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CROP MODELS AND THEIR UTILITY FOR STUDIES ON LAND USE SYSTEMS OF EASTERN REGION

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ABSTRACT
India's massive population, of which ample number are living below poverty line, make it all the more important to understand the relationship between population pressure, changes in land use and environmental degradation in the country. Agriculture, forestry and other land use sectors account for about a third of global anthropogenic GHG emissions. In recent years there has been a growing concern that changes in climate will lead to significant damage to agriculture, industrial and market sectors. It is becoming ever more apparent that climatic changes are occurring non-uniformly across various ecosystems and regions. General Circulation Models (GCMs), Geographic information systems (GIS) and crop simulation models are powerful and highly complementary tools that are increasingly used for predictive analysis of such changes. As human and the environment sub-systems are closely linked, human land-use and management activities can lead to changes in the functioning of ecosystem processes. A variety of simulation models like CERES, APSIM and GROWIT have been developed during the past years to simulate changing land-use and land-cover pattern. This paper gives an account of simulation modeling over land use systems and its applicability for eastern region of India.

Keywords: *Agro Forestry, Climate Change, Crop Models, Land Use and Simulation Models*

INTRODUCTION
The Earth's land resources are limited, whereas the population that earth support continues to grow rapidly. This has been a century of unparalleled population growth, economic development and environmental change. There has been extensive debate worldwide on the relationship between population growth, depletion of resources and environmental degradation. According to United Nations (2001), the world population grew by four times from 1.6 to 6.1 billion during 1900 to 2000, India accounts for 18 percent of world population, and is growing at 1.93 percent per annum. Population growth influence three areas; changes in land use, increase of toxins in the environment and depletion of natural resources. As population increases, this expanded growth begins to distort our environment, leaving what scientists call an ecological footprint. Agricultural areas (cropland, managed grassland and permanent crops including agro-forestry and bio-energy crops) occupy about 40–50 % of the earth's land surface (UNFCCC, 2004). The production and productivity must be increased to meet rapidly growing needs while protecting natural resources. New agricultural research is needed to supply information to farmers, policy makers and other decision makers to accomplish sustainable agriculture over the wide variations in climate around the world.

Climate change is the result of uncontrolled exploitation of natural resources, distortion of land use and ecosystems. Rapid industrialisation, urbanisation, deforestation, environmental pollution etc. are indeed major sources of human-caused emissions of greenhouse gases (GHGs). Schneider *et al.*, (2007) identified agriculture as a key vulnerable area to climate change and it will have a negative effect on food production in many countries. The agriculture sector is the largest contributor to global anthropogenic non –CO_2 GHGs, accounting for 56% of emissions in 2005 (U.S.EPA, 2011). Annual total non- CO_2 GHG emissions from agricultural production in 2010 was estimated to be 5.2─5.8 $GtCO_2$ eq/yr (FAOSTAT, 2013; Tubiello *et al.*, 2013) and comprised about 10-12% of global anthropogenic emissions. Enteric fermentation and agricultural soils represent together about 70% of total emissions, followed by paddy rice cultivation (9-11%) and biomass burning (7-8%) according to databases of FAOSTAT (2013), U.S.EPA (2006), and EDGAR (JRC/PBL, 2012). Land use changes accounted for emission of CO2 @ 1.6 gigatonnes per year during the decade 1981-90 in tropics (Bhadwal and Singh, 2002).

The impact of climate change over agriculture, forestry and ecosystems can be predicted through simulation modeling, which will help in forewarning and adopting strategies for mitigation. Penning de Vries (1977) emphasized that simulation models contribute to our understanding of the real system which in-turn helps to bridge areas and levels of knowledge. Auque *et al.*, (2009) indicated geological storage of carbon dioxide as main strategy to mitigate the impact of the emissions of this gas on global warming. Net GHG emissions from agricultural systems can be kept low when management is optimized toward better exploitation of the yield potential (Adviento *et al.*, 2007). Cropping systems play an important role in greenhouse gas status and improved cropping system can enhance carbon sequestration potential. Different simulation models like Century, Daycent and Agriculture Land use models (ALU) can estimate the potential carbon addition from different crop and land use systems. Adopting less intensive tillage systems such as no-tillage, strip-tillage, chisel plough and better crop residue cover are effective in reducing CO2 emission and thus improving soil C sequestration in a corn-soybean rotation (Al-Kaisi and Yin, 2005). This review paper is an attempt to bring out utility of simulation modeling over land use systems and its applicability for eastern region of India

