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Climate change and coconut plantations in India: Impacts and potential adaptation gains

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ABSTRACT

The assessment of impact of climate change on coconut, a plantation crop, is challenging. However, the development of a simulation model (InfoCrop-COCONUT) has enabled the process. We present the first simulation analysis of the potential impacts of climate change on coconut productivity in India following two approaches, namely: (i) 'fixed increase in temperature and CO_2, and (ii) scenarios as per PRECIS (Providing Regional Climates for Impact Studies) – a regional climate model. Impact of changed management on coconut productivity in current as well as in future climates is also assessed. Climate change is projected to increase coconut productivity in western coastal region, Kerala, parts of Tamil Nadu, Karnataka and Maharashtra (provided current level of water and management is made available in future climates as well) and also in North-Eastern states, islands of Andaman and Nicobar and Lakshadweep while negative impacts are projected for Andhra Pradesh, Orissa, West Bengal, Gujarat and parts of Karnataka and Tamil Nadu. On all India basis, even with current management, climate change is projected to increase coconut productivity by 4.3% in A1B 2030, 1.9% in A1B 2080, 6.8% in A2 2080 and 5.7% in B2 2080 scenarios of PRECIS over mean productivity of 2000–2005 period. Agronomic adaptations like soil moisture conservation, summer irrigation, drip irrigation, and fertilizer application cannot only minimize losses in majority of coconut growing regions, but also improve productivity substantially. Further, genetic adaptation measures like growing improved local *Tall* cultivars and hybrids under improved crop management is needed for long-term adaptation of plantation to climate change, particularly in regions that are projected to be negatively impacted by climate change. Such strategy can increase the productivity by about 33% in 2030, and by 25–32% in 2080 climate scenarios. In fact, productivity can be improved by 20% to almost double if all plantations in India are provided with above mentioned management even in current climates. In places where positive impacts are projected, current poor management may become a limiting factor in reaping the benefits of CO_2 fertilization, while in negatively affected regions adaptation strategies can reduce the impacts. Thus, intensive genetic and agronomic adaptation to climate change can substantially benefit the coconut production in India.

1. Introduction

Climate change is projected to increase global annual mean temperatures in the range of 1.8–4 °C; increase the variability in rainfall; and enhance frequency of extreme weather events such as heat waves, cold waves, droughts and floods (IPCC, 2007). All these changes could potentially influence agricultural production (Rosenzweig and Parry, 1994; Fischer et al., 2001; IPCC, 2007) so that many production systems may become vulnerable. For the Indian region, climate change impact assessments have focused on crops like wheat (Aggarwal and Swaroopa Rani, 2009), rice (Aggarwal and Mall, 2002; Krishnan et al., 2007; Naresh Kumar et al., in press), maize (Byjesh et al., 2010) and sorghum (Srivastava et al., 2010). However, it is important to understand the impact of climate change on plantation crops, which are perennial in nature and influenced by climate change and variability even during a single generation or in a standing plantation. For example, a seedling of coconut experiences the increased CO_2 concentrations, temperatures, changed rainfall patterns as it ages in the next 50 years of its economic yield producing lifespan. Further, plantation crops are grown mainly in ecologically sensitive areas such as coastal belts, hilly areas and areas with high rainfall and high humidity. These crops are of high economic value contributing substantially to agricultural exports at national and global level. Apart from

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these, plantations also demand long-time commitment for farmers' precious resources like land, inputs and time. All of these make plantation production vulnerable to climate change. In spite of this, the assessments of impacts of climate change on plantation crops are scarce. Only recently, research focus has shifted to quantification of impacts of climate change on various plantation crops and derivation of suitable adaptation measures.

Coconut palm (*Cocos nucifera* L.) is mainly a crop of humid tropics and is distributed between 23° north and 23° south of the equator and up to altitudes of about 600 m from the mean sea level for nut production. At global scale, coconut is grown in about 12.9 Mha in over 90 countries, with an annual production of about 61.2 billion nuts. Coconut plantations are grown mainly by resource poor farmers, with major production being contributed by countries like Philippines, Indonesia, India, Brazil and Sri Lanka. These plantations are generally of three types, namely: (i) monoculture, (ii) coconut based cropping systems that include annual and perennial crops, and (iii) home-stead gardens. India is one of the leading coconut growing nations with a production of about 15.73 billion nuts from an area of 1.89 Mha at an average productivity of 8300 nuts ha^{-1} (CDB, 2010). All three types of coconut plantations are present in India providing livelihood sustenance to about 10 million people. Even though coconut is grown in over 200 districts in India, the major producing area is confined to just about 20 districts (Fig. 1), which contribute almost 70% of national production.

Good production requires a well-distributed rainfall (130–230 cm/year), annual mean temperature of 27–29 °C (with diurnal variation of 5–7 °C) and about 2000 h of sun shine (250–350 W m^{-2}) in a year with at least 120 h $month^{-1}$ (Child, 1974; Persley, 1992; Rajagopal et al., 2006). Minimum temperatures above 10 °C trigger flowering and temperatures <10 °C for 1 month cause nut fall, while temperatures >40 °C during April to July in the tropics decrease functional leaf area index, dry matter production and nut yield (Naresh Kumar et al., 2008). High ambient leaf temperatures and high VPD (Escbach et al., 1982; Rajagopal et al., 2000), low water potentials (Repellin et al., 1997; Rajagopal et al., 2000), stomatal and non-stomatal limitations (Gomes et al., 2008; Siju Thomas et al., 2008) affect the photosynthetic rates resulting in reduced dry matter accumulation and yield. Consistent leaf area index and photosynthetic rates are considered to be important for high productivity in coconut (Siju Thomas et al., 2008) while leaf area is significantly correlated with pistillate flower and nut production (Kasturi Bai et al., 2003). The rainfall of the previous year had the most influence on total annual yield (Peiris et al., 1995; Peiris and Thattil, 1998). Coincidence of dry spell with sensitive stages of inflorescence and nut development (Rajagopal et al., 1996) as well as the amount of rainfall and length of dry spells over preceding 4 years largely influenced coconut productivity in different agro-climatic zones of India (Naresh Kumar et al., 2007) apart from other variables of weather (Naresh Kumar et al., 2009a). In a year with more than 150 days of maximum temperatures >33°C and a dry spell of about 200 days reduced yields (Naresh Kumar et al., 2009a,b).

