Adapting Smallholder Agriculture to Climate Change

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Abstract Agriculture and climate change are mutually impacted. The worst affected are the small and marginal farmers who constitute more than 70 per cent of the farming community in India. Extreme weather events like increased frequency of heatwaves and cold spells, droughts and floods in the last decade have become common. In India agriculture contributes about 28 per cent of the greenhouse gas (GHG) emissions; about 78 per cent of methane and nitrous oxide emissions are estimated to be due to the current agricultural practices. Sustainable agriculture approaches are now acknowledged for the wide range of ecological and economic benefits that accrue to the practitioners as well as consumers of agricultural products. These approaches, based on low external inputs, are also less energy-intensive and less polluting and so mitigate and help in adapting to climate change. Combined with coordinated action by groups or communities at the local level, and supportive external institutions working in partnership with farmers, sustainable agriculture will help to mitigate and adapt to climate change.

Most of India lives in villages. Being a predominantly agrarian society, nearly three-fourths of India's population live in rural areas. Agriculture is the main source of livelihood for two-thirds of the population. The profound changes in Indian agriculture since the 1960s have had cascading effects on India's agrarian economy and society. After the ecological and economic crisis the farmers are now faced with the changing climate. The worst affected in the process are the small and marginal farmers (SMF) who constitute 70 per cent of the farming community. According to Census data, operational holdings below 4.0 hectares (ha) constitute 93.6 per cent of all operational holdings in 2000/01, covering 62.96 per cent of the operational area, or about 100.65 million ha in absolute terms (GoI 2005).

Agriculture and climate change are mutually impacted. Often the impact of climate change is underestimated, and the contributions of agriculture to climate change are ignored. As a result, much of the discussion and debates on climate change and agriculture are around particular technologies which can help farming to adapt to climate change. In reality, if farmers have to adapt to the changing climate, we need to understand this in a broader context of the ecological, economic and sociopolitical crisis that Indian farmers are already undergoing and build support systems to facilitate the process of adaptation.

The relationship between climate change and agriculture is three-fold. First, climate change has a direct bearing on the biology of plant and animal growth. Second, there are changes in farm ecology – such as soil conditions, soil moisture, pests and diseases, etc. Third, there is the ability of the existing social and economic institutions, particularly in rural areas, to deal with the challenges posed by global warming. In the larger context of food security and climate change, it is also important to consider other sectors like animal husbandry and livestock, which are closely linked with agriculture.

1 Impact of climate change on agriculture

Climate change is manifesting itself in many ways across the country. Among the indicators, while long-term rainfall data analysis shows no clear trend of change, regional variations as well as increased rainfall during summer and reduced number of rainy days can be observed. In the case of temperature, there has been a 0.6°C rise in the last 100 years and it is projected to rise by 3.5–5°C

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by 2100. The carbon dioxide concentration is increasing by 1.9ppm each year and is expected to reach 550ppm by 2050 and 700ppm by 2100. Extreme events like frequency of heatwaves and cold spells, droughts and floods have been observed in the last decade. The sea level has risen by 2.5mm every year since 1950 while the Himalayan glaciers are retreating. These are all symptomatic of climate change (Smith *et al.* 2007).

Available research indicates that climate change-induced rises in temperature are going to affect rainfall patterns – farming in India depends on monsoons and there is a close link between climate and water resources.

Indian agriculture being predominantly rainfed may be more prone to the impacts of climate change. Rainfall extremities are being witnessed frequently. For instance, it is reported that about two-thirds of the sown area in the country is drought-prone and around 40 million ha are flood-prone. Climate change is also poised to have a sharply differentiated effect across agro-ecological regions, farming systems, and social classes and groups. The poorest people are likely to be hardest hit by the impacts of climate variability and change because they rely heavily on climate-sensitive sectors such as rainfed agriculture and fisheries. They also tend to be located geographically in more exposed or marginal areas, such as flood plains or nutrient-poor soils. The poor are also less able to respond due to limited human, institutional and financial capacity and have very limited ability to cope with climate impacts and to adapt to a changing hazard burden.

The organic carbon levels and moisture in the soil will go down while the incidence of runoff erosion will increase. Crop quality may also undergo change with lower levels of nitrogen and protein and an increased level of amylase content. In paddy, levels of zinc and iron will decline which will impact the reproductive health of animals. Insect lifecycles will increase which in turn will raise the incidence of pest attacks and virulence. Other likely impacts are change in farm ecology, *viz.* bird-insect relations, and an increase in sea levels which will cause salinity ingression and submergence.

