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Monitoring climate change impacts on agriculture and forests: trends and prospects

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Introduction

Consequences of climate change as manifested through enhanced atmospheric temperature, erratic rainfall pattern and frequent occurrence of climate extreme events such as heat waves, prolonged droughts, storms, flash floods and cloud bursts negatively affect agriculture and forest ecosystems by altering the phenological cycles of constituent species; reducing species diversity, productivity and ecosystem services; and enhancing the pest and disease attacks on crops. The climate change impacts the poor most and the developing nations are highly vulnerable. Since climate change is now a reality, it is essential to develop mitigation and adaptation technologies/strategies as fast as possible so that the climate change–related sufferings of human populations can be minimized. Keeping this in mind, the Council for Scientific and Industrial research (CSIR), represented by the CSIR-National Botanical Research Institute (CSIR-NBRI), Lucknow, India, in collaboration with the Department for International Cooperation of the Russian Academy of Sciences, Moscow, organized a webinar on 'Agriculture and Food Technologies and Mechanisms of adaptation to Climate Change' during 11–12 November 2020. Selected presentations from this webinar along with a few invited papers are published in this special issue entitled 'Monitoring climate change impacts on Agriculture and forests'.

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Agricultural and horticultural crops

Climate change impacts crop yield, soil processes, water availability and pest dynamics. Several adaptation strategies such as identification and cultivation of heat and water stress–tolerant crop varieties, adoption of improved agronomic management practices, enhancing water use efficiency of crop varieties, practicing improved agricultural practices and pest management systems, taking advantage of weather forecasts and other climate services have been in place in many countries including India to minimize the climatic risks. The tropospheric ozone (O_3) is a long-range trans-boundary secondary air pollutant, causing significant damage to agricultural crops worldwide and there are substantial spatial variations in O_3 concentration due to seasonal and geographical variations. However, works on adaptive strategy against ozone are extremely rare. For example, the impact of tropospheric ozone on wheat, which is one of the main cereal crops grown worldwide and is consumed by nearly 2.5 billion of the world population, is little understood. India is the second-largest wheat-producing country with ~ 30 million ha area under wheat cultivation producing 108 million tonnes of grains in 2019–2020. Wheat is a sensitive crop to tropospheric O_3 and high temperature as evident from a significant yield reduction. Similarly, *Citrus* is an important horticultural crop and is often prone to diseases, particularly under increased temperature scenarios. For developing disease-resistant *Citrus* varieties, conservation of wild relatives is extremely important. However, like several other horticultural species and their wild relatives, perpetuation of wild *Citrus* species against climate change remains uncertain.

Drought and cropland inundation

Drought is considered amongst the most perilous events with catastrophic consequences, particularly from the agro-economic point of view. The consequences are expected to exacerbate under the increasing meteorological aberrations due to changing climate, which necessitates investigating drought variability and their spatiotemporal characteristics to plan for optimum water resource utilization. The meteorological variables, specifically precipitation and temperature, are inherently associated with the hydrological cycle, and thus, their changing regimes have direct impacts on water resources. Cyclonic storms and extreme precipitation lead to loss of life and significant damage to land and crop production. The 'Gulab' cyclonic storm formed on 24 September 2021 in the Bay of Bengal (BoB) hit the eastern Indian coasts on 26 September and caused massive damage and water inundation of crop land and other land classes. The land use changes affect physical parameters such as infiltration, groundwater recharge, surface runoff, surface temperature and air quality. Remote sensing and GIS techniques help to monitor these changes with relatively low cost and time at appropriate spatial scale.

Pollution remediation, productivity and flowering

Plants play a vital role in remediation of air pollution and the plants growing especially in urban environments mitigate significant amount of air pollutants through filtering, intercepting and absorbing pollutants. However, information on the impacts of current and future levels of O_3 on trees is least explored. Tropical forests are species-rich and highly productive ecosystems that sequester maximum carbon compared to any other terrestrial ecosystem. However, the plants in deciduous forests are subjected to water stress during the dry season. Flowering is a major event in a plant's life cycle as it determines the reproductive competency of the plant. The timing of flowering in relation to environmental variables is important for successful seed-set and propagation. Climate change can affect all these functions; hence, the study of the flowering pattern and timing is one of the most important aspects in understanding plant adaptation to changing climate.