Coconut, being a C3 crop, is likely to benefit due to an increase in CO_2 (Naresh Kumar et al., 2008) as in case of other C3 species (Kimball et al., 2002; Ainsworth and Long, 2005). Since, climate change is projected to raise temperatures and affect rainfall patterns, it becomes important to understand the impacts of changing climate on this crop. Quantification of impact of climate change is studied by several approaches which include experiments in controlled environmental facilities like Open Top Chambers – OTC (Leadley and Drake, 1993), temperature gradient tunnels – TGT (Aranjuelo et al., 2005), Free Air Carbon dioxide Enrichment – FACE (Kimball et al., 2002; Ainsworth and Long, 2005), and Free Atmospheric Temperature Elevation – FATE (Kimball et al., 2008) in which the response of crops to elevated CO_2 and temperature are studied. Another approach is to use simulation models, which provide opportunity to use various climate change scenarios in combination with different management parameters for analyzing the regional impacts (Rosenzweig and Parry, 1994; Aggarwal, 2008).

In case of plantation crops, field experiments are not only expensive but also time consuming, however, they provide information for model inputs. Recently, a simulation model for coconut was developed and validated for different agro-climatic zones of India (Naresh Kumar et al., 2008). We used this model to assess the (i) impacts of climate change on coconut productivity with current management; (ii) impact of changed management on coconut productivity in current climates; and (iii) coconut productivity with changed management in future climates of PRECIS. The PRECIS (Providing Regional Climates for Impact Studies—which had the Hadley Centre Climate Model (HadCM3) as the global climate

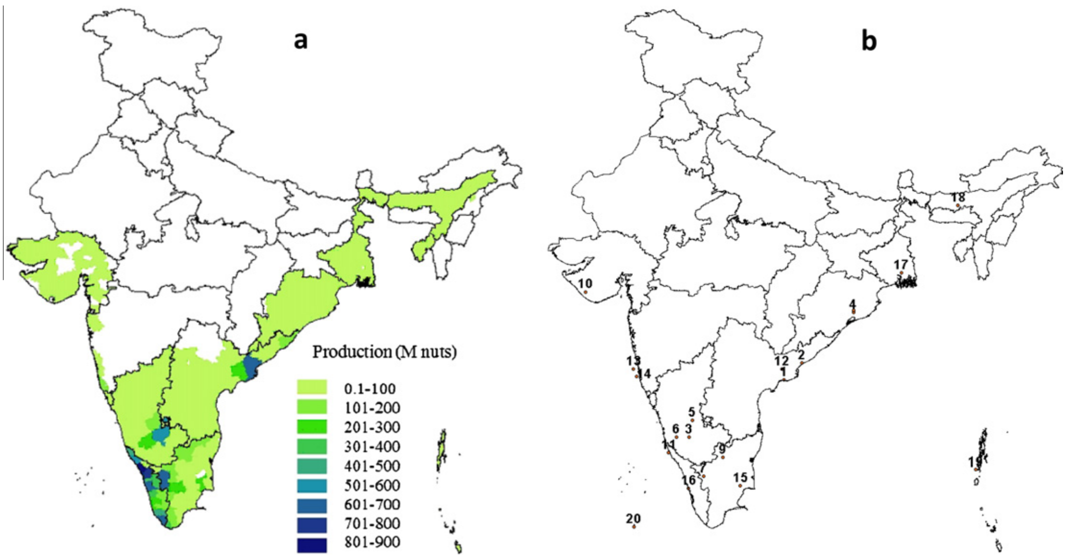

Fig. 1. (a) Spatial distribution of coconut production in India and (b) locations representing major production areas. In the analysis of climate change impacts in Approach I, data from these locations were used. For name of location, please refer to Table 1.

model (GCM) input) is a regional climate model (RCM)—is used extensively for climate change studies in India (NATCOM, 2012). Earlier, the results from Open-Top Chamber experiments of Central Plantation Crops Research Institute, Kasaragod (NPCC, 2009, 2010) were also used for fine-tuning the simulation model.

2. Materials and methods

The InfoCrop-COCONUT simulation model (Naresh Kumar et al., 2008), based on the InfoCrop generic model (Aggarwal et al., 2006), was validated for different agro-climatic zones of coconut growing areas in India (Naresh Kumar et al., 2008). The model simulates growth and development of crop based on the radiation use efficiency (RUE) on daily basis. The RUE is further governed by a crop-specific response of photosynthesis to temperature, CO_2 concentration, and water and nitrogen availability. The model considers the reduction of stomatal conductance in elevated CO_2 conditions, thus reducing transpiration rates. The influence of temperature on growth and developmental rates, photosynthetic rates, leaf area senescence, pollen sterility, nut retention and sink number are considered. The model estimates the potential evapotranspiration as per the Penmen Monteith Method; but in absence of wind speed data this is calculated based on the Priestly and Taylor method. The water balance is estimated based on the rate of change in soil water in a day considering the irrigation, rainfall, upward flux of water in soil layers, evaporation from soil surface, transpiration of crops and weeds, fraction of rainfall intercepted by crops, percolation, runoff, and drainage. Water stress affects the crop growth by reducing RUE, accelerating the leaf senescence and reducing potential sink. Details of model framework for simulating the effect of temperature, rainfall and CO_2 on plant growth, development and yield in InfoCrop were provided earlier (Aggarwal et al., 2006; Naresh Kumar et al., 2008, 2011; Srivastava et al., 2010). Using this model, simulations were carried out to analyze the impact of climate change on coconut productivity with current management. For this, two approaches were used namely (i) a matrix of 'fixed increase' in temperature and CO_2, and (ii) scenarios from a Regional Climate Model (PRECIS).

