

CLIMATE CHANGE IN NORTHEAST INDIA: RECENT FACTS AND EVENTS –WORRY FOR AGRICULTURAL MANAGEMENT

Anup Das*, P.K. Ghosh, B.U. Choudhury, D.P. Patel, G.C. Munda, S.V. Ngachan and Pulakabha Chowdhury

ICAR Research Complex for NEH Region, Umiam-793 103, Meghalaya, India

KEY WORDS: North East India, Climate Change, Drought, Agriculture, Management.

ABSTRACT:

The Northeastern Region of India is expected to be highly prone to the consequences to climate change because of its geo-ecological fragility, strategic location vis-à-vis the eastern Himalayan landscape and international borders, its trans-boundary river basins and its inherent socio-economic instabilities. Environmental security and sustainability of the region are and will be greatly challenged by these impacts. The region fall under high rainfall zone with subtropical type of climate. Still, under influence of global climate change even high rainfall areas are facing drought like situations in the current years. Droughts and floods are the adverse climatic conditions arising out of deficit and excess rainfall, respectively. Drought assumes significance mainly in rainfed conditions like in North East India. Unprecedented drought like situation affected very adversely the whole NER in recent years. Special reference may be made for the year 2005, 2006, 2009. Floods are equally devastating in the region. The increasing melting of glaciers in Himalayas are great concern for the region. In the absence of scientific data about the vulnerability of the region to climate change, conservation agriculture, afforestation, rain water harvesting, efficient use of inputs, following proper agro-techniques for management of drought are some of the management options that needs to be immediately popularized among the farming communities to mitigate the impact of climate change.

1. NORTH EAST INDIA-A NATURE'S GIFT

The North Eastern Region (NER) comprises of the states of Arunachal Pradesh, Assam, Manipur, Nagaland, Mizoram, Sikkim and Tripura. The region stretches between 21°50' and 29°34' N latitude and 85°34' and 97°50' E longitude. The region has a population of 39 m and geographical area of 26.2 million hectare, which is 3.85% and 8% of the population and area of the country, respectively. Assam is situated in the center and hill states (except Sikkim) are situated around it. Out of the total geographical area 28.3% has an elevation more than 1200 m, 17.9% between 600 and 1200 m and about 10.8% between 300 m and 600 m above mean sea level. The hilly areas of the region are sparsely populated (63 people/km²) compared to plains (369/km²). Assam has 68.2% of the total population against an area of 29.9% of the region. The region has about 72% area under hilly ecosystems. The region has inaccessible terrain, fragility, marginality, excessive sloping land with rolling topography, rich biodiversity, unique ethnicity and socio-ecological set up. The NE region received high rainfall and therefore clothed with diverse and dense vegetation. Beyond the transitional pre-glacial region with increasing altitude, there appears the greater Himalayan region devoid of significant vegetative cover. Rocky surface, alpine vegetation and snowcapped high peaks dominate the physical landscape of this area. The altitudinal pattern of north east varies from place to place. The plains mainly comprises of Brahmaputra and Barak valleys. The adjoining areas of Barak rivers are active flood plains with marshy lands subjected to extreme annual inundation. The Manipur basin has an area of 1,853 km². The Tripura plains have an area of 3500 m² and has land features of erosive nature.

The region has about 60% area under forest with Arunachal Pradesh having about 80% of its area under different kinds of forest, while Assam has the minimum percentage of forest area (30%). The varied physiological features and altitudinal differences gives rise to varied types of climate ranging from near tropical to temperate and alpine. The annual rainfall in the region is received mainly from south-west monsoon from middle of May and continue till October. On an average, the NE region receives about 2450 mm of rainfall. The Cherrapunji-Mawsynram range receives rainfall as high as 11,500 mm, annually. The region shows great variation in temperature regime too. The temperature varies from 15°C to 32°C in summer and 0 to 26°C in winter. The NE region is very rich in biodiversity and harbours the largest number of endemics and species then anywhere in the country. Of the total 17000 flowering plants of the country, about 5000 species is found in NE region. The distribution of various species has been restricted due to topographical features, deep valleys, slopes and river system. The agricultural practices of the region are broadly of two types, viz., (i) settled cultivation practiced in plains, valleys, foot hills and terraced slopes and (ii) shifting cultivation in hilly areas of all the states with the exception of Sikkim, where settled cultivation is practiced on terraces. Agricultural operations are carried out up to 3600 m altitude and on slopes up to 60%. Cropping system in the region is predominantly rice based except Sikkim, where maize based systems are dominant. More than 80% of gross crop area is under food grains and rice occupies 89.8% of the total food grain area and 93.2% of the total food grain production. The agriculture in the region is mainly at subsistence level. The region as a whole is having a deficit of 1.6 mt of food grains. The cropping intensity in the region is 120%. The low cropping intensity is mainly due to lack of irrigation facilities and insufficient soil moisture during winter.

