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Climate Change

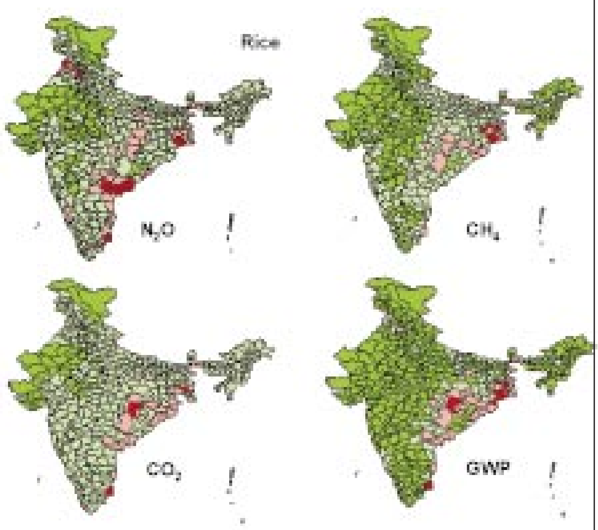
Spatial inventory of greenhouse gases emission from rice fields in India

Emission of greenhouse gases (GHGs), responsible for global warming, is a matter of concern. For its mitigation, it is important to quantify the total emissions of GHGs from different sectors, including agriculture. Field experiments and a validated InfoCrop model were used to estimate emissions of methane (CH_4), nitrous oxide (N_2O), and carbon dioxide (CO_2) from rice systems in India. Global warming potential (GWP) of these GHGs was calculated.

Simulated annual emissions from 42.21 million ha of rice fields of India were 2.07, 0.19 and 72.90 Tg (1 Tg = 10^{12} g) of CH_4-C, N_2O-N and CO_2-C, respectively. The global warming potential of the rice fields was 316.6 and 13.7 Tg CO_2 equivalents with and without CO_2 respectively. High emission of CH_4 was observed in some districts of West Bengal, due to their relatively higher soil organic carbon content, maintenance of continuous submergence and large area per district under rice. Emissions of N_2O-N were higher from the Andhra Pradesh and northern states because of large rice area and the use of relatively more N fertilizer. The eastern and southern parts of the country showed higher GWP, mainly because of higher CH_4 and CO_2 emissions with larger rice area per district. The GWP of the rice growing regions throughout the country was <1 to 10 Tg CO_2 equivalent per district. This spatial inventory will be helpful in identifying the regions from where excessive emissions of greenhouse gases are taking place and subsequently focused management practices can be implemented in these regions for mitigating the emissions.

Inventory of methane emission from livestock in India

Livestock sector is one of the main contributors to green house gases emission. An inventory of methane emission from enteric fermentation from livestock has been developed using the revised 1996 IPCC tier-2 approach for cattle and buffalo and tier-1 methodology for estimating emissions from small animals. The total emission of methane from the entire Indian livestock is estimated to be 9.37 Tg for the year 2003. Earlier studies showed



Legend	Emission per district			
	Methane (Gg C)	Nitrous oxide (Mg N)	Carbon dioxide (Gg C)	GWP (Tg CO_2 equiv.)
(dark green)	<1	<1	<1	<0.001
(light green)	1-20	1-100	1-500	0.001-2.0
(pink)	20-40	100-300	500-1000	2.0-4.0
(red)	40-80	300-500	1000-2000	4.0-10.0

Annual emissions of methane, nitrous oxide, carbon dioxide, and global warming potential from Indian rice fields. The spatial distribution of GHG emission and their GWP from the rice-growing areas of the country is presented at the district scale.

this value vary from 7.26 to 10.4 Tg. Buffaloes and indigenous cattle were the dominant source; both contributed 40% each. Indigenous female cattle contributed 2.2Tg and indigenous males emitted 1.55 Tg methane. Crossbred females, though small in number compared to indigenous cattle, emitted more methane per animal (0.63 Tg methane from 19.74 million heads). Emission from buffalo females was also higher (3.42 Tg-36.5% of the total methane emission). Dairy cattle and buffaloes contributed 3.42 Tg methane. Contribution of milch buffaloes, crossbred cows, and indigenous cows was 59.6%, 11.4% and 28.9%, respectively, to the total emissions from dairy animals. The total emission from draught animals has been estimated to be 1.2 Tg. Contribution of bullocks (indigenous and crossbreds) was 85%, while that of buffalo males was 10% and other transport and pack animals contributed about 5% of total methane emission.