2.1. Approach I: simulating the effect of 'fixed increase' in temperature and CO_2

For the first approach, weather data from 15 centers (Fig. 1; Table 1) representing 13 agro-climatic zones were used for analyzing the impacts of increase in temperature from 1 to 5 °C over baseline period (1969–1990), and increase in CO_2 levels from 369 ppm during baseline period to 380 ppm and thereafter, from 400 to 800 ppm at 50 ppm interval. Combination matrix of CO_2 and temperature changes was used for simulating the yields. Change in yield was expressed as per cent deviation from mean yields of the 2000–2005 period for respective districts.

2.2. Approach II: use of RCM scenarios

In this approach, the simulations were based on weather outputs from a RCM, viz., PRECIS A1b scenarios for 2030 (2020–2049; medium) and A1b, A2 and B2 scenarios for 2080 (2071–2100; future). The PRECIS is an atmospheric and land surface model of limited area locatable over any part of the globe with a spatial resolution of $0.44^\circ \times 0.44^\circ$. It accounts for meteorological dynamic flow, atmospheric sulfur cycle, formation of clouds and precipitation, radiative processes, land surface vegetation, incoming radiation, heat fluxes, soil temperature and lateral boundary conditions, and is more suitable for high resolution impact assessments (Jones et al., 2004). In this approach, the gridded weather (1969–1990; Indian Meteorological Department, Pune) was used as baseline data.

In both the approaches, model inputs also included characteristics of major soil types; currently followed practices for crop management by farmers in each agro-climatic zone (collected during surveys), and coefficients of the dominant coconut varieties in each agro-climatic zone. Further, projected CO_2 levels for respective scenarios—447 (A1b); 2080-639 (A1b), 682 (A2) and 552 (B2) were included while simulating the RCM based assessments.

2.3. Processing of input data

Details of input data processing for InfoCrop are presented in Naresh Kumar et al. (2011).

Table 1
Characteristics of locations representing major coconut growing areas in India. Locations 2–16 are used for the analysis on sensitivity of coconut plantations to rise in temperature and CO_2 in Approach I.

S. no.	Location	Latitude (N)	Longitude (E)	Altitude (mMSL)	Soil type	Annual mean temperature (°C)		Temperature range (°C)		Annual rainfall (mm)
						Minimum	Maximum	Minimum	Maximum	
1	Ambajipeta	16°39′	81°54′	8.5	Sandy clay loam	24.2	32.3	17.8–32.1	25.2–44.2	1275
2	Anakapalli	17°35′	82°59′	100.0	Sandy clay loamy	22.9	33.0	10.3–30.0	26.5–43.4	1219
3	Ariskeri	13°18′	76°15′	809.0	Red sandy loam	16.6	30.6	6.1–24.5	23.5–37.5	792
4	Bhubaneswar	20°16′	85°50′	43.9	Sandy loam	22.3	32.6	10.5–28.1	23.1–42.4	1472
5	Chitradurga	14°13′	76°34′	720.0	Red sandy loam	20.3	30.7	8.0–26.4	20.7–38.8	608
6	Chikmaglur	13°18′	75°46′	1029.0	Clay loam	17.7	28.2	12.2–21.9	20.8–34.6	890
7	Coimbatore	11°01′	77°01′	423.0	Sandy loam	21.4	31.7	13.0–25.5	21.5–37.5	775
8	Cuttuck	20°27′	85°52′	28.9	Sandy and sandy loam	22.0	32.1	10.9–30.0	21.0–45.1	1021
9	Dharmapuri	12°07′	78°09′	167.0	Sandy loam	21.3	32.6	11.8–26.7	22.5–39.8	870
10	Junagad	21°30′	70°27′	65.0	Sandy clay loam	20.1	34.0	4.9–29.0	23.2–43.8	828
11	Kasaragod	12°30′	75°01′	10.7	Red sandy loam, sandy	22.4	31.2	13.2–26.0	24.6–36.5	3469
12	Kovvuru	17°00′	81°43′	22.6	Sandy clay loam	24.7	34.1	16.0–34.5	26.0–47.0	1098
13	Mulde	17°00′	73°00′	17.0	Sandy loam	21.6	32.8	11.2–27.0	24.2–38.0	3068
14	Ratnagiri	16°58′	73°17′	3.2	Sandy loam	22.8	31.3	12.6–27.4	25.0–36.2	2874
15	Tanjavur	10°46′	79°07′	61.0	Sandy	24.3	34.7	17.2–29.0	23.5–43.4	1071
16	Trissur	10°31′	76°13′	12.5	Red sandy loam and sandy	23.3	32.1	15.0–26.6	24.8–38.0	2725
17	Kolkota	22°34′	88°22′	10.0	Gangetic alluvial soils	22.1	31.8	07.0–32.0	17.0–44.0	1641
18	Gawhati	26°11′	91°44′	54.0	Alluvial soils	19.1	29.3	07.5–25.5	19.1–33.4	1717
19	Port Blair	11°39′	92°44′	22.0	Sandy soils	23.1	30.2	18.0–27.0	24.0–37.0	3169
20	Minicoy	08°16′	73°02′	9.0	Sandy soils	24.3	30.4	15.0–26.0	24.0–37.0	1675

2.3.1. Varietal coefficients

Varietal coefficient inputs include base temperatures for vegetative growth, production period, nut retention, thermal time for vegetative and reproductive periods, minimum, optimum and maximum temperatures for growth, radiation use efficiency, individual nut weight, canopy light interception extinction coefficient, maximum specific leaf area, and root extension growth rate of commonly grown varieties (Naresh Kumar et al., 2008).

2.3.2. Management

Major management practices, viz., well irrigated and fertilized (organic and inorganic), irrigated with less amount of fertilizers and rainfed with less amount of fertilizers were used to represent the farmers' practice.