Climate and Climate Change

Climate in narrow sense is defined as average weather. Weather parameters include temperature, precipitation, wind, humidity, atmospheric pressure, cloudiness etc. Weather refers to a statistical description in mean variability of these parameters over a significant period of time. The classical period is 30 years as defined by World Meteorological Organization.

Climate change refers to any significant change in the measure of climate for an extended period of time. Murthy, 2003 defined climate change as any long term substantial deviation from present climate due to variations in weather and climatic elements. Earth's linearly averaged surface temperature has increased by 0.74°C during the period 1901-2005 (IPCC, 2007). Major characteristics of climate change include a rise in average global temperature, ice cap melting, changes in precipitation, storm, and the increase in ocean temperature leading to sea level rise (Govt. of India, 2012).

Climate models predict that the monsoon will continue to weaken (Kripalani *et al*., 2007) and that the global area affected by drought will likely increase in the future, with the frequency of heavy precipitation events are likely to increase over most areas (Pachauri and Reisinger, 2007). India will also begin to experience greater seasonal variation in temperature, with more warming in winter than summer (Christensen *et al.*, 2007). Increasing trends of rainfall and minimum temperature in Gangetic plains of Bihar was observed (Haris *et al.*, 2010a). Weather generators can be used to generate long term weather data wherever data is not available for impact studies. One such generator is LARSWG which was used and produced similar observations of rainfall and temperature as actual weather data for Bihar in eastern India (Haris *et al.*, 2010b).

The longevity of heat waves across India have extended in recent years, leading to warmer temperatures at night and hotter days-this trend is set to continue (Cruz *et al.*, 2007). These heat-waves will lead to increased variability in summer monsoon precipitation, with drastic effects on the agricultural sectors in India (Bhadwal, 2003).

The challenges that humanity face due to climate change require an unmatched ability to predict the responses of crops to environment and management. Climate change will have a negative impact on food production in many countries. Farmers' adaptation to climate change-through changes in farming practices, cropping patterns, and use of new technologies will help to ease the impact. As climate change deals with future issues, the use of General Circulation Models (GCMs), Geographic information systems (GIS) and crop simulation models are powerful and highly complementary tools that are increasingly used for such predictive analyses.

GIS is a helpful tool to capture this spatial heterogeneity and provides influential ways in which to visualize and communicate the actual or potential changes that are occurring. Several major assessments of the potential impact of climate change on agriculture based on GIS-based framework (Tubiello *et al.*, 2000; Fischer *et al.*, 2002; Parry *et al.*, 2004).

The geographic aspect makes GIS an attractive option for application to agricultural problems because so many of the environmental and socio-economic factors that impact agriculture or agricultural research vary greatly over regions (Benson, 1996).

Crop Models and Simulation Modeling

The application of crop models to study the potential impact of climate change and climate variability provides a direct link between models and the concerns of the society. Crop models integrate available information on plant physiology, soil chemistry, agro climatology and related fields, and simulate key processes to determine crop performance in a particular environment. Simulation refers as "Reproducing the essence of a system without reproducing the system itself". In simulation, the essential characteristics of the system are reproduced in a model, which is then studied in an abbreviated time scale. A model is a schematic representation of the conception of a system or an act of mimicry or a set of equations, which represents the behaviour of a system. Depending upon the purpose for which these are designed, models are classified into different groups or types. Of them a few are Statistical, Mechanistic, Deterministic, Stochastic, Dynamic, Static, Simulation, Descriptive and Explanatory models etc (Murthy, 2003).

