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Climate change, weather variability and associated impact on arecanut and cocoa in humid tropics of India

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ABSTRACT

This paper focuses on the weather variability and its influence on the yielding patterns of arecanut and cocoa over the past 43 years (1970-2012) at Vittal, Karnataka, which is located between 12° 15'N latitude and 75° 25'E longitude in humid tropics of India. After 2000, sudden changes in climate were noticed with increase in maximum and minimum temperatures, and $RH_{forenoon}$ and the decrease in total rainfall, sunshine hours and evaporation. The trends of temperature increase are +0.4°C for mean maximum ($P < 0.001$) and +0.4° C for mean minimum during the last decade. The observed difference between maximum and minimum is +0.8° C for the 43 year period. The on-station studies indicated that the yield variability in different years was 32% in arecanut and 38% in cocoa that explains the influence of climate on yield. The correlations and regressions between yield and weather parameters indicate differential response of arecanut and cocoa. The results indicate that the cocoa was more affected by climate variability than arecanut due to conspicuous changes in phenology and increased incidence of pests and diseases. The adaptation options available to farmers in changing climate scenario are also discussed.

Keywords: Arecanut, climate change, cocoa, humidity, rainfall, temperature, yield.

INTRODUCTION

Land productivity, represented by crop yield per hectare, depends on soil productivity, climate and management practices (FAO, 1985). Favourable climatic conditions are crucial in generating optimal crop yields. Agriculture is affected by climate change and variability (Salinger, 2005). The effect of climate change on crop yield has been dealt with lot of interest in recent literature. Increased variability in climate and weather is a part of climate change. Climate change, particularly inter-annual and intra-annual climatic fluctuations, has long term negative impact on agricultural productivity all over the world (Nellemann *et al*., 2009). Recent reviews have documented detectable effects of increasing temperatures and changing patterns of precipitation on crop species and entire ecosystem (Parmesan and Yohe, 2003; Root *et al*., 2003; Parmesan, 2007). Nelson *et al*. (2009) reported that an increase in temperature is mainly due to global warming, which reduces crop yields and encourages pest proliferation. Peltonen-Sainio *et al*. (2007) mentioned a worldwide decline in improvement rate of cereal yields. According to Berry and Spink (2006), oilseed rape yields have not increased in several countries. Relationships between weather and yield have been widely studied to identify critical climate factors for crops. Phenology is a good indicator of global warming (Chmielewski and Rötzer, 2000). Changes in temperature affect the crop yield mainly through phenological development process. McCarl *et al*. (2008) argue that while a temperature increase in the hotter areas could be principally detrimental for most of the crops, the temperature increase in the colder areas is mainly beneficial. One of the simplest ways to evaluate how climate change and variability affect crop yield is through historical records (Thompson, 1986; Changnon and Winstanley, 2000). Lobell *et al*. (2006) predicted downward pressure on yields of perennials due to climate change in USA. The uncertainty surrounding the resulting climate change poses challenges for implementation of strategies to manage the associated risks (Keller *et al*., 2008). Climate system can react abruptly and with only subtle warning signs before climate thresholds have been crossed (Stocker, 1999; Alley *et al*., 2003). Thus, researchers are also engaged in identifying suitable management options to sustain the crop productivity under the climate change scenarios. Poudel and Kotani (2013) opined that change in the temperature and rainfall levels induces heterogeneous impacts, which can be considered beneficial, harmful or negligible, depending on the altitudes and the kinds of crops and adaptation strategies must be tailor-made considering growing seasons, altitudes and the types of crops. Therefore, case studies are required to identify the relation between climate and agriculture focusing on a region.

Most research on the agricultural impact of climate change has focused on annual crops.

Perennial cropping systems are less adaptable and more susceptible to damage, thus improved assessments of yield responses to climate are needed to prioritize adaptation strategies. Arecanut (*Areca catechu* L.) and cocoa (*Theobroma cacao* L.) are the two major cash crops in humid tropics of India. These perennial plantations are sensitive to various biotic and abiotic stresses. Arecanut, which belongs to family *Arecaceae*, grows to height of 10-15 m with a crown of 8-9 leaves. In arecanut, flowering initiates in 4th year and yield stabilizes by 8th year. Cocoa belongs to family *Malvaceae* (formerly *Sterculiaceae*) and grows to a height of 2.0-2.5 m with 15-20 m^2 canopy area. In cocoa, flowering initiates in 3rd year and is segmental in repeated phases. The flowering to harvesting period is one year in arecanut and 150-180 days in cocoa. The average yield levels are 1.5-3.0 kg $palm^{-1}$ in arecanut and 1.0 - 2.0 kg $tree^{-1}$ in cocoa in West coast region of India. The arecanut-cocoa system is efficient and economically feasible. In the tropical belt where arecanut and cocoa are grown (28^o N and S of equator), precipitation is confined to six months from June to November with average rainfall of 3700 mm. Insufficient water has been a major limiting factor in post monsoon season (December-May) due to high evaporative demand of arecanut (Mahesha *et al*., 1990). In India, it is cultivated in 0.38 m hectares with a production of 0.47 m tonnes and productivity of 1202 kg ha^{-1} (GOI, 2011). Cocoa is cultivated as a component crop in arecanut, coconut and oil palm in 46,318 ha with a production of 12,954 tonnes and productivity of 380 kg ha^{-1} (GOI, 2011).