2.4. Simulating baseline yields

Simulations were run for the baseline (1969–1990) period using gridded data, and outputs were obtained on yearly basis for 22 years. Since coconut yields from ~6 years after planting, mean productivity of later 16 years was taken. The sum of the weighted yield from each grid fraction in a district gave 'baseline yields' for the respective district.

2.5. Simulating productivity in future scenarios

To get respective climate scenario data for input into the crop model, the 'delta method' was used where changes in temperatures (minimum and maximum) and per cent change in rainfall were coupled to the observed gridded baseline weather data for the 1969–1990 period (Naresh Kumar et al., 2011). All other simulation conditions were maintained as explained earlier. The grid-wise outputs were used to calculate the district-wise productivity with current management in future climates.

2.6. Estimating impacts with current management in future climates

To express the impacts of climate change, the net change in productivity in future climates from baseline yield was calculated and expressed as the per cent deviation from mean productivity for the 2000–2005 period. These projections on impacts assumed that the farmers continue to practice current management in future climates as well and the area under crop remains the same.

2.7. Estimating impacts with changed management in current and future climates

Adaptation gains by changed management were assessed for (i) current and (ii) future climates. For simulating adaptation gains in current climates as presented in Fig. 4, the changed management included (i) fully irrigated with medium fertilizers where all coconut plantations in India were provided assured irrigation with at least 2/3rd of the region-specific recommended dose of fertilizers, and (ii) intensive management strategy, where all plantations in India adopted improved coconut cultivars and provided drip irrigation, and a full dose of recommended inorganic and organic fertilizers, includes a compendium of genetic and agronomic adaptation. In genetic adaptation, growing improved coconut cultivars over local *Tall* or *Dwarf* cultivars can be the best option. Among the popularly grown cultivars, WCT, LCT, TPT, SKGT, ECT, GBGD are relatively tolerant to climatic stresses such as drought (Rajagopal et al., 1990; Kasturi Bai et al., 2009) and even to multiple stresses (Naresh Kumar and Kasturi Bai, 2009). In the agronomic adaptation, apart from the options mentioned above, soil-moisture conservation significantly improved productivity in different agro-climatic zones (Naresh Kumar et al., 2006a,b).

Apart from the above, for estimating the productivity in current and future climates with region-specific change in management (presented in Table 3), several adaptation options such as drip irrigation to irrigated plantations, summer irrigation to rainfed plantations, soil moisture conservation, and an array of levels of organic and inorganic fertilizer application were used in different combinations for not only minimizing the adverse impacts but also to maximize the beneficial effects. The combination, which gave highest productivity in each region, was taken as the best suitable adaptation strategy. In regions where productivity in future climates were less than the current in spite of changed management, intensive management, as mentioned previously, for the region was used. In all these cases, change in productivity with changed management in current and future climates was expressed as per cent deviation from mean productivity of the 2000–2005 period.

3. Results and discussion

3.1. Impact assessment using fixed increase in temperature and CO_2

Increase in atmospheric concentration of CO_2 benefits coconut as it is a C3 crop. However, increase in temperature, depending on the current temperatures, either complement or reduce this benefit. Interaction of both factors differentially influenced coconut productivity in different agro-climatic zones. Such response can be attributed mainly to variations in current climate and plantation management across the agro-climatic zones. Even though spatio-temporal variations exist, overall results indicate that coconut productivity is projected to increase with increase in atmospheric CO_2 concentrations and rise in temperatures up to 2–3 °C in the western parts of India and in the western-coastal areas. On the other hand, the eastern-coastal parts, interiors of Karnataka and Tamil Nadu are projected to face a decline in productivity with increased temperatures.

Regional projections indicate variations in offsetting points where the negative impacts of temperature are compensated by the beneficial influence of elevated CO_2 (Fig. 2). For instance, to offset the yield reduction due to a 2 °C increase in temperature, coconut palms in the central-west region of India may require 450 ppm of CO_2, while those in the upper eastern-coastal region may require 550 ppm. Similarly, to offset the yield reduction due to a 3 °C rise in temperature, CO_2 concentration should be 450 ppm in the central plains and 600 ppm in the south eastern-coast. On the other hand, even a 1 °C increase in temperature is projected to affect coconut productivity in central parts of coastal Andhra Pradesh and Orissa, reflecting current high summer temperatures and making these regions more vulnerable, in spite of beneficial effects of increased CO_2. In fact, coconut productivity currently suffers under high summer temperatures in these regions.

The above results assume that the current management and irrigation continues to be available in the future, and the rainfall amount and distribution remain unchanged. Since climate change has spatio-temporal variations for increase in minimum and maximum temperatures and variations in rainfall deviations, the climate scenarios of RCM were used.

3.2. Impact assessment using PRECIS RCM scenarios

On aggregated scale, climate change is projected to increase coconut productivity in India by ~4.3% in A1B 2030 scenario even with current management. However, these gains may vary from ~2% to 7% in 2080, with lesser benefit in A1B emission scenario and higher benefit in A2 and B2 emission scenarios. The magnitude of the impact varies spatially with scenario and time-scale (Fig. 3). Coconut productivity in the west-coast, viz., Kerala, coastal