For climate change assessments, yield responses for major crops are derived mainly from applications of crop growth simulation models coupled to global or regional climate change models and run under a range of emission scenarios. The crop growth models can be used to predict crop performance in regions where the crop has not been grown before or not grown under optimal conditions. Such applications are of value for regional development and agricultural planning in developing countries (Van and Wolf, 1986). Simulation studies are useful in predicting future climate scenario based on changing trends in temperature, CO_2 and rainfall etc (Haris *et al.*, 2010c; Haris *et al.*, 2012a). Simulation studies showed that long duration rice varieties are more prone to yield decline under future climate scenarios (Haris *et al.*, 2010d; Elanchezhian *et al.*, 2012, Haris *et al.*, 2013d). Kiniry *et al.*, (1991) showed that for maize, both simulated and measured mean yields with weeds are 86% of the weed-free yields.

A model can calculate probabilities of grain yield levels for a given soil type based on rainfall (Kiniry and Bockhot, 1998). Toole and Stockle (1987) described the potential of simulation models in assessing trait benefits of winter cereals and their capacity to survive and reproduce in stress-prone environment. Crop growth models have been used in plant breeding to simulate the effects of changes in the morphological and physiological characteristics of crops for different environments (Hunt, 1993; Kropff *et al.*, 1995).

Coupling crop simulation models like CERES and APSIM to a suite of five to ten widely accepted advanced GCMs, and evaluation under the standard range of IPCC emission scenarios has been a common approach (Defra, 2004; 2005).

Quantitative prediction of complex systems, however, depends on integrating information through levels of organization, and the principal approach for that is through the construction of statistical and simulation models. One of the main goals of crop simulation models is to estimate agricultural production as a function of weather, soil as well as crop management. These models use one or more sets of differential equations, and calculate both rate and state variables over time, normally from planting until harvest maturity or final harvest.

The crop growth models are being developed to meet the demands under the following situations 1. When the farmers have the tough task of managing crops on poor soils in risky climates 2. When scientists and research managers need tools that can assist them in taking an integrated approach to find solutions in the complex problem of weather, soil and crop management. 3. When policy makers and administrators need tools that can assist them in policy management. Crop models can be developed at various levels of complexity and the level of complexity required depends on the objective of the modeling exercise. The CROPSYST, WOFOST, EPIC, ALAMANC models are being successfully used to simulate maize crop growth and yield. The SORKAM, SorModel, SORGF and also ALMANAC models are being used to address sorghum crop management. CERES – pearl millet model, CROPSYST, PmModels are being used to study the suitability and yield simulation of pearlmillet genotypes. Similarly, the two most common

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growth models used in application for cotton are the GOSSYM and COTONS models. Similarly, the PNUTGRO for groundnut, CHIKPGRO for chick pea, WTGROWS for wheat, SOYGRO for soybean, QSUN for sunflower are in use to meet the requirements of farmers, scientists, decision makers, etc., at present. The APSIM, GROWIT added with several modules are being used in crop rotation, crop sequence and simulation studies involving perennial crops. The construction of contemporary crop models entails the combination of many algorithms for physiological processes and impact of environmental factors on process rates (Monteith, 2000).

Land Use in Eastern Region

At present India has 23% forest cover, 3% pastures and grazing land, 46% area is under agricultural use, 14% land is barren, 6% land is cultivable waste land and remaining 8% is fallow land (Statistical Abstract, 2002). Agriculture is the most important for the survival of the mankind out of different uses of land-forests, pastures, human habitations, and various economic activities. Eastern region of India including states; Eastern U.P, Bihar, Chhattisgarh, Jharkhand, West Bengal, Odisha and Assam has a total population of 405.94 million with population density 1.62 fold higher as compared to national average. Out of the total geographical area of 71.84 million hectare, the net sown area is only 31.09 m ha and cropping intensity 150%. A total of 4.05 m ha area is under wetland (Figure 1) and 6.16 m ha under wasteland (Figure 2) in eastern region.