* anup_icar@yahoo.com

The highly biodiverse but fragile mountain ecosystems of North East India have diverse vegetation types encompassing from the subtropical, submontane, montane, subalpine to alpine systems. North East India is nestled in the globally recognized biodiversity hotspot and an ecoregion and renowned for its high species diversity and endemism. It is also recognized as one of the centres of origin of cultivated plants. The dependence of the population on forest's resources is high which provides livelihood to more than 225 tribal groups native to the region.

2. WEATHER ANALYSIS OF NORTH EAST INDIA

The North Eastern Region (NER) of India, by virtue of receipt of heavy rainfall, falls in low rainfall variability category and it ranges from 8-15%. For the North Eastern states of India, the normal annual rainfall ranges from 200-300 cm. Green vegetation, big water bodies and the nature's beauties and mega-biodiversity are the attraction of the NER. The rainfall pattern of Umiam, Meghalaya has been analyzed using 'Ranking order method' (Doorenbos and Pruitt, 1984). The main finding was that rainfall is, more or less, normally distributed.

Of late, the region is loosing its nature's gifted fame. In high rainfall areas distribution of rainfall is of more concern as compared to its amount received. Erratic nature of rainfall, its intensity and frequency often make crop planning a difficult task in rainfed areas. The world highest rainfall area Mawsinram/Cherrapunjee also falls within the region.

2.1 Rainfall Analysis

The Fig.1 depicts the annual rainfall distribution pattern of Umiam, Meghalaya, India for the period of 27years (1983-2009). It indicates that the mean annual rainfall was less than normal mean (2400mm) during the year 1985, 1990, 1994, 1996, 1998 and 2006. The most deficit rainfall year was 1998 in which annual rainfall

was 1779.8mm. The most excess annual rainfall was 3360.2mm during the year 1988 followed by 2007 (3096.9mm) and 1989 (2903.0mm). During the year 1983-89 and 1999-2002, the rainfall trend was same whereas, during 1993-99 and 2006-09 has shown a significant erratic nature in the annual rainfall.

The Fig.2 indicates that the monsoon rainfall (June-September) distribution trend for the period of 27 years (1983-2009). It has significantly shown a drastic rise in monsoon rainfall from the year 2001. During 1983-2000, the mean monsoon rainfall was far below of 1000mm except the year 1991(1154.7mm). The monsoon rainfall significantly increased during the year 2001-09 up to 1102.6 to 1937.7mm. It indicates that the monsoon rainfall has shifted to post monsoon season.

Under influence of global climate change even high rainfall areas are facing drought like situations in the current years and the reverse i.e. flood is frequenting mostly in low rainfall areas like Maharashtra, Gujarat etc. Droughts and floods are the adverse climatic conditions arising out of deficit and excess rainfall, respectively. Drought assumes significance mainly in rainfed conditions. Unprecedented drought like situation affected very adversely the whole NER in general and Assam in particular during 2006. According to India Meteorological Department (IMD) a high-pressure area over the region occurs when there is a low-pressure system over the Bay of Bengal and a typhoon also exists over the South China Sea. This was exactly the situation observed in 2006. In 2006, the anti-cyclonic system - that is high-pressure system over the Eastern Tibet was visible on the far west of its normal position causing less rainfall in the NER of India. According to IMD records, the amount of rainfall received by the NER in 2006 monsoon season stands to be the scantiest for a period of 25 years, since 1982. Out of seven NE states, Assam seems to have suffered most from this deficit rainfall and high temperature prevailed in 2006 monsoon season.