It is projected that due to climate change, *kharif*[1] rainfall is going to increase and this might be positive for *kharif* crops. Further, for *kharif* crops, a 1°C rise in temperature may not have big implications for productivity. However, temperature rises in the *rabi*[2] season will impact the production of wheat, a critical foodgrain crop.

The surface air temperatures will increase by 2–4°C by 2070–2100. As mentioned earlier, the *rabi* crop will be impacted seriously and every 1°C increase in temperature reduces wheat production by 4–5 million tons, according to a study by the Indian Agricultural Research Institute. This loss can be reduced to 1–2 million tons only if farmers change to timely planting. Increased climatic extremes like droughts and floods are likely to increase production variability. Productivity of most cereals would decrease due to temperature increases and a decrease in water availability, especially in Indo-Gangetic plains (Agarwal *et al.* 2010). The loss in crop production is projected at 10–40 per cent by 2100, depending upon the modelling technique applied.

The impacts of climate change are already visible. A network of 15 centres of the Indian Council for Agriculture Research (ICAR) studying climate change has reported that apple production is declining in Himachal Pradesh due to inadequate chilling. This is also causing a shift in the growing zone to higher elevations (Rana *et al.* 2009). Similarly in the case of marine fisheries, it has been observed that sardines are shifting from the Arabian Sea to the Bay of Bengal, which is not their normal habitat. In fact, fisheries are the sector most vulnerable to climate change. Crops have the ability to adapt to extreme climate variability even up to, say, 4°C while fish and animals do not. It has also been recorded that the pest ecology of certain crops is changing due to climate change.

Global warming may increase average water vapour and evaporation, increase precipitation in high-altitude regions, significantly alter the monsoon pattern resulting in long dry spells and heavy downpours and change storm patterns which could influence the global movement of pests, especially pathogens.

1.1 *Pest and disease shift*

Insect populations, like all animal populations, are governed by their innate capacity to increase as influenced by various abiotic and biotic factors. The changes caused by the natural evolutionary forces are accelerated with human

Box 1 GHGs and their global warming potential

Measure of the ability of a gas in the atmosphere to trap heat radiated from the earth's surface compared to a reference gas, which is usually assumed to be carbon dioxide:

- carbon dioxide (CO_2) = 1
- methane (CH_4) = 21
- nitrous oxide (N_20) = 310
- sulphur hexafluoride (SF_6) = 23,900
- tetrafluoromethane (CF_4) = 6,500
- hydrofluorocarbons (HFCs): HFC-134a = 1,300
- chlorofluorocarbons (CFCs): CFC-114 = 9,300
- hydrochlorofluorocarbons (HCFCs): HCFC-22 = 1,700

Source Smith *et al*. (2007)

interventions. After changes like depletion of natural resources, environmental pollution and extinction of certain species of plants and animals, climate change – particularly that caused by inadvertent anthropogenic disturbances – has become more evident.

In agricultural ecosystems, soil, plant and animal interactions are rarely persistent enough, in time and space, to provide ecological stability but result in dynamic equilibrium. Pest shifts are observed with changes in the ecological balance. The natural balance between beneficial and harmful insects changes with cropping patterns, pest management practices and variability in the environment. Weather and climate have an impact on the pest population. Climate change leads to shifts in the pest incidence, migration and viability thresholds. Today, farming and farmers' lives are already affected by pests and the pest management practices they adopt. Hence, understanding the intricacies of climate change impact on pest management in agriculture is crucial.

1.1.1 *Temperature*

All life survives within a certain narrow temperature range. Deviations from this optimum range on either side are tolerated to some extent, depending on the physiological adaptations of the concerned species or populations. Temperatures above or below these limits can prove lethal. Exposure to lethal high or low temperatures may result in instant death, or failure to grow and reproduce normally. Harmful effects of exposure to sub-lethal temperatures may be manifested at a later critical stage such as molting or pupation. The temperature rise might also have a negative effect on delicate natural enemies such as hymenopteran parasitoids and small predators. This may affect the natural enemy–pest relationship. For example, the Brown Plant Hopper is 17 times more tolerant to 40°C than its predator *Cyrtorrhynus lividipennis* but the Wolf Spider *Paradosa pseudoannulata* is tolerant to 40°C.