Total methane emission from Indian livestock in 2003

Species	Enteric fermentation (Tg/year)	Manure management (Tg/year)	Total emission (Tg/year)
Indigenous cattle	3.34	0.41	3.75
Crossbred	0.63	0.08	0.71
Buffalo	3.34	0.46	3.8
Sheep	0.31	0.01	0.32
Goat	0.62	0.02	0.64
Others	0.09	0.06	0.15
Total	8.33	1.04	9.37

Change in temperature trends over India

Rise in temperature is one of the predicted impacts of climate change with significant implications for agricultural productivity. In order to assess the long-term trends in temperature, the minimum and maximum temperature data for 47 stations across the country for more than 50 years was analyzed. Overall, 55 to 80% stations located across the country showed increasing trends in average annual temperature. About 75, 60 and 54% of the stations in south, east and central India, respectively, showed increasing trend in maximum temperature, whereas only 8 and 13% of the stations in central and west India, respectively, showed decreasing trend. Similarly 80, 78 and 75% of the stations in east, north and south, respectively, showed increasing trends in minimum temperature.

Impact of temperature rise on crop water requirements

Rise in temperature is likely to increase the water requirement of crops due to high evaporative demand and crop duration due to forced maturity. The impact of simulated rise in temperature of one degree by 2020 (over the base year of 1990) on water requirement of major crops grown in Andhra Pradesh was assessed. The water requirement of all the major crops like maize, groundnut, pigeonpea and cotton will be increased with rise in temperature. The crop duration is expected to decrease by 1-2 weeks.

Projected changes in crop water requirements and crop duration of major rainfed crops in Andhra Pradesh by 2020

Station	Agro-climatic zone	Crop	Increase in water require-ment (mm)	Reduction in crop duration (weeks)
Anakapalli	North Coastal	Maize	51.7	1
		Groundnut	61.3	1
Anantapur	Scarce Rainfall	Groundnut	70.1	1
		Red gram	174.3	1
Jagtiyal	North Telangana	Cotton	60.5	2
		Maize	49.0	1
Rajendra-nagar	South Telangana	Red gram	114.5	2
		Groundnut	73.0	1
Tirupati	Southern	Groundnut	73.0	1

Micro-organisms for enhancing high temperature tolerance in plants

Rise in temperature is one of the causes of the predicted climate change. Role of micro-organisms in protection of plants from high temperature stress was investigated. It was found that seed inoculation with stress-tolerant strain of *Pseudomonas putida* helped sorghum and pearl millet seedlings survive at 50° C up to 21 days, whereas the controlled seedlings could survive only up to 10 days.

This remarkable protective effect was mediated through induction of the synthesis of novel high molecular weight proteins in the leaves, which were not found in the controlled seedlings. Inoculation also reduced the oxidative stress in seedlings exposed to high temperature (50°C) as evidenced by significantly lower oxidative enzyme activity in treated seedlings. The introduced organism successfully entered into the roots and induced the physiological changes at the whole plant level as confirmed by electron micrography.

Impact of elevated CO_2 on castor

Elevation of CO_2 is another phenomenon likely to be caused due to climate change. In order to assess the changes that might be caused under high CO_2, the growth, flowering and yield of castor were studied under elevated CO_2 conditions (700, 550 and 365 ppm) in open top chambers. All growth parameters of castor showed maximum response under elevated CO_2 of 700 ppm followed by 550 ppm. Elevated CO_2 improved total biomass, which was highest at 700 ppm (22%) followed by 550 ppm (11%). Elevated CO_2 also reduced the days to initiation of flowering by three days and days to 50% flowering by 15 days. At the maturity of first order spikes, the increase of reproductive biomass was 47% at 700 ppm and 35% at 550 ppm over ambient control. The improvement in effective spike length (12 and 15%), spike weight (46% and 47%), capsule number (65 and 98%), capsule dry weight (46 and 54%) and seed weight (155 and 167%) of primaries were recorded with CO_2 enrichment at 550 and 700 ppm, respectively. Oil content and quality were not changed significantly. However, the total oil yield was significantly higher due to higher seed yield. These results indicated that elevated CO_2 is a positive factor of climate change for castor bean. Under irrigated conditions where water is not a limitation, it is possible to realize higher yields due to elevation of CO_2 in castor bean.