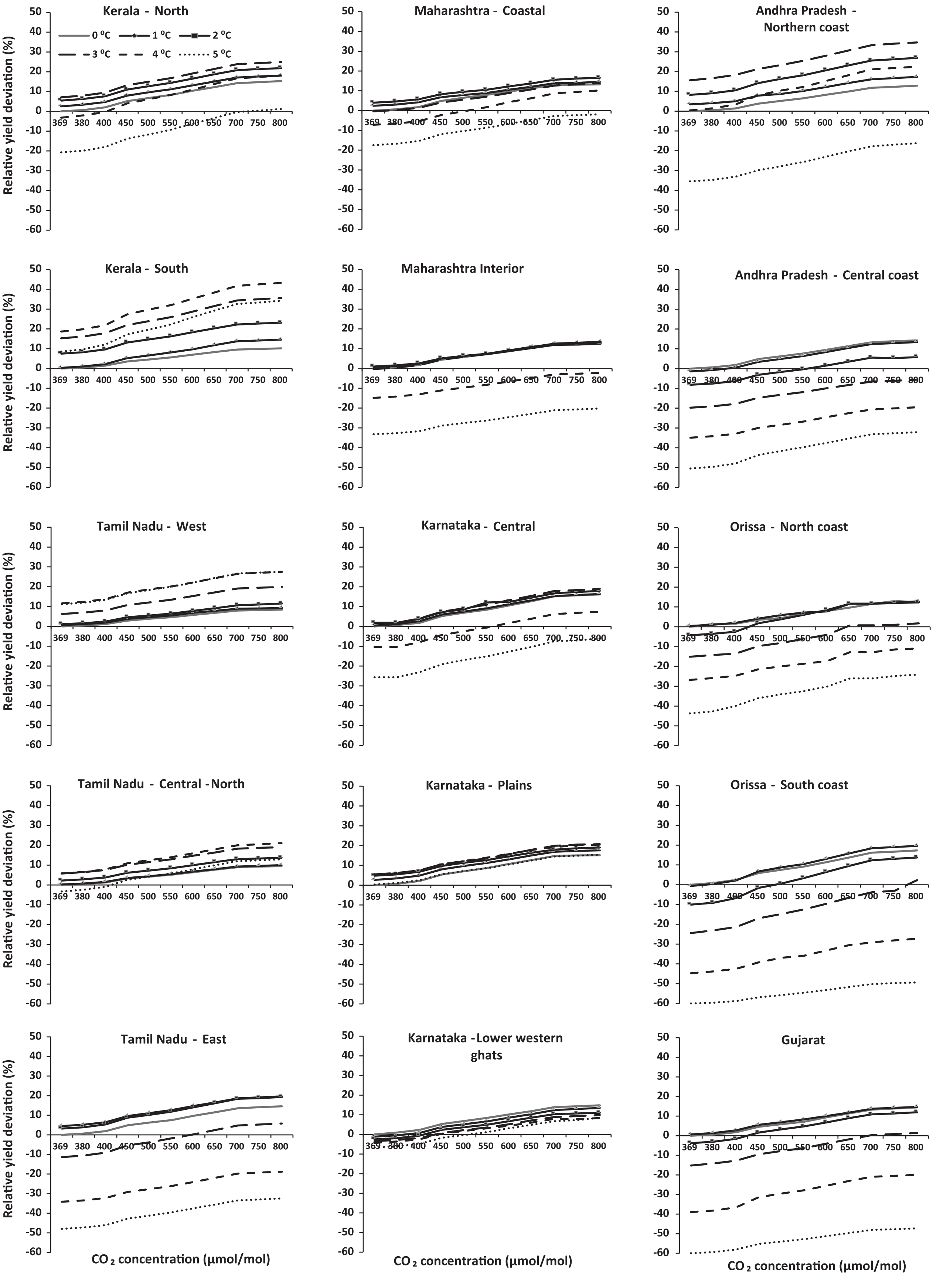

Fig. 2. Relative yield deviation (%) in different states of India due to 'fixed increase' in temperature and CO_2. Each point represents at least 16 years data. The yield change is relative to mean productivity of 5 years (2000–2005) period.