1.1.2 *Moisture*

Most terrestrial insects live in a dry environment. The only source of water for insects is the water obtained in food material from their host plants. These insects have therefore developed a variety of mechanisms to conserve water. In spite of these mechanisms, exceptionally dry air may prove lethal to most insects. Likewise, excessive moisture may also adversely affect many insects by encouraging disease outbreaks, affecting normal development and by lowering their capacity to withstand lower temperatures. The reproductive capacity of the insects is also affected by moisture but there are great differences in the capacity of different insects to tolerate conditions ranging from extreme dryness to near saturated environments. For example, the incidence of Rice Hispa (a rice insect pest) in the Telangana region of Andhra Pradesh has increased in the last two years due to prevailing dry situations.

In recent years a shift has been observed from leaf/fruit-eating caterpillars to sucking pests. While monoculture of crops/varieties and chemical pest management practices are understood to have caused such pest shifts, climate change has also contributed. For example, in cotton there is a shift towards sucking pests (mealy bugs, jassids) particularly after the introduction of *Bt* cotton.[3] Similarly, aphid incidence in groundnuts, and thrips and yellow mites in chillies are observed. Most of the sucking pests are also vectors of viral diseases. With the increasing incidence of sucking pests, viral diseases are also increasing. These include bud necrosis in groundnuts, tobacco streak virus in cotton, and similar viral problems in most of the fruit and vegetable crops.

2 Impacts of agriculture on climate change

Agriculture contributes around 10–12 per cent of total global greenhouse gas (GHG) emissions but is the main source of non-carbon dioxide (CO_2) GHGs, emitting nearly 60 per cent of nitrous oxide (N_2O) and nearly 50 per cent of methane (CH_4) (Smith *et al.* 2007).

Amongst various GHGs that contribute to global warming, carbon dioxide is released through agriculture by way of burning of fossil fuel; methane is emitted through agricultural practices like inundated paddy fields; nitrous oxide is released through fertilisers, combustion of fossil fuels, etc. Nitrous oxide has a global warming potential 310 times greater than CO_2. In India, it is estimated that 28 per cent of the GHG emissions are from agriculture; about 78 per cent of methane and nitrous oxide emissions are also estimated to be from agriculture.

2.1 Chemical fertilisers and climate change

Nitrogen fertiliser manufacture and application to the soil contributes significantly to GHG emissions and thus, climate change. India consumes ~14 million tonnes (Mt) of synthetic nitrogen every year, of which about 80 per cent is produced within the country, making it the second largest consumer and producer of synthetic nitrogen fertiliser in the world, after China. The GHG emissions from fertiliser manufacture and use in India was estimated to have reached nearly 100 million tonnes of CO_2 equivalent in 2006/07, which represents about 6 per cent of total Indian GHG emissions (Roy *et al.* 2010).

There are many sources of emissions in the manufacture of synthetic nitrogen fertilisers:

- the manufacture of synthetic nitrogen fertiliser is a very energy-intensive process, and currently requires large amounts of fossil fuel energy;
- natural gas is the main fuel and feedstock, which accounts for 62 per cent of the energy used in synthetic nitrogen fertiliser production;
- less efficient and more polluting fuels such as naphtha and fuel oil also represent a high share – 15 and 9 per cent respectively – of the energy used in fertiliser manufacture (values as at 2006/07, FAO 2007);
- of the various forms in which synthetic nitrogen fertilisers are available, urea accounts for a chunk of the total nitrogen fertiliser produced and consumed (81 per cent in 2006);
- the synthesis of urea is based on the combination of ammonia and CO_2 and its emissions are dominated by CO_2;
- while other synthetic nitrogen fertilisers comprise a smaller percentage of the fertiliser market, they make notable atmospheric emissions during both production and consumption. The author calculated emissions from the manufacture of synthetic nitrogen fertiliser using the Intergovernmental Panel on Climate Change (IPCC) methodology;
- total GHG emissions from the manufacture and transport of fertiliser are estimated at 6.7kg CO_2 equivalent (CO_2, nitrous oxide and methane) per kilogram of nitrogen.

Globally, an average 50 per cent of the nitrogen used in farming is lost to the environment. Significant amounts escape into the air, or seep into the soil and underground water, which in turn results in a host of environmental and human health problems, from climate change and dead zones in the oceans to cancer and reproductive risks (Galloway *et al.* 2008).

- 1.25kg of N_2O emitted per 100kg of nitrogen applied;
- as nitrate polluting wells, rivers, and oceans;
- volatilisation loss – 25–33 per cent;
- leaching loss 20–30 per cent.

