits, and costs in adaptation, but these are not fully understood (IPCC, 2007). There are great varieties of adaptation measures available in agriculture, including technological, behavioral, managerial and policy options.

*Costs of technological adaptation*

Traditional agricultural technologies practiced by the farmers are time tested for generations for matching to the climatic conditions of the place. Green revolution technology was developed for a certain set of climatic conditions of recommendation domain. But, such technologies are being obsolete due to changed climate. The farmers now need to modify the existing technology or adopt new technology for sustaining their farm production.

The technological options for adapting to the climate change include switching to more resilient and drought tolerant crop varieties and rainwater harvesting. Adaptations to the droughts and high rainfall include water harvesting and storage (Nkomo et al., 2006, and Osman et al., 2005). Development of the irrigation infrastructure reduces the dependence of farmers on rainfall decreasing the effects of drought. But, the development of water harvesting, storage and other irrigation infrastructure involves costs. Planting a variety of crops side-by-side can significantly reduce plant pests and increase productivity. It can also lead to environmental benefits such as improved soil fertility, better water retention and resistance to drought (Lotter et al., 2003, and Fleissbach et al., 2006).

The adaptation technology can be grouped into four, namely, soil and water management, crop variety selection, planting practices and livestock management. Some examples of the soil and water management includes zero tillage, erosion control, retaining crop residues in the soil, extending fallows, changing land use and irrigation. Agro-ecological practices that integrates biological and ecological processes make the local ecosystems more resilient (Ensor, 2009). Such practices replenish natural resources by, for example, nutrient recycling and soil regeneration.

Adoption of new crop varieties such as drought-tolerant crops and pest resistant varieties is also helpful in climate adaptation. The change in planting techniques includes changing row spacing, changing planting density and altering the timing of operations.

Livestock rearing is an opportunity for generating employment for smallholder farmers. Studies report that drought-tolerant goats and sheep are better than the climate-sensitive cattle and chickens (Van den Bossche and Coetzer, 2008). Development and promotion of new composition of livestock feeds and improved animal health technology can also be helpful for climate change adaptation.

Nepalese farmers, particularly those without the access to the irrigation water, need to struggle a lot to adapt to the changed climate. Such farmers are in a dire need of financial and technical resources for adaptation. Such farmers need farming technology and improved infrastructure such as climate information, research, good roads and access to energy (Mendelsohn et al., 2000).

Development of National Adaptation Plan of Action (NAPA) and its implementation diverts the scarce resources and attention from other uses. Selecting appropriate adaptation options depends on local conditions, and addressing impacts at the local level (Ziervogel et al., 2008). Considering such problems of differentiated effects on different parts of the country with varying nature of the climatic conditions, Local Adaptation Plan of Action (LAPA) is being emphasized. But, every effort involves costs.

*Cost of behavioral adaptation*

The farmers need to change their production and consumption behavior for adapting to the changed climate. The behavioral measures include changes in dietary choices and cultural celebrations. Such choices may not involve out of pocket expenses but compromising the taste and preference is also a form of the cost.

*Costs of managerial adaptation*

The managerial measures include the changes in farm management practices. Improved soil and water management is an important adaptation measure suitable to the smallholder farmers (ISDR, 2008). Crop diversification helps to insure against poor harvests and promote local biodiversity and food security (FAO, 2008). But, such technologies and their management incur additional costs to the farmers. Other management options include soil moisture monitoring, follow, climate forecasting, continuous reviewing of market conditions, insurance of crops and livestock and income diversification. None of them are free of cost for the farmers.

*Costs of compliance to policy options*

The policy options include planning regulations and infrastructural development policies. The policy also includes agricultural support and insurance policies, improvements in agricultural markets and the promotion of terai-hill-mountain flow of farm products (Kurukulasuriya and Rosenthal, 2003; John et al., 2005; Thornton et al., 2009). However, the suitable adaptation measures differ from location to location and farming system to system. For example, for nomadic and sedentary pastoral communities in Himalayan belt the climate adaptation means changes in the policies of the rangeland management, alteration of the rotation, selection of the breeds and construction of ponds for rainwater harvesting.

Adaptation to the climate change is on the agenda of researchers, policymakers and program planners. The adaptation in agriculture involves implementing measures that help build rural livelihoods that are more resilient to climate variability and related disasters (Nelson et al., 2009). Though several adaptation options are evolving from the climate change research globally, the adaptation may be constrained by the institutional, social, economic and political environment in which people must operate (Thornton et al., 2009). Though the institutional and political constraints severe in Nepal, the economic constraint is the most binding for those mostly indebted poor farmers operating under liquidity crunch.