Leaf area, niche distribution and ecosystem resilience

Leaf area index (LAI) is an important indicator of ecosystem productivity and helps in forest cover monitoring. However, due to difficulties faced during field sampling, complex topography and non-availability of cloud-free optical satellite data, LAI assessment at a larger scale continues to pose challenge, particularly in tropics and mountains. Similarly, the distribution mapping of invasive plant species in response to projected climate change helps in formulating effective strategies for the management of plant invasion. Climate change via alteration in precipitation and temperature, and other external disturbances such as anthropogenic activities, fire occurrences and insect outbreaks, redefines the vegetation conditions and regulates vegetation distribution (Behera & Roy, 2012). The climatic conditions and external disturbances determine the ecosystem resilience, resistance to a regime shift and recovery period. Climate change coupled with biological invasion and anthropogenic factors has brought many threatened species, particularly those with a narrow tolerance range, to the brink of extinction. The existence of threatened species against climate adversaries is constrained due to their small population size, narrow genetic base and narrow niche breadth.

Adaptation and mitigation

The Himalayas play a major role in climate regulation, and determine the monsoonal pattern of the Indian sub-continent. Enhanced trends in temperature at higher elevations of the Himalayas, particularly during the winter season, pose threats to water and food scarcity at local or regional scale, especially where snowmelt water exceeds the glacial melt. Ecotourism is visualized as an adaptation strategy for mitigating climate change impacts, as it can optimize carbon sequestration, recover biodiversity, provide livelihood benefits and generate new opportunities for the sustenance of the economy, environment and society of the area endowed with natural resources and cultural values.

Agricultural management

Pathak (2022) opined that mitigation of greenhouse gas emission from agriculture can be achieved by changing land use management practices and enhancing input-use efficiency. He reported that methane emission from lowland rice fields can be reduced by 40–50% with alternate wetting and drying (AWD), growing shorter duration varieties and using Neem-coated urea. Dry direct seeding of rice, which does not require continuous soil submergence, can reduce methane emission by 70–75% in India. This review addresses the dual problems of climate change and food insecurity, and can address the increasing demand for food production and decreasing availability of suitable land. Gupta et al. (2022) reviewed yield losses in agricultural crops due to rising O_3 pollution and variations in O_3 sensitivity amongst cultivars and species. They discussed the use of ethylene diurea (EDU) as a research tool in assessing the losses in yield under ambient and elevated O_3 levels. They also provided an overview of interactive effects of O_3 and nitrogen on crop productivity and offered several recommendations for future research and policy development on rising concentration of O_3 in India.

Wheat and citrus crops

Naaz et al. (2022) predicted the wheat-growing areas under future climate change scenarios in 2050 using two global general circulation models (GCMs) (IPSL-CM5A-LR and NIMR-HADGEM2-AO) with four Representative Concentration Pathways (RCPs) and estimated crop yield under such scenarios, and corroborated through simulation FACE experiments. The models predicted significant reduction in wheat cultivation area under RCP 8.5 in 2050 while only two of the eight cultivars did not exhibit yield decline suggesting their suitability in the future climate change scenarios. Banakara et al. (2022) used multiple linear regression (MLR) and time delay neural network (TDNN) and ARIMAX models for wheat yield forecast using weather parameters, and suggested use of the former for consistent results. Barik et al. (2022) determined the climatic niche of six wild relatives of cultivated *Citrus* species through appropriate climate models (IPSL-CM5A-LR and NIMR-HADGEM2-AO) with four Representative Concentration Pathways (RCPs); and identified the geographical areas in India that would remain climatically stable in future. They reported that precipitation-related bioclimatic variables could be the key climatic determinants in distribution of six wild relatives of cultivated *Citrus* species, and therefore suggested in situ conservation, and establishment of germplasm banks and *Citrus* orchards in the identified areas.