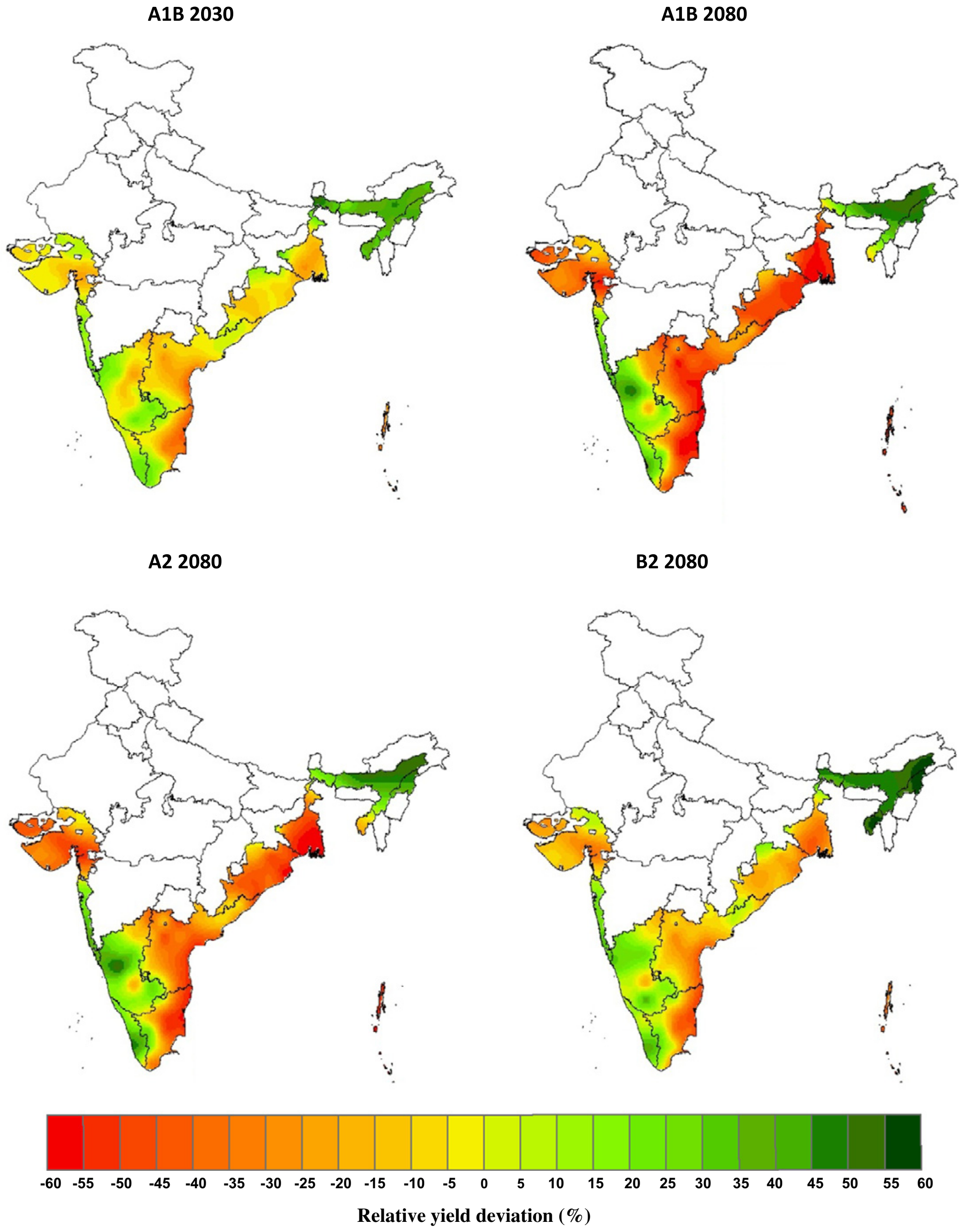

Fig. 3. Spatial variation in impact of climate change on coconut productivity in India with current management in PRECIS A1B 2030 and 2080; A2 – 2080 and B2 – 2080 climate scenarios. The yield change is relative to mean productivity of coconut for 5 years (2000–2005) period.

Karnataka, Goa and costal Maharashtra, and also in North-Eastern states, and islands of Andaman and Nicobar and Lakshadweep are projected to improve due to climate change (Fig. 3 and Table 2). Apart from these, coconut plantations in north-west and in south-east parts of Karnataka, south-west and western parts of Tamil Nadu are projected to benefit. However, other areas, particularly currently high yielding areas in Andhra Pradesh, Orissa, south and central parts of West Bengal, Gujarat, plains of Karnataka, and eastern and south-eastern parts of Tamil Nadu are projected to have reduced productivity. The negative impacts in the currently irrigated areas may become greater if future irrigation sources are limited. On aggregated scale, coconut productivity in states of Karnataka and West Bengal is projected to increase till 2030, but by 2080 the productivity is projected to decline.

From the forgoing, projected impacts of climate change on coconut show four trends. (i) Increased productivity in regions that are with sub-optimal temperatures currently and projected to have optimum temperatures besides increased post-monsoon as well as winter rainfall in future climates. The western-coastal areas may fall in this category. (ii) Productivity increase in regions with current low winter-temperatures, where moderate increase in temperatures and significant increase in rainfall is projected. Areas in the North-Eastern region and parts of West Bengal and parts of Orissa may fall in this category. (iii) Decreased productivity in areas that have high temperatures and projected to have higher temperatures in spite of marginal increase in rainfall in future climates. Currently irrigated and high yielding areas of Andhra Pradesh and Tamil Nadu may fall in this category. (iv) Decreased productivity

Table 2
Impact of climate change on coconut productivity with current management in different states of India in PRECIS climate scenarios. Each datum represents at least 16 years data.

State	Productivity (mean of 2000–2005, nuts ha^{-1} year^{-1})	Impact in climate scenarios of PRECIS (per cent deviation from mean productivity of 2000–2005)			
		A1b 2030	A1b 2080	A2 2080	B2 2080
Andaman and Nicobar	3896	7.4	−10.3	4.9	15.0
Andhra Pradesh	10,878	−1.4	−31.4	−21.2	−3.4
Assam	7158	59.1	>60.0	>60.0	>60.0
Goa	4978	35.6	42.5	52.6	46.7
Gujarat	7584	−9.0	−38.6	−38.0	−19.2
Karnataka	4353	5.3	−8.8	−9.5	−11.2
Kerala	6220	6.5	18.5	21.2	14.0
Lakshadweep	19,642	6.5	33.5	34.5	16.5
Maharashtra	10,297	15.7	25.6	30.5	26.3
Nagaland	3519	>60.0	>60.0	>60.0	>60.0
Orissa	4466	−6.5	−48.2	−40.7	−16.9
Pondicherry	11,160	−25.7	−45.2	−41.0	−30.8
Tamil Nadu	10,226	−1.6	−10.3	−5.3	−2.8
Tripura	2094	54.6	>60.0	>60.0	>60.0
West Bengal	13,065	2.9	−39.6	−24.2	−3.9
All India	7171	4.3	1.9	6.8	5.7

in areas that are projected to have higher temperatures along with reduced rainfall in future climates. Parts of Tamil Nadu and Karnataka may fall in this category.

Analysis indicates that annual mean, maximum and minimum temperatures above 28 °C, 33 °C and 23 °C respectively, affect coconut productivity. Intra-annual or seasonal variations in temperature regimes substantially influence productivity. For instance, inter-seasonal variations for mean temperature in the west-coast was up to 3 °C, up to 7 °C in the east-coast, and >12 °C in the north-eastern region. The seasonal variations for temperature were wider with increase in latitude and these influenced immensely the growth and productivity of coconut. Very low minimum temperatures (<8 °C) during winter season in northern latitudes was found to affect the inflorescence production and yield. In these regions, increase in winter temperatures and rainfall in future climates may help inflorescence and pistillate flower production, pollination, nut retention and yield.

In general for the 2030 time period, projected increase in mean minimum temperature is less in the west-coast (0.5–1.5 °C), particularly in Kerala than in the east-coast and inlands (1.5–2 °C), while that of mean maximum temperature is 1–1.5 °C in the west-coast and 1.5–2 °C in the east-coast, and inlands. Rainfall is also projected to increase up to 10% in the west-coast and in many parts of inlands, while it is projected to reduce by 10% in some regions of interior Karnataka and Tamil Nadu. Such trends are projected to magnify in the 2080 time period. This implies that currently warm areas are projected to become warmer and areas with current rainfall of about 700–1200 mm are projected to receive ~10% more rainfall in future scenarios. Present high rainfall zones may also become wetter by about 10% while some regions with current rainfall of about 800 mm may become drier by 10%.