2.2 Burning crop residues

Another major contributor to GHGs is the burning of crop residues. In Punjab, wheat crop residue from 5,500sq km and paddy crop residues from 12,685sq km are burnt each year. Every 4 tons of rice or wheat grain produce about 6 tons of straw. Emission factors for wheat residue burning are estimated as: CO – 34.66g/kg; NOx – 2.63g/kg; CH_4 – 0.41g/km; PM10 – 3.99g/kg, PM2.5 – 3.76g/kg (Gupta *et al.* 2004).

Figure 1

CH_4 emissions (Tg CO_2–eq.yr^{-1})	References
55.2–138	Parashar *et al.* (1994)
135	Yan *et al.* (2003)
94.07 ± 27.37	Gupta *et al.* (2009)

Burning of crop residues also impacts soil fertility. Heat from burning straw penetrates into the soil up to 1cm, elevating the temperature to as high as 33.8–42.2°C. Bacterial and fungal populations are reduced immediately and substantially in the top 2.5cm of the soil upon burning. Repeated burning in the field permanently diminishes the bacterial population by more than 50 per cent. The economic loss due to the burning of crop residues is colossal. Each year 19.6 million tonnes of straw of rice and wheat, worth crores of rupees are burnt. Used as recycled biomass, this potentially translates into 38.5 lakh tonnes of organic carbon, 59,000 tonnes of nitrogen, 2,000 tonnes of phosphorous and 34,000 tonnes of potassium every year.

2.3 *Inundated paddies*

Another potent GHG is methane which is emitted in copious amounts through inundated paddy cultivation. Rice paddies emit CH_4 when they are flooded as the anaerobic decomposition of organic matter in the soil produces the gas, which then escapes to the atmosphere mainly through diffusive transport through the rice plants (Nouchi *et al.* 1990), or it is oxidised before reaching the surface. The level of CH_4 emission from any given rice paddy is related to factors that control the activity of the methane-producing (methanogens) and methane-oxidising bacteria (methanotrophs) such as temperature, pH, soil redox potential and substrate availability, and also soil type, rice variety, water management and fertilisation with organic carbon and nitrogen (see reviews by Le Mer and Roger 2001, and Conrad 2002).

In India, of a total area of 99.5 million hectares (Mha) under cereal cultivation, 42.3 Mha (or 42.5 per cent) are under rice cultivation. Rice is grown under flooded conditions and the seedbed preparation involves puddling or ploughing when the soil is wet to destroy aggregates and reduce the rate of water infiltration. Such anaerobic conditions lead to the emission of methane and possibly nitrous oxide through inefficient fertiliser use.

Emission of methane from rice paddies in India is differentially estimated. The average methane flux from rice paddies ranges from 9–46g/m2 over a 120–150-day growing season.

2.4 *Large dams and GHGs*

Another indirect contribution of agriculture to GHG emissions comes in the form of large dams. Large dams contribute an estimated 18.7 per cent of emissions in India. Total methane emissions from India's large dams could be 33.5 million tonnes (MT) per annum, including emissions from reservoirs (1.1MT), spillways (13.2MT) and turbines of hydropower dams (19.2MT). The methane emission from India's dams is estimated at 27.86 per cent of the methane emission from all the large dams in the world, which is more than the share of any other country worldwide (Lima *et al.* 2007).

2.5 *Livestock sector*

India is now among the world's largest producers of milk, poultry, meat and eggs. It has the world's biggest dairy herd, 300 million strong, comprised of cows and buffaloes, and is the second largest global producer of cows' milk and first in buffalo milk. It is also the world's top national milk consumer and demand for milk and other dairy products is growing by 7–8 per cent per year. This country is also the world's fourth largest producer of eggs and fifth largest producer of poultry meat, principally from chickens.

However, livestock in India is more distributed and household-based and mostly integrated with crop production. The crop residues are used as fodder and animal waste is used as the manure for the crop fields. The impacts of livestock on climate change need to be understood in this context. Livestock is also impacted by climate change. Possible temperature increases in India of between 2.3–4.8°C by 2050 will cause heat stress to animals used in milk production and will affect reproduction and the amounts of milk each animal provides. Crossbred cows may be most vulnerable to higher temperatures. Increased temperatures and sea level rises may also reduce the availability of land to grow feed, and result in lower crop yields and an increase in the severity and spread of animal diseases.