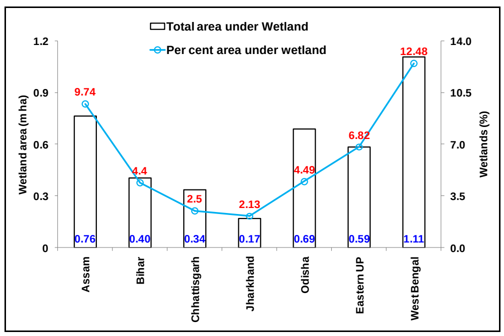


Figure 1: Wetland area in eastern region

This region has the higher area under forests than normal average i.e. 19.46 m ha (Figure 3). The total food grain production of the region has been reported to be 63.4 m tonnes i.e. 27.04% of the total food grain production of the country. Eastern region has a total of 1.57 m ha sown area under fruit and plantation crops, 40.97% area is under vegetable cultivation, contributing 47% of the total vegetable production at national level (Bhatt *et al.*, 2011).

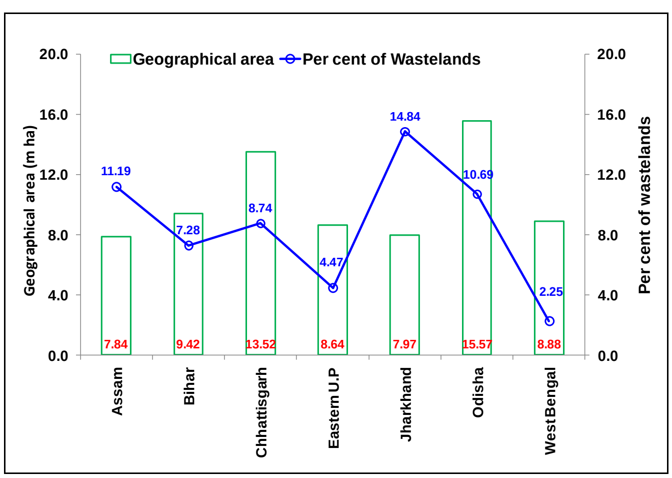


Figure 2: Wasteland area in eastern region

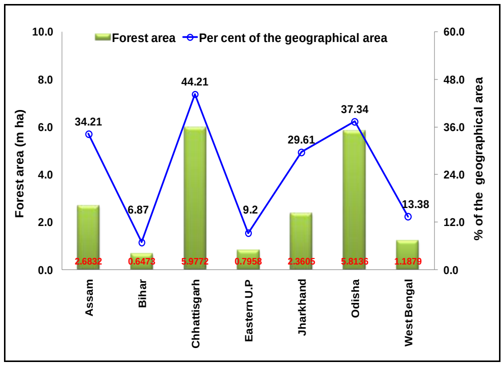
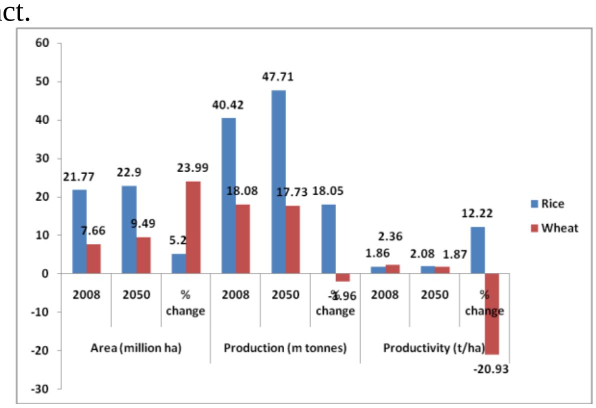


Figure 3: Forest cover in eastern region

Eastern states are likely to be worst hit by climate change. Significant decline in wheat production is expected by 2050 due to climate change. It may result into price rise and jeopardizing the food and nutrition security of the masses. Rice area in eastern region may increase slightly (from 21.7m ha to 22.9 m ha by 2050) with 18 % increase in production (Haris *et al.*, 2013a) and 12.2% increase in productivity, respectively (Figure 4). For kharif rice a yield reduction to the tune of 20% and 27.8% was predicted for the year 2025 and 2050 respectively at Bidhan Chandra Krishi Vidyapeeth, Mohanpur, and West Bengal due to climate change impact.