The low productivity of arecanut and cocoa is due to climatic, crop and soil constraints and strategies are developed to improve productivity (Bhat *et al*., 2007; Bhat and Sujatha, 2008; Bhat *et al*., 2012; Sujatha and Bhat, 2013b). Acidic laterite soils are known for cultivation of plantation crops in humid tropics of India. As perennial plantations remain productive for several decades, weather variability influences the yield. The cultivated area of arecanut increased by 63% during 1994-2007 but the productivity increase was only 19%. Not only climate change, but also technological and resource constraints are likely to limit productivity (Mendelsohn and Dinar, 2003). During the past decade, conspicuous and sudden changes like delayed flowering in cocoa and increased infestation of pests and diseases are noticed. With this background, an attempt was made in this study to assess overall changes in weather pattern in humid tropics and its impending influence on productivity of arecanut and cocoa.

MATERIALS AND METHODS

Description of study site

The study site is experimental farm of ICAR-Central Plantation Crops Research Institute, Regional Station, Vittal, Karnataka, India (12^o 15'N latitude and 75^o 25'E longitude, 91 m above MSL). The climate of the location is humid tropical with average annual rainfall of 3686 mm. Generally the year at the study site can be classified into four seasons, *viz*., cold weather (December–February), hot weather (March–May), Southwest monsoon (June–September) and Northeast monsoon (October–November). Mean temperature ranges from 18ºC (minimum) to 36ºC (maximum). The average relative humidity varies between 61 to 94%. The soil of the study site is sandy clay loam. The textural composition of the soil is 50% sand, 14% silt and 36% clay at 0 to 60 cm depth.

Weather data

The weather data was collected from records maintained at the Institute. The weather variables like rainfall (RF), maximum temperature (T_{max}), minimum temperature (T_{min}), sunshine hours (SS hrs), pan evaporation (PE) and relative humidity (RH) are being recorded from the existing meteorological observatory at the Institute, which was monitored regularly by Indian Meteorological Department. The meteorological data is recorded daily at 7.30 and 14.20 hrs. The study area covered about 68 hectares of the farm and all the experimental fields are located within 500 m vicinity from the observatory. The descriptive statistics of weather variables of the study site is given in Table 1. Weather data variations were computed to determine the anomalies (departures from normal) for each month and year for the period from 1970-2012. The normal weather variable was taken as the average of last 43 years.

General details about arecanut and cocoa

Arecanut was planted at a spacing of 2.7 m x 2.7 m and cocoa was planted as mixed crop at a spacing of 2.7 m x 5.4 m in arecanut plantation. General management aspects were kept constant in all experiments. Irrigation was given equivalent to open pan evaporation. Basin and sprinkler irrigations methods were followed up to 2000 and drip irrigation was adopted in all plots afterwards. Bordeaux mixture (1%) was sprayed on bunches twice at 45 days

Table 1. Descriptive statistics of weather variables and weather variability during 1970-2012

Variable	Mean	Minimum	Maximum	Std. deviation	Weather variability during 1970-2012		
					1970-99	2000-12	Change in 2000-12 over 1970-99
Max. temperature (æ%C)	32.4 ±0.06	31.2	33.2	0.42	22.2	21.8	+ 0.4
Min. temperature (æ%C)	22.0±0.06	21.2	22.8	0.37	32.3	32.7	+ 0.4
RH at 7.30 hrs	93.8 ±0.17	91.3	96.1	1.10	93.5	94.5	+ 1.0
RH at 14.20 hrs	60.8 ±0.28	57.1	64.7	1.87	60.8	60.8	-
Sunshine hours	6.6 ±0.10	5.1	7.6	0.67	6.9	6.1	- 0.8
Evaporation (mm)	4.0 ±0.08	3.1	5.0	0.54	4.3	3.7	- 0.6
Rainfall (mm)	3686± 95	2113	5610	624	3846	3315	- 531
Rainy days	139 ± 2.04	111	165	13.4	141	134	- 7

interval during monsoon season (June–September) to prevent fruit rot incidence caused by *Phytopthora* sp. The pest and disease incidence in arecanut and cocoa was monitored every month under surveillance programme in the farm.