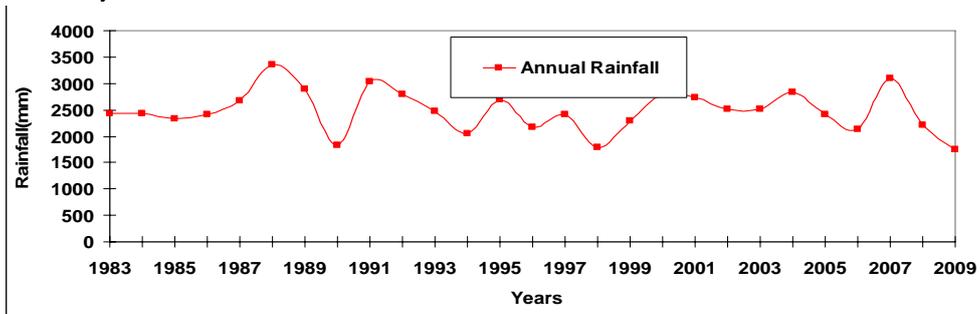


Figure 1. Annual Rainfall Distribution Pattern at Barapani Over the Last 27 Years (1983-2009)

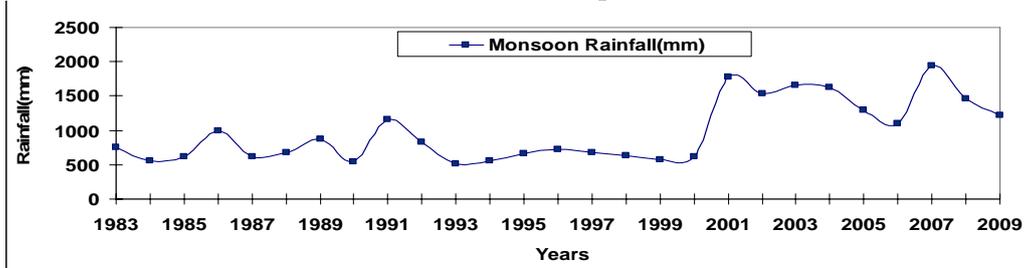


Figure 2. Monsoon Rainfall Distribution Pattern at Barapani over the Last 27 Years (1983-2009)

State	Excess (+) / Deficiency (-)	
	2005	2006
Assam & Meghalaya	-23%	-32%
Arunachal	Normal	-25%
Nagaland	-22%	-25%
Manipur	-22%	-25%
Mizoram	-22%	-25%
Tripura	-22%	-25%

Table 1: Amount of Deficit Rainfall Recorded in North East

Source: IMD, Guwahati, India

Worst is the situation in 2009 (upto end July). Most of the NE states are affected by drought like situation. Manipur, Nagaland, Meghalaya witnessed severe meteorological drought. Other states have recorded moderate drought. Till July, 20, 2009 Manipur recorded 67 % rainfall deficiency followed by Nagaland (-63), Meghalaya (-56), Assam (-34),

Mizoram (-32), Tripura (-31) and Arunachal Pradesh (-29). Assam - Meghalaya Division has recorded a deficit of 45% this year compared to 32 % in 1986 making it highest rainfall deficit year in last three decades (Times of India, 22 July, 2009). Arunachal Pradesh (6 districts), Assam (3 districts), Nagaland and Sikkim (1 district in each) remained very severely affected by Drought, which has received less than 55 mm of rainfall in consecutive 4 previous weeks (NESAC, 2009). This has severely affected the transplanting and sowing of rice in the drought affected areas. Between 1991 and 2000, only four years saw normal or above normal rainfall in NER. Conventionally it becomes difficult to complete agricultural operations due to heavy and continuous showers. Coupled with this scorching heat is further aggravating the situation. But this time, one can see crack (small to medium size) in low land, dried crops in upland even in the wettest month of July in the region. In the absence of a organized water resources and irrigation plan, the region is in threat for complete or partial crop loss. One living in Shillong at this point of time hardly believes such adversities of weather in the region. Rice is the predominant crop of the region (occupies about 84 % of cultivated area). The total area affected by agricultural drought during south-west monsoon period constitute about 40% of the NER geographical area and 39% of rice cultivated area. In other words NEW will suffer about 25 % reduction in rice production during 2009-10 and may have to import about 24 lakh tons of additional food grain to compensate loss.