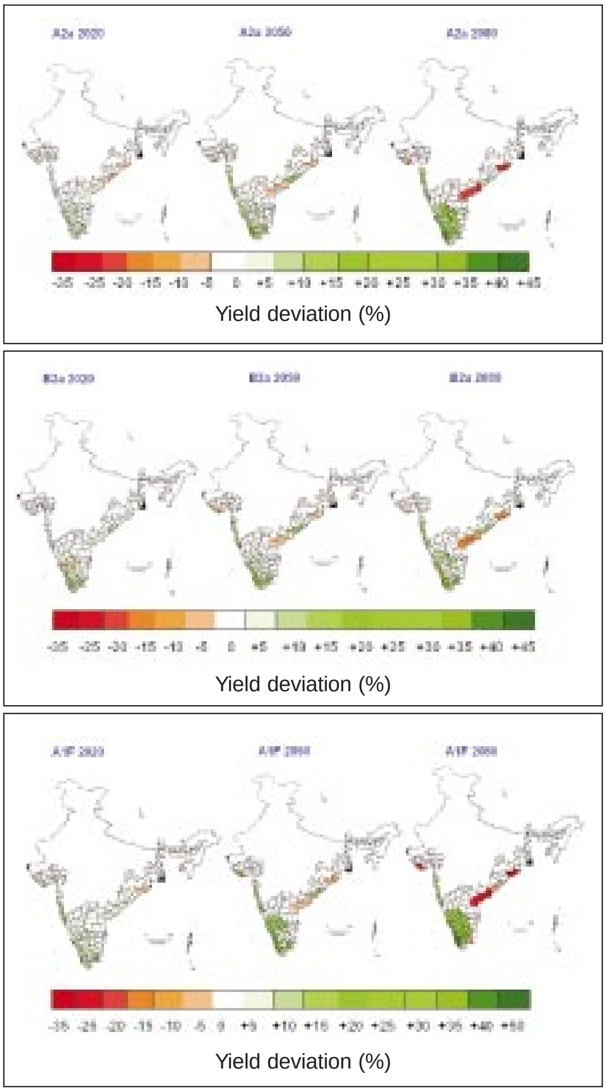
Impact of Climate Change on

Coconut production

Impact of climate change on coconut production was assessed for 13 agro-climatic zones represented by 16 centres using validated Info Crop-Coconut simulation model. These areas contribute over 90% to the coconut production in India. The model output on temperature and rainfall projections as simulated by Had CM3 model for the years 2020, 2050 and 2080 for 3 scenarios viz., A2a, B2a and A1F wherein which the atmospheric concentrations would reach by 715, 562 and 1150 ppm and the corresponding increase in global temperatures would be about 3.3°, 2.3° and 4°C, respectively by the end of the century. Also location weather data for past 30 years, major soil type of the agro-climatic zones, and currently followed farmers' practice for crop management in each Agroclimatic zones were used as inputs into the coconut simulation model. Outputs were obtained on yearly basis for 30 years and mean effects of 30 years were used to compute relative impacts over current yields. Relative impacts on yield were worked out to district level in each agro-climatic zone and up-scaled to the state and national projections assuming that the area under coconut remains unchanged in future scenarios.

Results indicate that under all scenarios, coconut productivity on all India basis is likely to go up by up to 4% during 2020, up to 10% in 2050 and up to 20% in 2080 over current yields due to climate change. In west coast, yields are projected to increase by up to 10% in 2020, up to 16% in

Coconut yield relative deviation from current yield due to climate change



Projections on relative yield change of coconut in A2a, B2a and A1F scenarios (please note that the districts with white colour are not simulated.)

2050 and up to 39% by 2080 while in east coast yields are projected to decline by up to 2% in 2020, 8% in 2050 and 31% in 2080 scenario over current yields. Yields are projected to go up in Kerala, Maharastra and parts of Tamil Nadu and Karnataka while they are projected to decline in Andhra Pradesh, Orissa, Gujarat and parts of Tamil Nadu and Karnataka. However, situations may vary if future irrigation sources are limited particularly in currently irrigated areas such as in Tamil Nadu and Karnataka.

Apple cultivation in Himachal Pradesh

The impact of climate variability/change on apple cultivation in Himachal Pradesh was studied**.** Temperature in apple growing regions of Himachal Pradesh showed increase, whereas precipitation showed decrease in recent years. This led to reduction in chilling units in the normal apple growing zone (1200-1800 msl) which led to reduction in this zone under apple orchards but increased area at higher elevation (2400-2700 msl) where optimum chilling units are available for this crop. These findings were also corroborated by socio-economic surveys by farmers in the region which stated that apple cultivation is expanding to higher altitudes in Lahaul and Spiti and Kinnaur districts in recent years.

Marine fisheries

The Indian mackerel is able to adapt to rise in sea temperature by extending its distribution towards northern latitudes, similar to oil sardine and also by descending to depths. The carbon footprint of marine fishing boats was determined and an inventory on vulnerability of coastal fishing villages to sea level rise was made.

The catch data of oil sardine and mackerel from 1926 to 2005 showed that the revival of oil sardine fishery in 1950's and late 1990's coincided with heavy rainfall and presence of an opitmal environmental window (OEW).

Inland fisheries

A perceptible shift was observed in geographic distribution of the warm water fish species, *Glossogobius giuris*, *Puntius ticto*, *Xenentodon cancila* and *Mystus vittatus* towards the colder stretch of the river Ganga up to Haridwar with an enhancement of annual mean minimum water temperature of 1.5ºC in the Haridwar stretch during the period 1970-86 to 1987-2003. This has become a congenial habitat for these warm water fishes.