In the western-coastal region, where coconut is generally rainfed, increase in yield may be mainly attributed to extended availability of soil moisture because of projected increase in rainfall during post-November period as well as due to optimal temperatures, apart from CO_2 fertilization benefits. Shift in temperatures towards optimum increases the leaf and inflorescence production rates, leaf area and photosynthesis during clear days from the October to May period. This can compensate for reduced sunlight during the monsoon season and improve dry matter production, resulting in higher productivity in future climates. Since current temperatures are relatively low in these areas, increase in temperature by 2 °C may prove beneficial to the growth and yield of coconut palm.

On the other hand, very high (40 to >46 °C) summer temperatures and low monsoon rainfall found in the east-coast affect the pollination, nut retention and ultimately nut yield. Due to the existing high temperatures, crop growth will be affected even with a 1 °C increase in Godavari districts of AP, Orissa, Gujarat and parts of Karnataka and Tamil Nadu. Projected high temperatures affect the growth and development of plantations for extended duration in a year causing severe loss in productivity. Even though, the transitory reserves in coconut palms are reported to sustain the overall tree growth for 1–2 months (Mialet-Serra et al., 2005), high temperatures inhibit photosynthesis, enhance respiration losses and hasten leaf senescence apart from causing pollen sterility, button-size nut shedding and immature nut fall, thus reducing the

Table 3
Productivity of coconut with changed management in different states of India in current climates and in PRECIS climate scenarios. Each datum represents at least 16 years data.

STATE	Per cent deviation from mean productivity of 2000–2005					
	Adaptation strategy	In current climates	Climate scenarios			
			A1b 2030	A1b 2080	A2 2080	B2 2080
Andaman and Nicobar	Summer irrigation with medium dose of fertilizers	29.0	32.4	14.6	31.3	37.6
Andhra Pradesh	Intensive management	32.4	29.8	1.6	5.0	26.9
Assam	Summer irrigation with medium dose of fertilizers	>60.0	>70.0	>70.0	>70.0	>70.0
Goa	Minimal irrigation with medium dose of fertilizers	37.5	>60.0	>60.0	>60.0	>60.0
Gujarat	Assured irrigation and improved dose of fertilizers	32.6	26.62	3.7	5.2	18.3
Karnataka	Assured irrigation and improved dose of fertilizers	28.9	29.7	12.3	8.2	6.9
Kerala	Medium irrigation with improved dose of fertilizers	36.0	38.0	45.3	46.3	39.4
Lakshadweep	Summer irrigation with medium dose of fertilizers; management of plant density	43.1	46.0	>60.0	>60.0	47.4
Maharashtra	Assured irrigation with medium dose of fertilizers	22.4	34.2	45.8	46.9	43.6
Nagaland	Summer irrigation with medium dose of fertilizers	>60.0	>70.0	>70.0	>70.0	>70.0
Orissa	Assured irrigation with improved dose of fertilizers	34.5	28.7	1.3	2.6	20.0
Pondicherry	Intensive management	26.2	4.2	0.2	0.2	1.2
Tamil Nadu	Intensive management	40.2	28.0	9.5	19.1	33.0
Tripura	Summer irrigation with medium dose of fertilizers	>60	>70.0	>70.0	>70.0	>70.0
West Bengal	Assured irrigation and improved dose of fertilizers	29.8	39.7	2.4	4.6	28.7
All India	With above mentioned regional specific adaptation	36.2	33.5	24.6	27.8	31.9

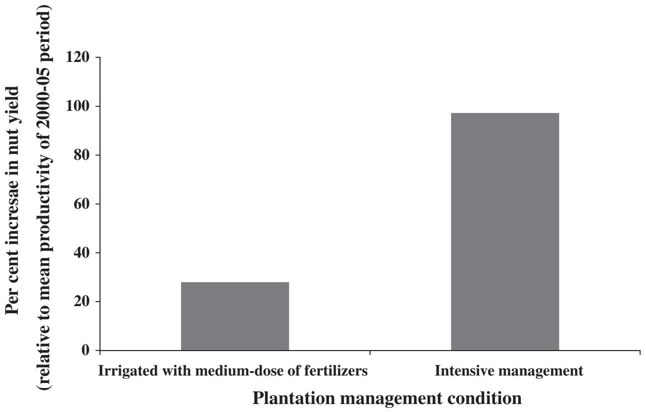

Fig. 4. Gains in coconut productivity due to adoption of improved management in current climates in India. The yield change is relative to mean productivity of coconut for 5 years (2000–2005) period. In irrigated with medium fertilizers, all coconut plantations in India were provided assured irrigation with at least 2/3rd of the recommended dose of fertilizers. In intensive management, all plantations in India adopt improved coconut cultivars managed with year-round drip irrigation and full dose of recommended inorganic and organic fertilizers.

yields. Water stress confounds the severity of this problem, since availability of water to the palms can help them in canopy cooling by transpiration and can partially offset the adverse influences of high temperature.

In coconut, the source-sink imbalances can be partly compensated by the transitory reserves, variable radiation use efficiency in short-term, and by adjusting fruit load in the long-term (Mialet-Serra et al., 2008). Therefore, even though short-term weather variability may not significantly affect the physiological capacity of palms for higher production, long-term stresses like droughts and prolonged high- or low-temperatures affect productivity. Continuous adverse weather for 3–4 years severely affects the productivity of coconut plantations, which need equal period for recovery due to the palm's unique floral phenology (Naresh Kumar, 2011), thus causing a perennial loss of farm income.

3.3. Deriving adaptation strategies for climate change

In plantation crops, sustaining productivity through crop management is important especially during adverse conditions since they live through the climate change and variability effects. Simulation analysis indicates that the negative impacts can be overcome by adaptation strategies such as assured irrigation through drip system coupled with soil-moisture conservation and providing fertilizers/nutrients through organic and inorganic sources in doses higher than those currently applied by the farmers (Table 3). Such measures also maximize the positive impacts of climate change. However, in areas such as the east-coast and parts of Tamil Nadu where temperatures are projected to go beyond optimum, intensive management of existing plantations including planting of improved and tolerant varieties managed with high input use efficiency is required. Plantations in Andhra Pradesh, Tamil Nadu and West Bengal need to be intensively managed to offset negative impacts and to enhance production in future climates.