The weather this time would have a disastrous impact on the agriculture sector of the State. The dry spell has left a significant number of the farmland in NER without any tilling activities even upto the first week of August. Due to absence of operational irrigation facilities the farmers faced a totally disastrous condition due to lack of inadequate rainfall for paddy cultivation that otherwise face perennial problem of flood during the monsoon season. Estimate of crop (Rice) production loss in Assam has been fixed around 15-20%. This weather condition has also posed a

serious threat to the tea and fish sectors. The situation would lead to early closure of the plucking season this time. Crop failure due to a severe drought in previous years left many families penniless and the situation was not likely to improve this year too owing to a delayed and weak monsoon.

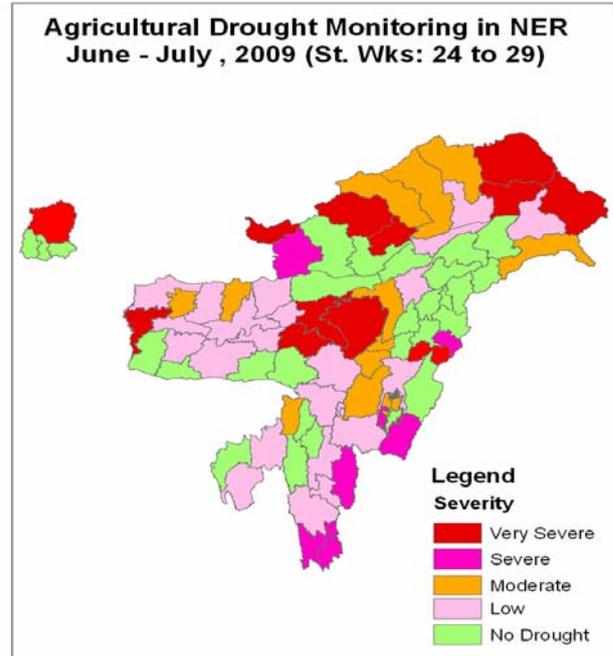


Figure 3. Drought Scenario in North East India
(Source: NESAC, Shillong, India)

Drought conditions prevailing in almost all the fish farming areas have adversely affected rearing of fish. The issue attracting a lot of concern is the condition of available fish seed and the prospect of their survival. 'Carried over seed' is the source for farmers to rear the next season's fish. Low water levels in *beels* (natural landlocked water bodies), ponds and rivers, accompanied by high temperature inhibits fish breeding, a phenomenon more pronounced in shallow water bodies. *Son beel* (Karimganj, Assam) case may be referred here for current drought situation. Soaring temperatures lowered the biological oxygen demand (BOD) in ponds, *beels* and man made tanks, which hampered the growth of fish. Reduced fish population in the *beels* located in forests could have an impact on the migratory bird population that flocks to the protected areas every winter. The pine, the naturally dominated tree species in mid-altitudes are encroached upon by another tree species *Schima walchii*, climatic consequences of which needs to be thoroughly evaluated.

2.2 Climate Change and Northeast India – Some Recent Evidences

The northeast Indian region of India is expected to be highly prone to the consequences to climate change because of its geo-ecological fragility, strategic location vis-à-vis the eastern Himalayan landscape and international borders, its trans-boundary river basins and its inherent socio-economic instabilities.

Environmental security and sustainability of the region are and will be greatly challenged by these impacts.

The impacts of climate change on regions like northeast India are less explored and less known till now making the future scenarios more uncertain for vulnerability assessment and risk management. However, certain indicators point to impacts being already visible in the region.

Studies on rainfall and the temperature regimes of northeast India indicate that there is no significant trend in rainfall for the region as a whole i.e. rainfall is neither increasing nor decreasing appreciably for the region as a whole (Das and Goswami, 2003; Das, 2004). However, for a part of the region that the meteorologists of the country officially refer to as the 'South Assam Meteorological Subdivision' (that covers mainly the hill states of Nagaland, Manipur, Mizoram and Tripura and parts of the Barail Hills in southern Assam), a significant change in seasonal rainfall has been observed. The summer monsoon rainfall is found to be decreasing over this region significantly during the last century at an approximate rate of 11 mm per decade (Das 2004, Mirza et al., 1998).