Adapted from "Vision 2050" document ICAR-RCER, Patna

Figure 4: Projected area, production and productivity in major cereals of Eastern Region

In case of wheat, simulated yield showed decline of 3 to 38% for Patna and 3 to 28% for Ranchi from 2020 to 2080 time periods (Haris *et al.*, 2011), though the area is projected to increase by 24% in 2050 the productivity may decline by 20.93%. Simulated yield of winter maize showed an increase from the baseline period. This increase was in the range 8.4– 18.2%, 14.1–25.4% and 23.6–76.7% for 2020, 2050 and 2080 respectively (Haris *et al.*, 2013b). Predicted increase in temperature for future time periods may prove to be detrimental in future time periods for Rabi crops, however, crop like winter maize may be benefitted due to increase in temperature upto some extent, i.e. there is possibility of substituting wheat to winter maize in Bihar (Haris *et al.*, 2013b; Chhabra and Haris, 2014). Generally, chickpea adapts to high temperatures, however, heat stress during reproductive phase can cause significant yield loss (Haris *et al.*, 2014). Krishnan *et al.*, (2007) analyzed the impacts of elevated CO2 and temperature on irrigated rice yield in eastern India by ORYZAI and Info Crop-rice models, and the result shows that increased CO_2 concentration can increase the rice yield, which is concerned with the sterility of rice spikelets at higher temperature, the sowing time and the selection of genotypes.

Effects of elevated CO_2, temperature and water stress on tomato and onion was studied at IIHR, Bangalore (NPCC Annual Report, 2008-09). For tomato, yield increase of 26.5% and increase in antioxidants was observed at elevated CO2 concentration compared to chamber control. In onion, bulb

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initiation stage was found to be sensitive to continuous flooding resulting in maximum reduction in bulb size (27%) and bulb yield (48%). The bulb diameter and fresh bulb weight decrease under flooding and the loss were greater in plants subjected to 8 days flooding irrespective of growth stages (NPCC Annual Report, 2010-11).

Land Use and Crop Modeling

Land is a dynamic canvas on which human and natural systems interact. Land-use change is locally and globally significant. Land-use change is considered as one of the most important processes when attempting to understand and model global change (Foley *et al.,* 2005). As there is currently no single theory to describe all the complexities involved (Veldkamp *et al.,*, 2001), a variety of simulation models have been developed during the past years to simulate changing land-use and land-cover pattern. As human and the environment sub-systems are closely linked, human land-use and management activities can lead to changes in the functioning of ecosystem processes. A major difference in the underlying modeling philosophy of land-use changes either based on inductive or deductive approaches involve different possibilities for the use in context of a scenario analysis. Concerning the time horizon of a scenario analysis, inductive approaches make long-term projections difficult (Verburg and Denier van der Goon, 2001). This shortcoming is potentially overcome by deductive approaches that explicitly model the inter-action between underlying drivers of land-use change and decision making processes. They allow the modeling of changes over time in these relationships as part of the scenario assumptions and therefore increase their suitability to model the changing dynamics of land systems over a longer time period. A model, HyLand was constructed to simulate the transient effects of changes in land use on vegetation properties and carbon stocks. When CO_2 is held constant, large areas of the globe become net sources of carbon, including S.E. Asia. The relatively small predicted source regions in Central Asia, China and India are related to land use change. The effect of land use change can also be positive or negative, depending on whether cropland is contracting or expanding in the scenario. Land-use change models are used by researchers and professionals to explore the dynamics and drivers of land-use/land-cover change and to policies of such change. A broad array of models and modeling methods are available to researchers, and each type has certain advantages and disadvantages depending on the objective of the research. Vitousek (1994) notes that "three of the well-documented global changes are increasing concentrations of carbon dioxide in the atmosphere; alterations in the biochemistry of the global nitrogen cycle; and on-going land-use/land-cover change." Globally and over a longer period, nearly 1.2 million km^2 of forest and woodland and 5.6 million km^2 of grassland and pasture have been converted to other uses during the last 3 centuries, according to Ramankutty and Foley (1999). During this same period, cropland has increased by 12 million km^2. Humans have transformed significant portions of the Earth's land surface: 10 to 15 percent currently is dominated by agricultural row crop or urban-industrial areas, and 6 to 8 percent is pasture (Vitousek *et al.,* 1997).