Data acquisition

The palm/tree wise yield data of arecanut and cocoa were collected from records of different experiments in arecanut and cocoa at the Institute. Arecanut palms (n = 1000-3000) and cocoa trees (n = 200-500 trees) after stabilized yield stage with age variation of 1 or 2 years were considered for average yield and this nullifies the impact of alternate bearing habit if any and adjusts the variations in yield levels. The data set included on-station experiments on agronomic approaches conducted during 1970–2012. Data gaps were filled with experiments on crop improvement in case of cocoa. Other sources included published reports and publications from the Institute. Details of many experiments have been reported previously (CPCRI, 1996; Bhat and Mohapatra, 1989; Balasimha, 2007; Balasimha, 2009; Bhat *et al*., 1999; Sujatha *et al*., 1999; Bhat *et al*., 2007; Sujatha and Bhat, 2010; Sujatha *et al*., 2011; Sujatha and Bhat, 2013a, b). Management changes have occurred during 1995-2012 like changes in crop varieties, irrigation, pest control and planting material (seedlings to grafts) in cocoa. It was ensured that the yield potential of variety did not change substantially. In cocoa, grafts replaced seedlings in on-station experiments after 1995 due to similar yield levels in seedlings and grafts. It was assumed that slight variations in management practices were not correlated with the climatic variables for the given year. In arecanut, the flowering to harvesting period falls during December of previous year to February of the following year. In cocoa, pod growing period is 150-180 days with peak harvest in May but sparse flowering and pod development are noticed throughout the year. Hence, it was assumed that the weather parameters of that particular year influence the yield of same year in both crops.

The average yield for a particular year was computed from all the records to nullify treatment or technology effect. The national statistics mostly cover local cultivar of arecanut, cocoa seedlings, irrigation practices like basin and sprinkler and organic farming approaches. Major harvesting of arecanut was spread over November to March months. Ripe nuts were harvested as and when ready and dried to 8 per cent moisture after recording fresh weight. Dried nuts were de-husked and kernel weight was recorded for computing the yield. Dry kernel weight was reported as kg per hectare in this study. Cocoa yield was recorded as fresh pod yield, wet bean yield and dry bean yield (DBY), which was reported as kg per tree.

Statistical analysis

Linear correlations and regressions were worked out to establish the quantitative relationship between weather variables and yield in MSTATC, Microsoft excel and SPSS. A multiple regression analysis was done using weather variables for the period 1970–2012 and the yield levels obtained for that particular year at the Institute. Stepwise multiple regressions were done for weather variables month wise and the significant variables obtained from each weather variable were used for multivariate analysis.

RESULTS

Time trend of weather variables during 1970-2012

Time trend of weather variables for the period of 1970–2012 is shown in Fig. 1. The weather variability after 2000 in comparison to data of 1970-99 is presented in Table 1. Precipitation trends indicated very low variability for total rainfall and rainy days among different years. Inter-annual variability of rainfall is generally large in the tropics. For