The predicted increase in the precipitation in the forest areas in the Indian subcontinent is higher than that of the non-forest area. Climate models predict 2.0 -3.50 C increase in temperature and 250 – 500 mm increase in precipitation in the North Eastern region. Increase in rainfall may not have significant impact on the forest areas of North East which are already experiencing high rainfall but change in temperature regime may cause severe impact and significant changes.

Analysis of long-term temperature data for the region points to a distinctly rising trend in surface air temperatures. The annual mean maximum temperatures in the region are rising at the rate of +0.11°C per decade. The annual mean temperatures are also increasing at a rate of 0.04°C per decade in the region (Das 2004). This may well be a manifestation of the regional impact of global warming/climate change. However, more rigorous study needs to be done at regional scale before anything can be said conclusively.

Several districts of Assam were badly affected due to drought like situations consecutively for two years in 2005 and 2006 which had a signature of climate change on them as vindicated by the IPCC report of 2007 (IPCC, 2007). In the intense drought-like conditions that prevailed in as many as 15 districts of Assam during the summer monsoon months of the year 2006 owing mainly to below normal (nearly 40%) rainfall in the region, more than 75% of the 26 million people associated with livelihoods related to agriculture in these districts were affected and the state suffered a loss of more than 100 crores due to crop failure and other peripheral affects. Other states of the region also received rainfall 30 – 40 % below their normal rainfall except Mizoram. Normally such fluctuations are considered as results of inter-annual variability of the monsoons, but then climate change impacts are supposed to affect the southwest monsoon also by increasing the normal mode of its variability.

The year 2005 saw prolonged dry periods in Mizoram with many springs and streams drying up accompanied by large scale landslides (ICIMOD, 2008). Rainfall occurring earlier or later has adversely affected sowing and harvesting of crops, harvestable grains have been damaged. Moreover, there are reports that natural wetlands are shrinking in many parts of the region. Some ecologists have informed about appearance of more number of invasive species and changes in their distribution pattern in the region. Some have reported more number of diseases and pests in citrus species. One significant impact which many plant scientists agree to is the change taking place in the phenological phases in plants (ICIMOD, 2008).

2.3 Water and Climate Induced Hazards: Concerns for NE India

As a result of global warming and climate change, glaciers in the Himalayas are retreating at an average rate of 15 meter per year, consistent with the rapid warming recorded at Himalayan climate stations since the 1970s. In the Himalayan region alone 67% of the glaciers have retreated in the past decade, e.g. the *Gangotri* glacier has been receding at a rate of 28 meter per year. Under a warming environment the Himalayan glaciers are expected to melt faster leading to increased summer flows and flooding initially for a few decades followed by progressive reduction in flow as the river-feeding glaciers recede and disappear from the headstreams. Widespread water scarcity in the river basins like those of the Indus, the Ganga and the Brahmaputra is a serious consequence on the cards. Moreover, in case of glacier-fed rivers, glacial-melt runoff is seen to augment winter flow in the lean season. With glacial contribution decreasing over the years, in future lean season flow will decrease and water stress will increase in the Brahmaputra basin where large populations depend on agriculture for livelihoods. Glacial retreat in the Himalayas may lead to serious alterations in the hydrological regime of the Brahmaputra river system as the mainstream of the Brahmaputra (known as the *Yarlung Zangbo* in Tibet, China) and some of its tributaries like the *Subansiri* and the *Jia-Bharali* are partly fed by snow-melt runoff. Projected increase in rainfall and accelerated summer flows may give rise to more intense flooding and flood hazards, but consequent retreat of glaciers may reduce flows in the long run (Das, 2009).

Extreme precipitation events (heavy rain storm, cloud burst) may have their own impacts on the fragile geomorphology of the Himalayan part of the Brahmaputra basin causing more widespread landslides and soil erosion. The response of hydrologic systems, erosion processes, and sedimentation in the Himalayan river basins could alter significantly due to climate change. Two extremely intense cloud bursts of unprecedented intensity- one in the western Meghalaya hills and Western Arunachal Pradesh in 2004 produced two devastating flash floods in the *Goalpara* and *Sonitpur* districts of Assam bordering Meghalaya and Arunachal respectively causing hundreds of deaths and enormous loss to the animals and agriculture.