Land use applications involve both baseline mapping and subsequent monitoring, since timely information is required to know which current quantity of land and which type of use and to identify the land use changes from year to year (Read and Lam, 2002; Campbell, 2002). Remote sensing techniques are important in acquiring useful data of the earth or its surface by mean of sensors. These remotely collected data will be analyzed to obtain information about the objects, areas or phenomena being investigated (Schowengerdt, 2007; Lillesand *et al.,* 2008). In addition, it includes the analysis and interpretation of the acquired data and imagery, which are the most aspects for environmental scientists to provide relevant information for monitoring earth resources (Landgrebe, 2003; Chuvieco and Huete, 2010). Multi-spectral imagery used for quantification of resources and Monitoring resources during a period. Remote sensing techniques help in developing areas in studying deforestation of changes in vegetation cover (Barredo and Sendra, 1998).

Future land use is greatly influenced by current land use, autonomous socio-economic developments and spatial policies and in the long term climate changes and other changes in the physical environment. By using scenarios, hypotheses about developments in government policy, socio-economic factors, the climate and the physical environment can be combined.

Agroforestry Land Use Systems

Land use has a strong influence on the water balance of a given area: Groundwater recharge varies per land use type because of differences in infiltration and evaporation rates. The 'Land Use scanner' is a GIS based model that simulates future land use. The model has been used recently the simulation of future agricultural land use in the Netherlands (Koomen *et al.*, 2005). It is also estimated that about three fourths of the total emissions from agriculture and land use originate in the developing countries. The FAO Profile on Climate Change-2009 notes that agriculture has the technical potential to mitigate between 1.5 and 1.6 GtC equivalent/year (5.5–6.0 Gt of CO_2 equivalent/year) mainly through soil carbon sequestration in the developing countries. The biophysical mitigation potential of forestry is estimated to average 1.5 GtC equivalent/year (5.4 Gt CO_2 equivalent/year). According to IPCC (2007) forestry and agriculture contribute 17.4 and 13.5% of total greenhouse gas emissions, respectively. Thus, agriculture, forestry and other land use sectors account for about a third of global anthropogenic GHG emissions. Diversifying the production system by including agroforestry may reduce the risks associated with climatic variability in synergy with climate change mitigation. The interactions of the different components of agroforestry systems can help absorb and sequester carbon dioxide and other greenhouse gasses from the atmosphere (Haris *et al.*, 2012b) and mitigating climate change by reducing fossil fuel emissions improves quality of soil and water resources and enhances agronomic productivity (Haris *et al.*, 2013c). The livelihood of indigenous tropical peoples will be adversely affected if climate and land-use change induce forest losses. These peoples depend on a large diversity of forest products that are expected to undergo declines in biodiversity and forest regeneration due to climate change and may be subject to forest degradation apart from land conversion.