Land and water resources

Swain et al. (2022a) presented a thorough spatiotemporal assessment of drought trends and variability over an agriculture-dominated region, and reported an increasing trend of drought occurrences. Murali et al. (2022) quantified the composite impact of meteorological, hydrological and agricultural drought events from 2001 to 2017, and identified hotspots in terms of the occurrence of drought events in central India. Swain et al. (2022b) reported a general warming trend over Narmada river basin using 68-year temperature data. They found that the basin has a significant element of anthropogenic contribution. Jaya Prakash et al. (2022) analysed the precipitation pattern across India over monsoon and post-monsoon seasons at various temporal scales and highlighted the water inundation and crop land damage over the eastern Indian states using satellite data products and cloud computing. They recommended the use of spatiotemporal data for disaster management, mitigation response and crop insurance. Halder et al. (2022) identified the temporal changes in LULC using the SVM classifier and further simulated the future land use distributions using the cellular automata model. They projected an increase in 4% of agricultural land and built-up area over a reservoir by 2030.

Field measurements and experiments

Jamal et al. (2022) assessed the impact of ambient and future ground-level O_3 on nine commonly growing urban tree species under Free Air Ozone Enrichment condition and observed that *Saraca asoca* and *Ficus religiosa* trees are tolerant, while *Bougainvillea spectabilis* and *Azadirachta indica* are sensitive to elevated ozone. They suggested that varied water use efficiency (WUE), stomatal traits and photosynthesis rates should be taken as O_3-responsive parameters, and the plantation of O_3-tolerant trees could be a viable strategy to improve air quality in urban India, especially in many pockets of peninsular India and Indo-Gangetic plains. Behera et al. (2022) measured the annual NPP amongst three community types from nine Long-Term Ecological Research (LTER) plots, and correlated it with tree density, height and DBH, species diversity, microclimate and edaphic variables and leaf area index using principal component analysis and generalized linear modelling. They observed air temperature and humidity are strongly related to NPP in all the community types, suggesting climatic regulation. Chandra et al. (2022) reported complete absence of flowering in *R. arboreum* population in an alpine zone of Himalayas using automated phenocam for time-lapse photography. They suggest a possible relationship between soil temperature and flowering, pointing towards necessary root apex vernalization stimuli in shallow rooted *R. arboreum*. Mudi et al. (2022) used digital hemispherical photography (DHP) and LAI-2200C to assess the LAI across four different forests and predicted a maximum LAI of 3.4 for the temperate forests. Recent rise of frequent forest fires in the changing climate prompts for better understanding of fuel load in terms of surface fuel or canopy fuel (Mudi et al. 2021) that can be interlinked to LAI estimates, they pointed out.

Modelling, adaptation and mitigation

Verma et al. (2022) used a species distribution model to report very high spread (stage III invasion) of *Ageratina adenophora*, one of the high-concern invasive species (HiCIS) in the Sikkim Himalaya. They cautioned that an enormous shift in the distribution pattern along elevational gradients within a short time span is alarming for the Himalayan ecosystem since the species' thrival corroborated with anthropogenic activities. Das et al. (2022) employed a process-based dynamic vegetation modelling (MAPSS-CENTURY: MC) approach to project change in vegetation life forms under projected climate conditions that suggested highly resilient/stable forest covers in wet climate regimes and moderately resilient in dry semi-arid regions of India. The spatially explicit model simulation provides opportunities to develop long-term climate change adaptation and conservation strategies. Singh et al. (2022) predicted distribution of three threatened Ilex species, viz. *I. khasiana*, *I. venulosa* and *I. embelioides*, endemic to Meghalaya state of India using ecological niche model under the current (2022) and future (2050) climatic scenarios (IPSL-CM5A-LR and NIMR30 HADGEM2-AO). They inferred that the future distribution and continued existence of the three *Ilex* species are strongly associated with morpho-physiological adaptation and demographic response. Sharma et al. (2022) explored the potential of extended cultivation during winters using low-cost inputs by comparing different technological options for temperature retention for vegetable cultivation. They observed confidence building (knowledge gathered, interventions to solve the major problem of water scarcity) through locally adaptable solutions (portable polyhouse, ice reservoir, increased plant productivity) motivated the villagers in trans-Himalayan high altitude to combat threats of climate change. Ashok et al. (2022) integrated ecological and socio-economic factors for Ecotourism Resource Management (ERM) for developing an ecotourism sustainability maximization model, as an adaptation strategy for mitigating climate change impacts.

Studies on climate change impacts on agriculture and forests are relatively less and under-reported from Asian countries. This special issue is expected to fill this long-standing gap.

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