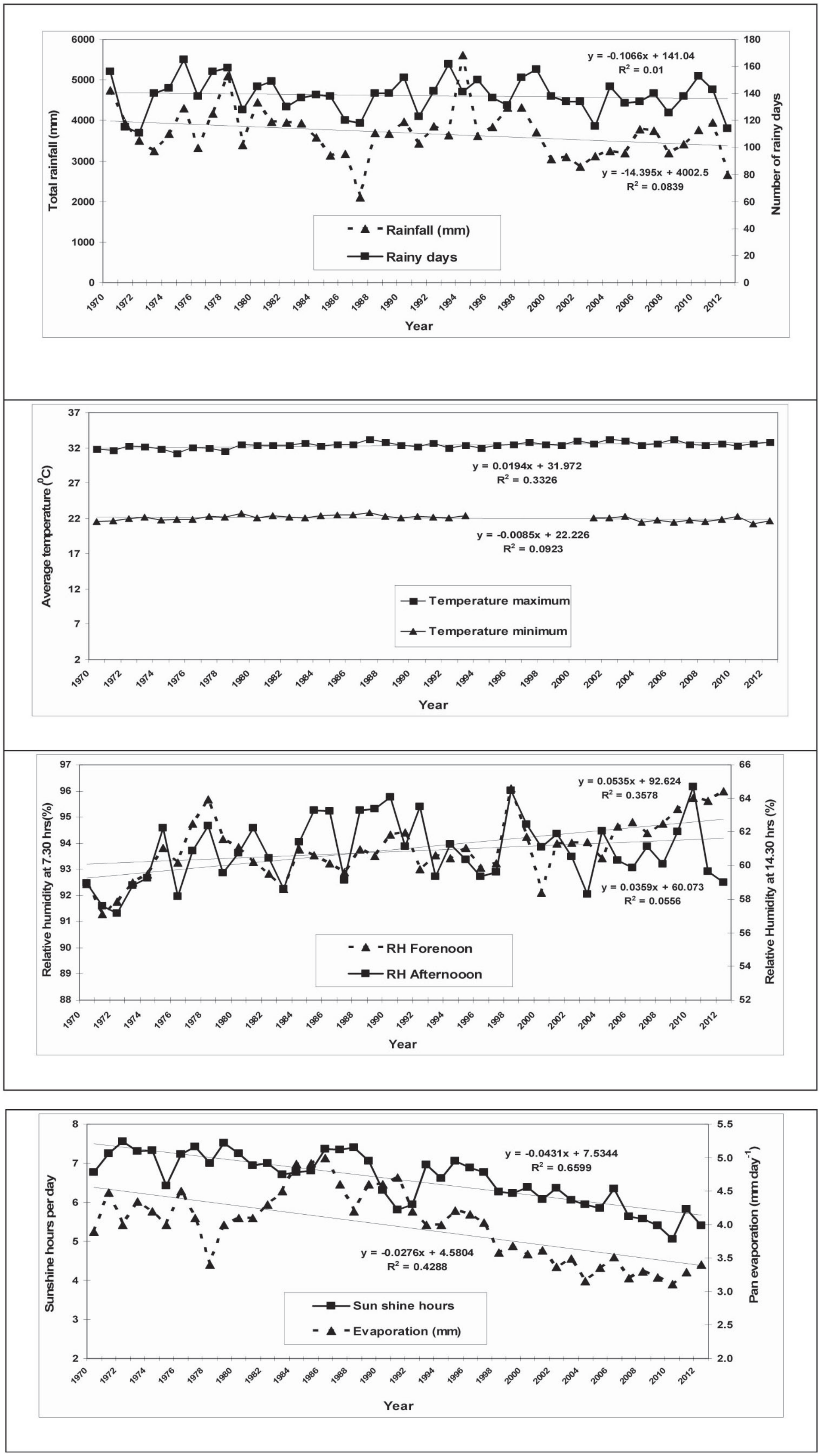


Fig. 1. Weather variable trends, anomalies, departures from the normal from 1970 to 2012