On an aggregated scale, present coconut productivity in India can be improved by 28% if all plantations are provided assured irrigation with a medium dose of fertilizers (Fig. 4). By intensive management, which includes adopting improved cultivars along with assured irrigation and full fertilizer management, coconut productivity can be almost doubled in India in current climates. Recent increase in coconut productivity (∼15%) in India can be attributed to better management. Region specific change in management of plantations can also improve current productivity in the range of 22% to >60% in different regions (Table 3). On an all India scale, change in management is projected to increase coconut productivity by about 34% in A1b 2030, and by ∼25–32% in the 2080 climate scenarios (Fig. 5).

Improved management enhances productivity much more at present than in future climates in spite of positive impacts of climate change in some regions. This may be due to limitation of source capacity of palms to support further increase in nut yields or due to limitation of nutrients or management options considered in this study. Irrigated coconut areas are dependent on rainfed-river systems and ground water resources in peninsular India. With projected increase in precipitation in India in future climates, water yield of majority of river systems may not decline in mid-century scenario, however, they may have spatial variations (NATCOM, 2012). Even if the availability of irrigation water slightly declines due to competition from other sectors, efficient use of water can meet the requirement of coconut plantations in future climates. Improved and efficient water use at various levels of agricultural production is highly desirable even in current climates.

Yield enhancement of cultivars through population improvement and utilization of identified *in situ* drought tolerant coconut palms in population improvement programme is very important (Naresh Kumar et al., 2006a,b) for making the crop more resilient to climate change. Since standing plantation crops cannot be replaced easily with tolerant varieties because of the long establishment period for economic yield, crop management becomes crucial. In addition to these, institutional support for community level adaptation options including making farmers aware about climatic stresses, water harvesting and recycling, fore-warning on

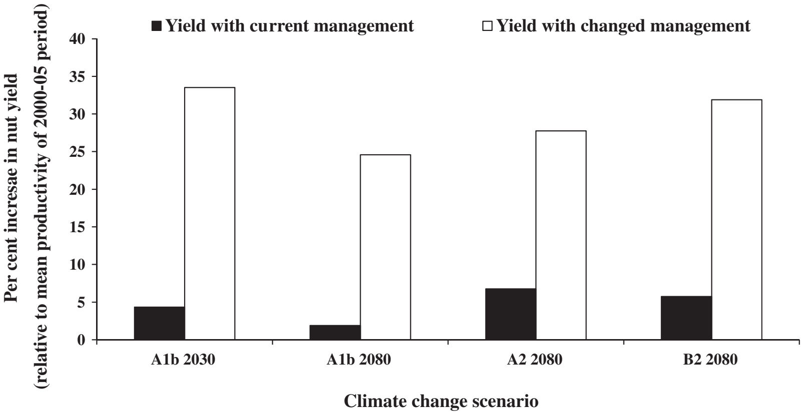

Fig. 5. Change in coconut yield with current as well as with changed management in India in PRECIS climate scenarios. For details of changed management, please refer to Table 3.

weather aberrations, and weather based agro-advisory will help in making coconut plantations climate resilient.

The above mentioned analysis has limitations due to various assumptions and uncertainties. These include (1) the uncertainties of climate change scenarios; (2) future rainfall distribution is assumed to be similar as that existed during baseline period; (3) frequency of climatic extremes are assumed to be similar to that which existed during baseline period; (4) area under crops is assumed to be similar to that in baseline; (5) future technology development in crop improvement and management may exceed the proposed adaptation strategies; and (6) pest and diseases will be managed in future climates as done currently. In spite of the above mentioned limitations, the analysis provides information on possible impacts of climate change on coconut plantations and also the adaptation strategies required to not only reduce the negative impacts, but also to maximize the positive influences in future climate scenarios.

4. Conclusion

Climate change is projected to increase coconut productivity in Kerala and parts of Tamil Nadu, Karnataka and Maharashtra (provided current level of water and management is made available in future scenario as well), as well as in North-Eastern states, islands of Andaman and Nicobar and Lakshadweep. Apart from these, coconut plantations in north-west and in south-east parts of Karnataka, south-west and western parts of Tamil Nadu are projected to benefit. However, other areas, particularly currently high yielding areas in Andhra Pradesh, Orissa, south and central parts of West Bengal, Gujarat, plains of Karnataka, and eastern and south-eastern parts of Tamil Nadu are projected to have reduced productivity. On an all India basis, climate change is projected to increase productivity in the range of $\sim$4.3% in A1B 2030, $\sim$1.9 in A1B 2080, $\sim$6.8% in A2 2080, and $\sim$5.7% in B2 2080 scenarios of PRECIS, a RCM, even with current management. Agronomic adaptation like soil moisture conservation, providing assured irrigation, efficient technologies like drip irrigation, and application of recommended dose of fertilizers can minimize losses in many parts of India. However, plantations in some regions need intensive management by adopting improved and tolerant local *Tall* cultivars or hybrids in combination with improved crop management. This will be useful for long-term adaptation of plantations across India to climate change. Adaptation by change in management will increase the productivity by about 34% in A1b 2030, and by $\sim$25–32% in 2080 climate scenarios. In fact, even in current climates, productivity can be improved by 20% to almost double if all plantations in India are provided with above mentioned management. Hence, improved management of coconut plantations can provide higher productivity in areas projected to have positive impacts of climate change, while intensive management can reduce the negative impacts in states like Tamil Nadu, Andhra Pradesh and West Bengal. In order to do this, there is an urgent need for population improvement of coconut with drought/heat tolerant palms and implementation of region-specific comprehensive adaptation strategies for reducing the negative impacts and for maximizing the positive impacts of climate change.

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