Elevated temperature range (0.37ºC–0.67ºC) and alteration in the pattern of monsoon proved a major factor for shifting the breeding period of Indian major carps from June to March in fish hatcheries of West Bengal and Orissa. *Ex-situ* experiment carried out indicated a rising trend in the specific growth rate of *Labeo rohita* with increasing temperature between 29ºC and 34ºC.

Livestock production

Preliminary studies indicated that an increased temperature of 2°C above the minimum temperature led to measurable reduction in milk production in Murrah buffaloes. Extreme events like heat wave (>40°C and cold wave <3°C) reduced the milk yield by 10-30% in first lactation and 5-20% in second and third lactations in cattle and buffaloes. The results were *in situ* and not observed after the events.

Insect host plant interaction

Studies on the impact of elevated atmospheric CO_2 on insect pests showed that larvae of *Spodoptera litura* consumed more foliage of plants raised under high CO_2 than ambient CO_2. The total consumption of castor foliage during entire feeding period was significantly more under elevated CO_2 than ambient CO_2. Final larval dry weights differed among treatments and the impact of elevated CO_2 on larval weight of *S. litura* on castor was significant. The larval weights were higher with elevated CO_2 foliage compared to ambient CO_2 foliage. The developmental period for larvae fed with castor foliage grown under elevated CO_2 conditions was longer (18 days) compared to larvae fed with ambient CO_2 foliage. The study showed that elevated CO_2 results in increased foliage feeding by the insect larvae and an increase in larval duration.

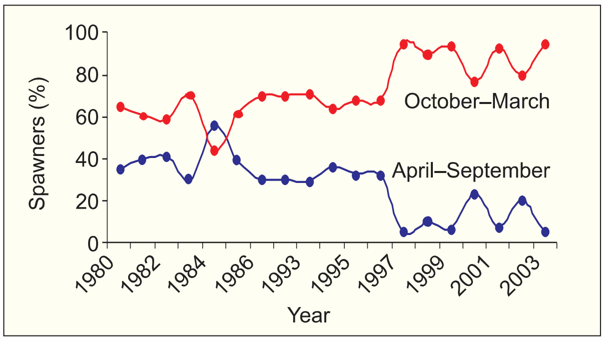
Effect of elevated CO_2 on *Spodoptera litura* reared on castor foliage

CO_2 enrichment	Weight of leaf ingested (g)	Larval weight (g)	Larval duration days
Elevated CO_2 550 –foliage	0.820 ±0.131	0.137 ±0.002	18.27 ±0.113
Elevated CO_2 700 –foliage	0.869 ±0.054	0.137 ±0.001	18.22 ±0.195
Ambient CO_2 Chamber foliage	0.594 ±0.044	0.117 ±0.006	16.11 ±0.253
Ambient CO_2 Open foliage	0.588 ±0.192	0.118 ±0.002	16.13 ±0.083
SEm±	0.048	0.0003	0.085
LSD (p=0.05)	0.166	0.011	0.261
CV%	11.59	4.70	3.10

Spawning season of *Nemipterus japonicus*

The threadfin breams *Nemipterus japonicus* and *N. mesoprion* are the dominant fish species distributed along the entire Indian coast at depths ranging from 10 to 100 m. Past data (1981 to 2004 except for the years 1988-1992) were analyzed to determine if there has been any change in the spawning season of *N. japonicus* and *N. mesoprion* off Chennai coast. The months in which the spawning females occur are taken as the months of spawning, as males too spawn during those months.

Though there were wide monthly fluctuations in the number of spawners, grouping the number of spawners into two major seasons, i.e., warm (April to September) and cool (October to March) seasons showed a clear pattern in the shift of the spawning season. Whereas 35.3% of the spawners occurred during the warm months in 1980, the number of spawners gradually reduced and only 5.0% of the spawners occurred during the same season in 2004. In 1980, it was observed that 64.7% of the spawners occurred during October-March, whereas as high as 95.0% of the spawners



Change in spawning season of *Nemipterus japonicus* off Chennai

occurred during the same season in 2004. In other words, the number of spawners reduced in summer and shifted towards cooler months.

Analysis of historical weather data showed that during April – September, the annual average sea-surface temperature (SST) off Chennai coast increased from 29.07°C during 1981-85 to 29.38°C by 2001-04; and from 27.86°C to 28.01°C during October-March. There was good correlation between SST and spawning activity of the two species of threadfin breams. The occurrence of spawners (percent of spawners in the annual total number of spawners) of *N. japonicus* linearly decreased with increasing temperature during April – September, and increased positively during October – March. It appears that SST between 28° C and 29° C may be the optimum and when the SST exceeds 29°C, the fish shift the spawning activity to seasons when the temperature is around the preferred optima.