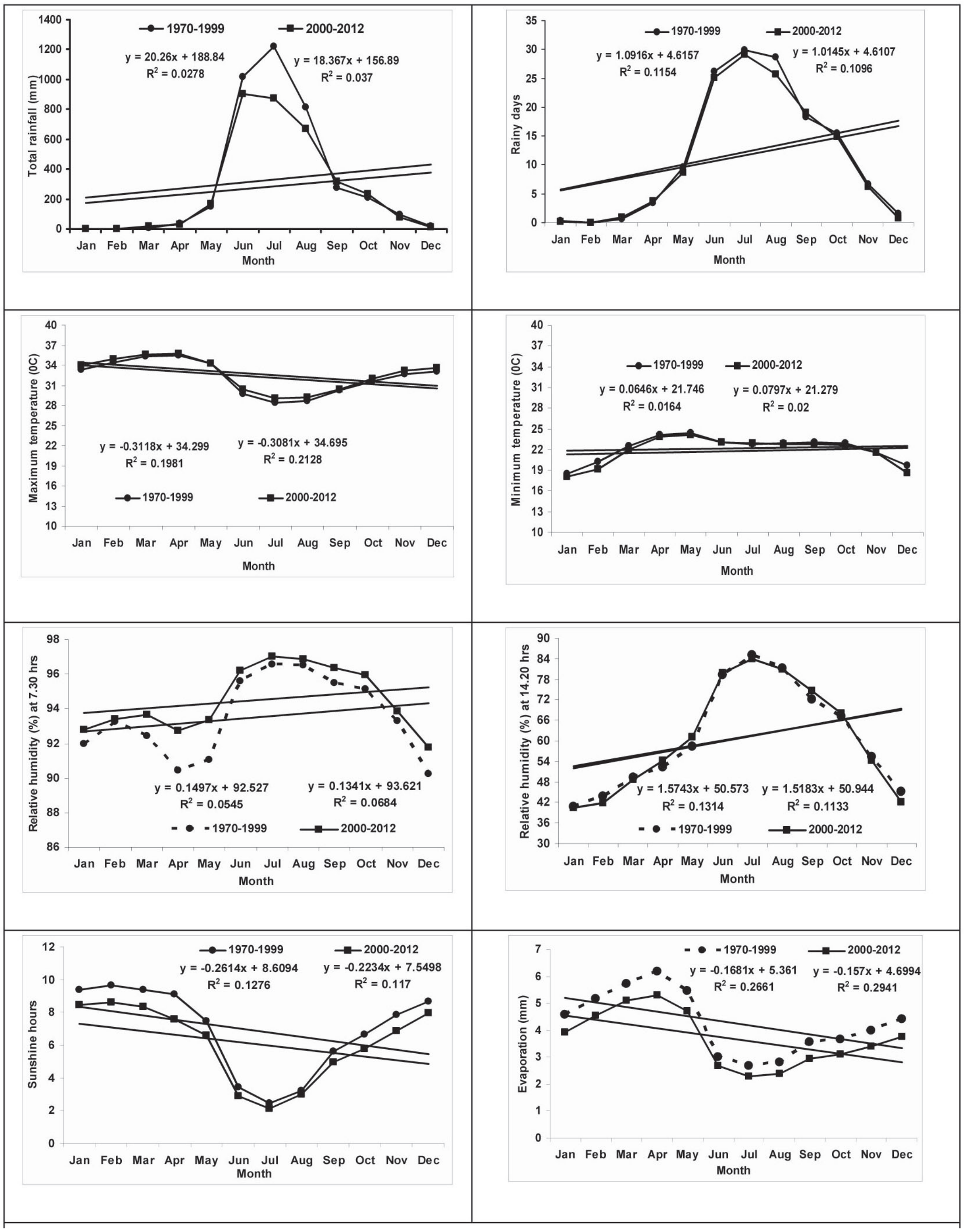


Fig. 2. Month wise variability in weather parameters for 1970-2012

the period 1970–2012, the mean annual precipitation is 3686 mm and ranges from 2114 mm in 1987 to 5610 mm in 1994. The total RF decreased by 531 mm i.e., 14% during 2000-2012 compared to 1970-1999. With respect to air temperature changes, years explained higher variability for T_{max} (33%) than T_{min} (9%). The trends of temperature increase are + 0.4°C for mean maximum (P <0.001) and + 0.4°C for mean minimum during the last decade (P < 0.002). Thus, for the 43 year period, the observed difference between maximum and minimum is +0.8°C. Years explained 36 and 6% variability in RH at 7.30 and 14.20 hrs, respectively. The RH at morning time increased, while RH at afternoon reduced during the observed period. Years showed maximum variability for number of sunshine hours per day (66%) and pan evaporation (43%) among all weather parameters. Both SS hrs and pan evaporation reduced during 2000-2012 compared to preceding years.

Changes in monthy weather variables

Month wise variability in weather parameters is depicted in Fig. 1. The degree of variability was high for variables like evaporation (29%), T_{max} (21%), SS hrs (12%) and RH at 14.20 hrs (11%). Overall trends showed decrease in pan evaporation (0.3 to 0.9 mm), SS hrs (0.2 to 1.1 hrs) and total rainfall in monsoon season (108 to 274 mm) during 2000-2012 over 1970-1999. During the same period, T_{max} increased by 0.1 to 0.7 ^oC except in May and T_{min} by 0.1 to 1.1^oC except in monsoon months of June to August. The rates of change of maximum and minimum temperatures are in the range -0.1 to +0.7 and -0.1 to +1.1^oC during 2000-2012 over preceding decades, respectively. Relative humidity at 7.30 hours increased by 0.1 to 2.4 % in all months and increase is higher in summer months and December. Relative humidity at 14.20 hrs increased during April –June and September-October by 0.6 to 2.8%, while it decreased during November to March and July-August by 0.3 to 2.9%.

Area, production and productivity trends of arecanut and cocoa

National statistics clearly indicated that area of arecanut exhibited an upward trend over time together with production explaining 92% variability during 1970-2010, but the productivity showed 41% variability with stagnant trend during last decade (Fig. 3). The productivity of arecanut (kg ha^{-1}) fluctuated from 857 in 1970 to 1379 in 2002 and 1195 in 2012. Years explained 71, 92 and 10% variability in area, production and productivity of cocoa in India. Though area and production of cocoa showed upward trend, productivity fluctuated registering decline in 2010. At the institute, years explained 32 and 38% yield variability in arecanut and cocoa (Fig. 3).

Relation between yield of arecanut and weather variables

Correlations between arecanut yield and year wise weather variables were positive and significant for T_{max} (r=0.48), T_{min} (r=0.16) and RH (r=0.32 to 0.49) (Table 2). Correlations were negative between arecanut yield and rainfall/sunshine hours (r = -0.20 to -0.21), while no relation was observed for evaporation and rainy days. Simple correlations showed that kernel yield was more closely related to RH and T_{max} than T_{min}, SS hrs and RF (Table 2). Table 3 summarizes regression equations showing relationship between yield of arecanut and weather parameters. Monthly variation in weather variables like RH and evaporation explained higher yield variability (41-47%) than rainfall, temperature and SS hrs (22-37%). Positive yield influence was visible for monthly variables like $RH_{forenoon}$ in Dec and May, $RH_{afternoon}$ in Jan, Oct and Apr, RF in Dec, T_{max} in Dec, Mar and Aug, T_{min} in May, SS hrs in July and Oct and evaporation in July. Monthly variables like July RF, Oct $RH_{forenoon}$, Oct T_{min}, SS hrs in Jan and evaporation in Feb negatively influenced the kernel yield. A single linear regression of yield against total annual rainfall explained only 32% of the variation. For arecanut, over 64% of yield variability could be explained by three climatic variables like $RH_{afternoon}$, T_{max} and RF (Eqn. 9 in Table 3). Among monthly weather parameters, $RH_{afternoon}$ and SS hrs in October and $RH_{forenoon}$ and T_{max} in December positively influenced the KY of arecanut with 81% variability.