In 2010, India was the world's fastest growing poultry market, outpacing Brazil, China, the USA, the European Union and Thailand. The cost of producing chicken for meat in the country is the world's second lowest, and production of eggs in India is cheaper than in any other country, according to the Poultry Federation of India. India is the top global exporter of buffalo meat and it also exports increased quantities of maize and soy, both important ingredients in commercial feed. In addition, India's leading poultry producers are expanding their sales to countries in Asia and the Middle East.

GHGs are generated at virtually every point along the livestock production chain. Enteric fermentation in livestock released 212.10 million tons of CO_2 eq. (10.1 million tons of CH_4). This constituted 63.4 per cent of the total GHG emissions (CO_2 eq.) from the agriculture sector in India. The estimates cover all livestock, namely, cattle, buffalo, sheep, goats, poultry, donkeys, camels, horses and others. Manure management emitted 2.44 million tons of CO_2 eq. (MOEF 2010).

In India, the emissions from the energy used by the agriculture and fisheries industries totalled 34 million tons of CO_2 or 3 per cent of the GHGs produced by the energy sector. This does not include emissions from electricity taken from the national grid to, for instance, cool large poultry or egg operations or dairies, or to slaughter and process animals and their products. Soil cultivation related to animal agriculture globally emits about 28 million tons of CO_2 every year. More than half of this energy used in producing milk and eggs can be attributed to feed production. There are other indirect CO_2 emissions, specifically from the manufacture of chemical and nitrogen-based fertilisers. About 41 million tons of CO_2 are emitted globally each year from the production of nitrogen fertilisers applied to feed crops.

Carbon dioxide is also released when forests and other vegetation are destroyed to make way for feed crops or pasture. Considerable uncertainty exists in calculating overall GHGs from such changes in land use, though the Food and Agriculture Organization (FAO) estimates that 2.4 billion tons of CO_2 are emitted every year due to deforestation to create pasture land for livestock or land for cultivation of feed crops. On the top of this, 100 million tons of CO_2 are released every year from livestock-induced desertification of land.

Figure 2

Operation type	Emission level (kg CO_2 – eq.ha^{-1})
Tillage	4.40–73.60
Drilling or seeding	8.10–14.30
Application of agrochemicals	1.80–37.00
Combine harvesting	22.10–42.10

Source Calculated from data in Lal (2004).

2.6 *GHG emissions from the use of farm machinery*

The other major source of energy emissions in intensive farming models is the use of fossil fuels for machinery like tractors, harvesters, pumps for irrigation, etc.

3 Adapting to climate change

Conventional approaches to understanding climate change were limited to identifying and quantifying the potential long-term climate impacts on different ecosystems and economic sectors. While this approach is useful in depicting general trends and dynamic interactions between the atmosphere, biosphere, land, oceans and ice, this top-down, science-driven approach failed to address the regional and local impacts of climate change and local abilities to adapt to climate-induced changes (TERI 2005).

3.1 *Approaches to climate change adaptation*

The two main types of adaptation are autonomous and planned adaptation. Autonomous adaptation is the reaction of, for example, a farmer to changing rainfall patterns, in that s/he changes crops or uses different harvest and planning/sowing dates, by trial and error.

Planned adaptation measures are conscious policy options or response strategies, often multisectoral in nature, aimed at altering the adaptive capacity of the agricultural system or facilitating specific adaptations. For example, deliberate crop/varieties selection, promoting/discouraging certain practices by incentivising/regulating, etc. And the adaptation measures are to be considered holistically, including trade-offs among biophysical and sociopolitical factors.

Biodiversity in all its components (genes, species, ecosystems) increases resilience to changing environmental conditions and stresses. Genetically diverse populations and species-rich ecosystems have greater potential to adapt to climate change. It is essential to use indigenous and locally adapted plants and animals, thus ensuring the selection and multiplication of crop varieties and animal species that are locally adapted and resistant to adverse conditions.

Work on adapted crops and animals cannot be separated from their management options within agro-ecosystems. For example, rice, one of the staple food crops of India, has several varieties with different abilities to tolerate high temperature, salinity, drought and floods. Rice varieties with salinity tolerance have been used to expedite the recovery of production in areas damaged by the 2004 tsunami (FAO 2007). Similarly, practices like the System of Rice Intensification (SRI) can reduce water usage and thereby methane emissions from the paddy fields. It was observed that methane emissions are four times lower and nitrous oxide emissions are five times lower from SRI fields compared to conventional paddy fields (Karki 2010).