The most recent examples of such flash floods originating from extreme rainfall are two events that occurred in the north bank of the Brahmaputra River and caused significant damage to human life and property. The first of the two events occurred during the

monsoon season on June 14th, 2008 due to heavy rainfall on the hills of Arunachal Pradesh north of *Lakhimpur* District causing flash floods in the rivers of *Ranganadi*, *Singara*, *Dikrong* and *Kakoi* that killed at least 20 people and inundated more than 50 villages leading to displacement of more than 10,000 people. The other that occurred in the post monsoon season on October 26 affected a long strip of area of northern Assam valley adjoining foothills of Bhutan and Arunachal Pradesh causing flash flooding in four major rivers (all are tributaries of the river Brahmaputra) and a number of smaller rivers. This episode of flash floods caused by heavy downpour originated from the Tropical Depression 'Rashmi', (a depression over the West Central Bay of Bengal adjoining Andhra coast) and affected mainly the catchments of the rivers *Puthimari* (Assam-Bhutan border), *Jia-Bharali* (Assam-Arunachal Border), *Ranganadi* (Assam-Arunachal Border), and the *Subansiri* (Assam-Arunachal Border).

The southern part of *Nagaon* district in central Assam valley and adjoining parts of *Karbi Anglong* form a rain-shadow zone where annual rainfall is as low as 800-1200 mm. Water scarcities are a potential constraint for the people living in this rainshadow zone and absence of effective irrigation systems or water harvesting practices adds to the vulnerability of the people. But what is of immediate concern is that rainfall in this zone is decreasing slowly as found in *Lunding* where rainfall is on the decline at a rate of 2.15 mm per year (Das, 2004). As a result water crisis might aggravate in this region in the coming years.

Floods have caused mayhem in the region, especially in Assam, every year causing tremendous loss to crops, infrastructure, economy, livelihoods and lives of the people. During the period of 45 years between 1953 and 2004, the seven states of the region suffered together a loss of about 2 billion rupees due to flood damage to crops, houses and public utility while 1.25 million hectares of land were affected due to floods. In some years floods have affected more than 3.8 million hectares of Assam's total area of 7.8 million hectares (WB, 2007). Floods inundate at least 2,000 villages every year in addition to destroying other infrastructure. The problem is further exacerbated by riverbank erosion, which destroys about 8,000 hectares of riparian land along the Brahmaputra annually. Vast areas in the region have been affected by erosion e.g. 1 million hectares in Assam; 815,000 hectares in Meghalaya; 508,000 hectares in Nagaland; 108,000 hectares in Tripura; and 14,000 hectares in Manipur (Venkatachary et al., 2001).

3. SOME MANAGEMENT OPTIONS TO MITIGATE CLIMATE CHANGE

In the wake of such a shift in climate in the region, there is a urgent need for reassessment of the agricultural practices. The foremost important thing i.e., afforestation programme should be taken up by the community, Institutes, NGOs, schools and Governments. The agricultural practices that conserves natural resources and has the advantage to delay effect of stress should be given importance and necessary policy or subsidy may be encouraged. Some of the resource conserving technology suitable for the region are-

- Minimum tillage or zero tillage with residue cover in surface for improving soil quality and conserving soil moisture.