Table 2. Correlation between yield and weather variables

Variable	Arecanut	Cocoa
Min. temperature	0.16*	0.30*
Max. temperature	0.48**	-0.14*
RH at 7.30 hrs	0.32**	-0.30*
RH at 14.20 hrs	0.49**	-0.02
Sun shine hours	-0.21*	0.42**
Evaporation	-0.05	0.37**
Total Rainfall	-0.20*	0.13*
Total rainy days	0.00	0.08

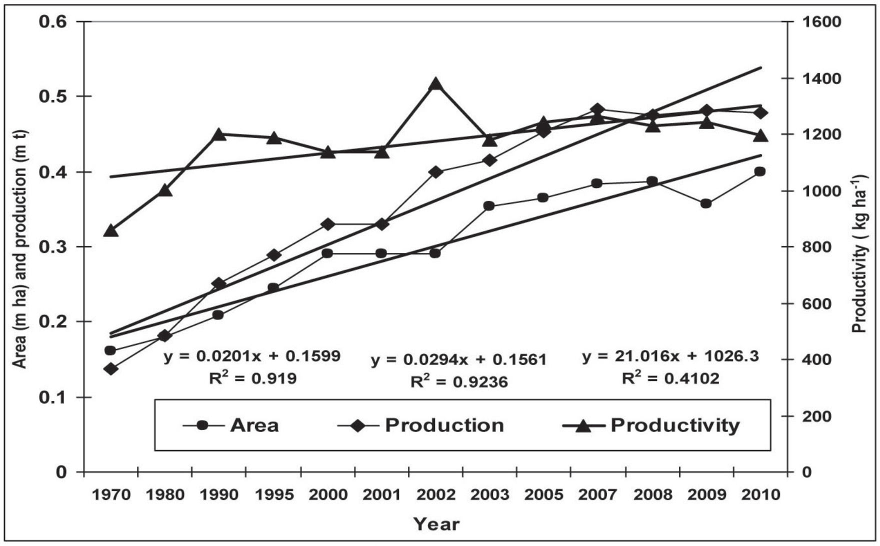
Relation between yield of cocoa and weather variables

Correlations between dry bean yield and weather parameters indicated significant positive impact of SS hrs, PE, T_{min} and RF (Table 2), while correlations were negative for T_{max} and $RH_{forenoon}$ with DBY. Regression analysis of month wise weather parameters showed that variables like $RH_{forenoon}$, T_{max}, SS hrs and RF explained higher yield variability of cocoa than T_{min}, $RH_{afternoon}$ and evaporation (Table 4). Positive yield influencing monthly weather variables were T_{max} in May and Sept, T_{min} in Feb and Oct, RF in Nov, $RH_{forenoon}$ in November and July, $RH_{afternoon}$ in Feb, SS hrs in Mar, PE in Apr and Jan in cocoa (Table 4). Precipitation (Sept, Dec and Jan), T_{max} (Aug), forenoon RH (Sept), afternoon RH (Apr), SS hrs (June and Feb) and PE in Feb negatively affected the cocoa yield. Regression model with annual averages explained only 28% of the variation in DBY due to positive influence of SS hrs and RF. But cumulative effect of negative influence of Apr $RH_{afternoon}$, T_{max} in Aug and May, RF and $RH_{forenoon}$ in Sept, Oct T_{min}, Apr Ep and June SS hrs, and positive influence of May SS hrs, Nov $RH_{forenoon}$ and Feb $RH_{afternoon}$ resulted in 70% variability of DBY of cocoa.