Research needed to conduct a more accurate assessment of climate change impacts on future forest product availability includes (1) obtaining new data needed to demonstrate and quantify direct effects of atmospheric CO2 on ecosystem productivity and tree growth, and (2) uniform reporting and assembly of national forest inventory data sets. New mathematical models will be needed especially to (a) simulate transient (lagged) responses of forests to rapid climate change, (b) integrate relationships among climate changes, ecological responses, and economic forces and responses, and (c) simulate regional climate changes and their effects. The 1990 IPCC assessment of forestry (IPCC, 1990) was confined to managed forests—difficult entities to assess because forest areas or volumes are rarely measured as "managed" or "unmanaged," and when they are so divided, the definitions of "managed" vary widely. Globally, forests in 1990 covered one-fourth to one-third of the earth's land surface (FAO, 1993). Although the great majority of these forests can be considered as managed to some degree, only about 4% of forests consist of intensively managed plantations (Kanowski *et al.*, 1990). WRI (1994) cites a doubling of forest plantations during the decade from 1980 to 1990, with three-fourths of all plantations being in Asia. The plantations may produce a disproportionate amount of forest products. The availability of forest products in the year 2050, as limited by climate and land use, appears to be adequate to meet projected needs in temperate and boreal regions but not in tropical regions.

Future opportunities to conserve and sequester CO_2 in forest systems are potentially significant, but land-use practices and global change will influence the size of this C pool and CO_2 sink. In the future, a greater proportion of forests at all latitudes could become a greenhouse gas (GHG) source if sustained management and conservation policies are not employed. The timing and magnitude of future changes in forest C pools and flux will depend on environmental factors such as changing climate, accumulation of atmospheric CO2, and increased global mobilization of nutrients such as N and S, and on human factors such as demographics, economic growth, technology, and resource management policies (Office of Technology Assessment, 1993; Krankina and Dixon, 1994; Woods and Hall, 1994). Forest systems play a prominent role in the global C cycle and the opportunity exists to manage or conserve forests as C reservoirs at low, mid, and high latitudes. Global change impacts on forest systems could be significant, but uncertainty exists with regard to our ability to project future forest distribution, composition, and productivity in response to climate change processes (Dixon *et al.,* 1994). Robust, large scale models have not been developed that concomitantly consider the impacts of climate change on forests, as well as the role of forest feedbacks to the Earth's climate system. For example, the role of forest management in mitigating C flux to the atmosphere under transient or non transient climate change scenarios has yet to be fully evaluated. The potential of forest system adaptation to help minimize C emissions is considerable in mid-latitude forests given current infrastructure and technology (Smith, 1996). Unfortunately, our understanding of forest adaptation processes and principles is in its infancy. Other socioeconomic factors which significantly contribute to global C emissions, such as decline in forests and expansion of agriculture, should also be considered in the development of integrated assessments of natural resource management options (Rosenzweig and Parry, 1994).

Conclusion

The changes in land use reflect the pressure on land resources due to rising population. The distressing features are in the form of considerable increase in land put to non-agricultural uses, rise in fallow land, steep decrease in area under miscellaneous tree crops and groves. Area under non-agricultural use has grown very fast but not at the cost of cultivable area. It is a fact that there is a lack of sufficient, accurate and up-to-date data on land conversion and infrastructure deployment patterns as a serious impediment for designing better land management and human settlement policies in India. The study also reveals that from environmental monitoring point of view, the land use data as collected are of very limited use and at times they may be misleading. Thus, the present system of land use fails to capture both the quantitative as well as qualitative changes. There is a need to strengthen the land use statistics in this context, so that, the objective for which it is generated, i.e. to assess the agricultural performance of a region can be fulfilled. Despite their valuable contributions to the country forests have been neglected in planning, and agencies working to manage them are poorly funded. To check forest degradation and fulfil the needs of forest-dependent people, rehabilitating of degraded forest areas and afforestation of wastelands, improving forest management through involvement of local communities are the strategies that need to be taken up. Close interaction is essential among the three levels of government: centre, state, and local bodies and also between various departments of government, so that, India can move in the direction of set targets to control population growth and environmental degradation. Assessment of land use is required at frequent intervals for optimum use of natural resources to cope with demands of increasing population. Simulation studies are helpful in bringing out projected changes in cropping pattern, water availability, land use, food production and availability. A combination of model with geographic information system and land use data from satellites can help in developing proper land use guidelines which will lead to sustainable food production in changing climatic scenarios.

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