Climate change adaptation for agricultural cropping systems requires a higher resilience against both excess of water (due to high-intensity rainfall) and lack of water (due to extended drought periods). A key element to both problems is organic soil matter, which improves and stabilises the soil structure so that the soils can absorb higher amounts of water without causing surface runoff, which could result in soil erosion and, further downstream, in flooding. Soil organic matter also improves the water absorption capacity of the soil so that it can withstand extended droughts. While intensive tillage reduces soil organic matter through aerobic mineralisation, low tillage and the maintenance of permanent soil cover (through crops, crop residues or cover crops and the introduction of diversified crop rotations) increase soil organic matter. A non- or low-tilled soil conserves the structure of soil for fauna and related macropores (earthworms, termites and root channels) to serve as drainage channels for excess water. Surface mulch cover protects soil from excess temperatures and evaporation losses and can reduce crop water requirements by 30 per cent. Thus organic/ecological farming can increase soil organic carbon, reduce mineral fertiliser use and reduce on-farm energy costs.

A broad range of agricultural water management practices and technologies are available to spread and buffer production risks. Enhancing residual soil moisture through land conservation techniques assists significantly at the margin of dry periods while buffer strips, mulching and zero tillage help to mitigate soil erosion risks in areas where rainfall intensities increase. The inter-annual storage of excess rainfall and the use of resource-efficient irrigation remain the only guaranteed means of maintaining cropping intensities.

The negative impact of ruminants on GHG emissions can be addressed through changes in animal husbandry including ruminant diets and animal stocking ratios to avoid nitrous oxide emissions. Effective waste management in the form of biogas, etc. can also reduce methane emissions.

The risks to and vulnerabilities of the poor who live in insecure places and need to build their resilience to cope with climatic fluctuations are among the more important challenges in adapting to increasing climate variability and climate change.

To sum up, sustainable agriculture (ecological farming/organic farming/LEISA[4]/Non-Pesticidal Management [NPM]/SRI, etc.) approaches are now acknowledged for the wide range of ecological and economic benefits that accrue to the practitioners as well as consumers of agricultural products. These approaches, based on low external inputs, are also less energy-intensive and less polluting and so mitigate and help in adapting to climate change.

However, the promotion of sustainable agriculture on a large scale is often challenged about its potential as well as its practical limitations. In the last five years, two large-scale initiatives – scaling up NPM (Community-Managed Sustainable Agriculture – CMSA) in Andhra Pradesh (Ramanjaneyulu and Rao 2008) and SRI promotion in Tripura, Orissa and Tamil Nadu – have brought in new learnings and diluted earlier apprehensions on scaling up such practices and their relevance on a large scale.

These successful experiences had three elements in common. First, all have made use of locally adapted resource-conserving technologies. Second, there has been coordinated action by groups or communities at the local level. Third, there have been supportive external (or non-local) government and/or non-governmental institutions working in partnership with farmers. Almost every one of the successes has been achieved despite existing policy environments that still strongly favour 'modern and established' approaches (technology and support systems) to agricultural development.

Now the challenge is how these can be scaled up onto a large scale across the nation given the wide diversity of situations. This needs a newer approach in terms of capacity building, horizontal learning, newer institutional systems and newer forms of financial support. The programmatic support to agriculture today favours only high external input-based agriculture. As a result, none of the mainstream programmes provide any support for promotion of these new, sustainable models. This needs the recasting of programme guidelines or initiating newer programmes to provide support to more sustainable models in agriculture which can be easily accessible to small and marginal farmers.

Therefore any effort to initiate a programmatic support to scale up sustainable agriculture must have a broad framework of:

- reducing the risks attached to uncertain weather conditions and degraded and limited natural resources in these regions, by adopting suitable cropping patterns and production practices;
- diversifying the assets and income sources to sustain livelihoods by integrating livestock and horticulture into agriculture and promoting on-farm and off-farm employment opportunities;
- conserving and efficiently using the available natural resources like soil and water, and promoting biomass generation;
- organising farmers into institutions which can help them to have better planning, greater control over their production, help to access resources and support, improve food security and move up the value chain;
- building livelihood security systems to withstand natural disasters like drought, floods and other climate uncertainties.

Notes

1 *Kharif* is the rainy season from June to September.

2 *Rabi* is the winter season from October to February.

3 *Bt* cotton is genetically modified cotton which produces a toxin to manage bollworm infestation.

4 Low External Input Sustainable Agriculture.

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