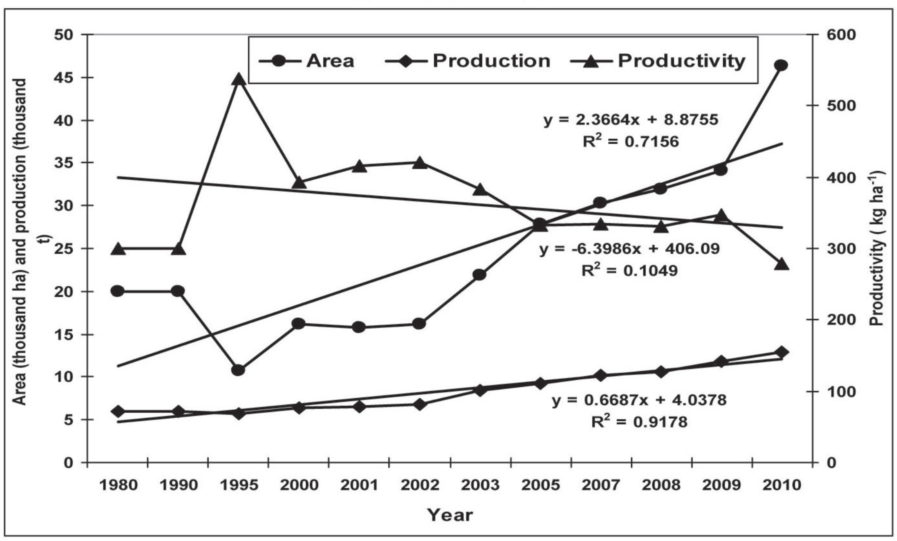
DISCUSSION

Weather variability and impact on arecanut and cocoa

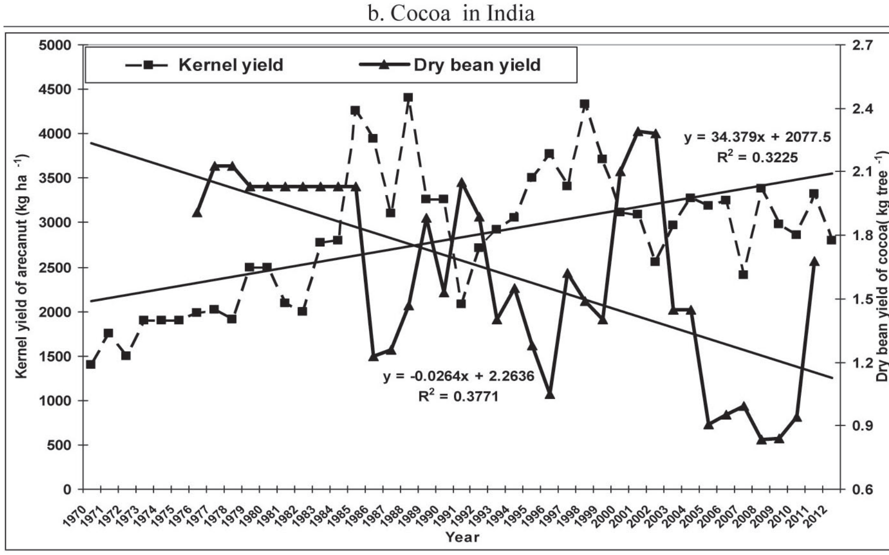
Arecanut sustains millions of small and marginal farmers in humid tropics of India and cocoa is slowly fitting in to plantation based cropping system from 1995 onwards. Plantation crops mainly arecanut and cocoa are grown in



a. Arecanut in India



b. Cocoa in India



c. Average productivity of arecanut and cocoa in different years at the institute

Fig. 3. Area, production and productivity trends in different years

Table 3. Relation between kernel yield of arecanut (KY) and weather variables (1970-2012)

Variable	Regression equation	R^2	Equation No.
RH at 7.30 hrs	KY = -1937.4 + 143.2 Dec + 116.2 May -244.7 Oct	0.410 (=0.012)	1
RH at 14.20 hrs	KY = -5606.2 + 48.1 Jan + 44.6 Oct + 77.52 April	0.471(P=0.011)	2
Rainfall	KY = 3568 – 0.889 Jul + 10.74 Dec	0.323 (P=0.041)	3
Rainy days	KY = no influence	0.133 (P=0.129)	4
Max. temperature	KY = -27357 + 454.7 Dec + 351.0Mar + 303.7 Aug	0.371 (P=0.029)	5
Min. temperature	KY = -3589.7 + 605.8 May - 649.1 Oct	0.218 (P=0.05)	6
Sunshine hours	KY = 6682.5 - 661 Jan + 186.5 July + 244 Oct	0.298 (P=0.018)	7
Evaporation	KY = 4617.1 - 718 Feb + 380 July	0.471 (P=0.001)	8
All variables (Year means)	KY = -33403 + 266 $RH_{afternoon}$ + 748 T_{max} - 0.47 RF	0.646 (P=0.00001)	9
All variables (Monthly means)	KY = -20018 + 69 Oct $RH_{afternoon}$ + 326 Oct SS hrs + 79 Dec $RH_{forenoon}$ + 326 Dec T_{max}	0.814 (P=0.0005)	

Table 4. Relation between dry bean yield of cocoa (DBY) and weather variables (1976-2011)

Variable	Regression equation	R^2	Equation No.
Max. temperature	DBY = -2.35 - 0.287Aug + 0.119 May + 0.218 Sept	0.526 (P=0.009)	1
Min. temperature	DBY = -7.03 + 0.169 Feb + 0.591Oct	0.282 (P = 0.037)	2
Rainfall	DBY = 0.87 - 0.001 Sept - 0.03 Jan - 0.006 Dec + 0.002 Nov	0.513 (P=0.023)	3
Rainy days	DBY = -1.53 + 0.07 June + 0.07 July - 0.12 Mar- 0.032 Oct	0.437 (P=0.029)	4
RH at 7.30 hrs	DBY = 16.18 - 0.498 Sept + 0.076 Nov + 0.18 July	0.616 (P =0.001)	5
RH at 14.20 hrs	DBY = 3.29 + 0.03 Feb - 0.054 Apr - 0.034 Oct	0.476 (P =0.013)	6
Sunshine hours	DBY = -0.043 + 0.37 Mar - 0.12 June - 0.225 Feb	0.519 (P =0.001)	7
Evaporation	DBY = 1.143 - 0.66 Feb + 0.326 Apr + 0.505 Jan	0.397 (P =0.016)	8
All variables (year wise)	DBY = -1.088 + 0.315 SS hrs + 0.0002 RF	0.283 (P = 0.013)	9
All variables (Month wise)	DBY = 38.1 - 0.139 Apr $RH_{afternoon}$ - 0.356 Aug T_{max} - 0.0011 Sept RF + 0.214 May SS hrs - 0.20 May T_{max} + 0.077 Nov $RH_{forenoon}$ - 0.403 Oct T_{min} + 0.0257 Feb $RH_{afternoon}$ - 0.211 Apr Ep -0.122 June SS hrs - 0.11 Sept $RH_{forenoon}$	0.701 (P=0.009)	