POSSIBLE BENEFITS OF CLIMATE CHANGE

The costs analysis will not be complete without pondering over the benefits of the climate change. Farmers in Himalayan region can benefit from temperature rise by shortening of the crop lifecycle and increasing growing seasons. The faster growth of the crops and longer growing season can increase the production of some crops. In addition to the nitrogen, phosphorus and potash the plants need carbon for their growth. Increased concentration of the carbon in the atmosphere is believed to accelerate plant growth and the phenomenon is commonly known as carbon fertilization. This is particularly true for C3 plants (like rice, soybean, wheat, rye, oats, millet, barley, potato) but not for C4 plants (like maize, sorghum, pearl millet and sugarcane). The effect is however, non linear increasing the production more for initial increase of the carbon dioxide in the air and tapering off the effect as the concentration increases.

The shorting of the growing period of the crops in the cold region can increase the cropping intensity (the number of the crops grown successively per year in the same land). The rise in temperature may reduce the heating costs in poultry farms. The rise is temperate can also help the farmers to shift the crop cultivation to the upper areas in the mountains, provided water is available in the upper slopes.

These benefits of the climate change in aggregate is, however, very small as compared to the costs that needs to be incurred by the smallholder farmers. From the analysis above, it is clear that the conditions of the poor smallholder farmers will go further aggravated due to climate change if we do not take necessary policy measures to rescue them. Additional investments required for the adaptation to the climate change are presented in Table 3. The investments may not guarantee that all the negative consequences of climate change can be defeated, but continuing with a business-as-usual approach will almost certainly guarantee disastrous consequences (Nelson et al., 2009). The increased investment in agricultural research, irrigation and rural roads can help the farmers to cope partially with the adverse effects of the climate change.

Table 3: Additional annual investment expenditures needed to counteract the effects of climate change on nutrition (US$ million at 2000 price)

| | Budget heads | South Asia | Developing countries |
|---|---|---|---|
| 1 | Agricultural research | 185 | 1373 |
| 2 | Irrigation expansion | 344 | 882 |
| 3 | Irrigation efficiency | 1006 | 2128 |
| 4 | Rural roads (area expansion) | 16 | 2881 |
| 5 | Rural roads (yield increase) | 13 | 74 |
| | Total | 1565 | 7338 |

Note: Based on CSIRO simulation model that does not include the effects of $CO_2$ fertilization. Source: Nelson et al. (2009)

## DISCUSSIONS AND CONCLUSIONS

It is evident that the climate is changing. Significant changes in physical and biological systems have already reported from all the continents and in most oceans, and most of these changes are in the direction expected with warming temperature (Rosenzweig et al., 2008). Due to the heavy dependence of the agriculture on ecosystems and biodiversity, agricultural production is highly sensitive to the climate change.

Economists are using several microeconomic models to help the farm level decision making regarding the crop choice and area allocation, methods of production, allocation of farm resources such as land, labor and capital. Such models can be extended adding suitable climate variables. Ricardian approach can be used for economic analysis of the climate change using spatial analogues, that is, cropping patterns in areas with climates similar to what may happen under climate change (Mendelsohn et al., 1994, 1999). Economic models that link climate variables to economic indicators statistically are helpful to identify the farmers' potential decisions on the adaptation to the changed climatic conditions and likely costs the farmers have to bear in future.

Support to the agriculture sector, particularly smallholders, is helpful in improving food security conditions in the country. Interventions like improved crop varieties, drought-tolerant livestock, irrigation infrastructure and suitable farming technology can be helpful to the farmers. Creation of the off-farm employment opportunities plays an important role by providing the farmers with sources of income that are less affected by the climate change than agricultural sources of income. Farming system researches are necessary for the identification of location and endowment specific management trade-offs suitable for the poor farmers. National and international policy measures for compensating the farmers for the costs incurred by them due to the climate change are advisable. Public sector investments in agricultural production are necessary to safeguards the farmers from the vagaries of the climate change. Agricultural research programmes need to the accelerated to develop technologies necessary for climate change adaptation. A series of further researches are necessary for quantification of the costs and benefits of the climate change in relation to the farmers and also to the food security of the nation.

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