- Cover cropping, in-situ residue management and restoration of degraded lands for soil moisture conservation and improved C-sequestration.
- Agroforestry with multipurpose trees, crops and animal components for improving hydrology.
- Integrated farming systems and watershed development with animal, fishery and hedge row cropping for soil and moisture conservation and nutrient recycling.
- Screening short duration varieties for their drought resistance.
- Popularization of technologies like system of rice cultivation (SRI) and aerobic rice cultivation for water saving and mitigation of green house gas (GHG) emission.
- Rain water harvesting: in-situ (land configuration, mulching etc.) and ex-situ (Ponds, micro water harvesting structure -*jalkund* etc).
- In-situ biomass management in shifting cultivation (cover about 1.6 million hectare in NER) instead of biomass burning to reduce CO₂ emission and improve hydrology.
- Promotion of technologies that enhance biological N-fixation and improve nutrient and water use efficiency to reduce N₂O emission and dependence on non-renewable energy.
- Change in planting dates and crop varieties are another adaptive measure to reduce impacts of climate change to some extent. For example, the Indian Agricultural Research Institute study indicates that losses in wheat production in future can be reduced from 4 – 5 million tons to 1 – 2 million tons if a large percentage of farmers could change to timely planting and changed to better adapted varieties.
- In North East India with the shift in rainfall pattern and rise in temperature it is important to relook at the present date of sowing and varieties. An example of this is that at mid-altitude of Meghalaya (950 m ASL), where it was not possible to grow a second crop of rice after *kharif* (rainy season) rice due to early onset of winter, presently double cropping is possible at least at the experimental field with the adjustment of sowing dates and varieties.

Many of the strategy/conservation agriculture practices mentioned here are proven and well tested for enhancing productivity and resource efficiency but could also be mitigation and adaptive strategies to combat climate change. What is needed is the more data generation through intensive research and their adoption at farm level with proper extension and support policies.

REFERENCES

Das, P.J., 2004. Rainfall Regime of Northeast India: A Hydrometeorological Study with Special Emphasis on the

- Brahmaputra Basin. Unpublished Ph.D. Thesis. Gauhati University (accessed October 25, 2009).
- Das, P.J., 2009. Water and climate induced vulnerability in northeast India: Concerns for environmental security. WATCH Research Report 1. AARANYAK. Guwahati, Assam, India. www.aaranayak.org (accessed October 25, 2009).
- Das, P.J. and Goswami, D.C., 2003. Long-term variability of rainfall over northeast India. *Indian Journal of Landscape Systems and Ecological Studies*, 26(1):1-20. 8 .
- Doorenbos, J. and Pruitt, W. D., 1984. Guidelines for predicting crop water requirements. *FAO Irrigation and Drainage Paper*, pp. 72-74.
- Dash S.K., Jenamani R.K., Kalsi S.R. and S.K. Panda., 2007. Some evidence of climate change in twentieth-century India. *Climatic Change*, 85:299–321.
- North Eastern Space Application Centre (NESAC), 2009. Weekly agricultural drought monitoring based on rainfall data (from IMD site, ISRO-AWS sites and TRMM multi-sensor data) June 11 to July- 22, 2009.
- Goswami, D.C. and Das, P.J. ,2003. The Brahmaputra River, India: The eco-hydrological context of water use in one of world's most unique river systems. *Ecologist Asia. Special issue on large dams in northeast India- Rivers, forests, people and power*, 11(1):9-14.
- ICIMOD., 2008. Recorded proceedings of the two day 'Climate Change and Vulnerability of Mountain Ecosystems in the Eastern Himalayan Region, North-East India & Bhutan Stakeholders Workshop' 11-12 March, 2008, Shillong. Organised by International Centre for Integrated Mountain Development Kathmandu, Nepal .
- IPCC., 2007. Summary for Policymakers. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
- Mirza, M.M.Q., Warrick, R.A., Ericksen, N.J. and Kenny, G.J.,1998. Trends and persistence in precipitation in the Ganges, Brahmaputra and Meghna river basins. *Hydrological Sciences- Journal-des Hydrologiques*, 43(6):845-858.
- Times of India, 2009. 22 July, Shillong, Meghalaya, India
- Venkatachary, K.V., Bandyopadhyay, K., Bhanumurthy, V., Rao, G.S., Sudhakar, S., Pal, D.K., Das, R.K., Sarma, U., Manikiam, B., Meena Rani, H.C. and Srivastava, S.K. 2001. Defining a space-based disaster management system for floods: A case study for damage assessment due to 1998 Brahmaputra floods. *Current Science*, Vol. 80. No.3 pp 369-377.
- WB., 2007. Development and growth in Northeast India: The Natural Resources, Water and Environment Nexus. World Bank report No. 36397-IN. the International Bank for Reconstruction and Development/ The World Bank, DC, USA.