ecologically sensitive areas such as coastal belts, hilly areas and areas with high rainfall and humidity. These plantations experience recurrent biotic and abiotic stresses due to weather variability, nutrient losses, water shortage, water stagnation, diseases and pests. Weather changes control the profitability of these two crops by influencing the yield and quality. Perennial systems are slow to adapt and more vulnerable to climate change (Rosenzweig and Hillel, 1998; Burton and Lim, 2005). Both arecanut and cocoa are perennial in nature with high commercial value. Thus, climate change will have agronomic impacts on yields and also generate economic effects on prices, demand and trade. At national level, conventional practices and low soil fertility status might be partly responsible for lower yields in arecanut during 1970's and 80's (Fig. 3). Despite development of efficient technologies, the productivity levels remained more or less stagnant during 1990-2010. The productivity of cocoa declined during the last decade. Despite adoption of recommended package at the Institute, yield variability in different years was 32% in arecanut and 38% in cocoa (Fig. 3). The yield levels were reduced by 9% and 20% in arecanut and cocoa, respectively during 2000-2001 over 1981-1999 at the Institute (Fig. 3). This explains the influence of climate on yield. The significant relation of weather parameters with yield further substantiates the impact of weather (Table 2, 3 and 4). The yield reduction might be due to reduced recovery and changes in phenology.

Generally the climate is equable in humid tropics of India. The weather data of 43 year period (1970-2012) at the study site indicates sudden changes in climate after 2000 (Fig. 2 and 3). The increase in weather variables like T_{max}, T_{min} and $RH_{forenoon}$ and the decrease in parameters like RF, SS hrs and evaporation during the last decade (Fig. 2) might influence net photosynthesis, evapo-transpiration, flowering, pollination and yield. Several reports indicated similar impact of weather changes on several crops (White *et al*., 1999; Kramer *et al*., 2000) and in cocoa (Joly and Hahn, 1989; Balasimha *et al*., 1991). This study indicates that the yield of arecanut and cocoa show sign of stagnation or decrease following weather variability. Reduced rainfall particularly in monsoon season (June to August) during 2000-2012 showed positive impact on yield as the distribution of rainfall was fairly good (Fig. 2 and 3). Similar results are noticed at study site with better yields (2555-3107 kg ha^{-1}) in low rainfall years such as 1987 (2114 mm) and 2002 (2869 mm). In many cases, high precipitation was associated with a reduction in yields due to reduced pollination and increased diseases in wetter years. High rainfall (5610 mm in 1994) with high intensity rains results in spread of fruit rot (*Phytophthora sp.*) and water stagnation in root zone leading to yield reduction in arecanut (CPCRI, 1996; Sujatha *et al*., 1999). In 2007, fruit rot caused 40% yield loss in arecanut due to continuous rainfall (>2500 mm in July-September) associated with high RH and less SS hrs (Jose *et al*., 2009). December RF positively influenced the yield as it might have helped the palm to overcome low temperature stress (Table 4). The results give indication that continuous and heavy rainfall as in July (1116 mm) is not ideal for arecanut as it creates water logging, higher incidence of *Phytophthora* diseases and hampers pollination/ nut development. But similar impact was not visible in cocoa as pod development stage escapes high seasonal rainfall.

Differential response of arecanut and cocoa

Attainable yield is mainly limited by water or nutrient supply (van Ittersum and Rabbinge, 1997; Stewart *et al*., 2005). Yield stagnation in arecanut or yield decline in cocoa at national level might be due to influence of weather as farmers adopt management practices like organic nutrition, irrigation and disease control in these crops. The yield trend, which showed linearity, was negative in cocoa and positive in arecanut both at national level and at Institute (Fig. 3). The results indicate that the cocoa was more affected by climate variability during the last decade than arecanut. This might be due to conspicuous changes in phenology and increased incidence of pests and diseases like tea mosquito bug, mealy bug and black pod (Personal communication). Phenology is a good indicator of global warming (Chmielewski and Rötzer, 2000) and an increase in air temperature is associated with an extension of growing season (White *et al*., 1999). Phenological response to increased temperature depends on the plant species (Kramer *et al*., 2000). Both arecanut and cocoa are highly cross pollinated and thus weather variability might influence phenology. It is difficult to notice phenological changes in arecanut as inflorescence emerges every 45 days. But, peak flowering time in cocoa has changed during the last few years (Personal communication). The sudden changes in weather are noticed after 2000 and sudden phenological changes are noticed after 2002. Till 2000, peak flowering time was spread during October-December with maximum being in October-November. After 2008, peak but sparse flowering was noticed during December-January, which results in harvesting time coinciding with heavy rains and higher incidence of black pod disease. The cumulative effect of increase in T_{max} during June-December (0.4 - 0.7), T_{min} (0.3-0.4) in Sept and Oct, RH and RF in Sept and Oct and decrease in SS hrs and evaporation might have caused delay in flowering of cocoa.

On an average, 25% infestation of tea mosquito bug was noticed in cocoa after 2007. The incidence of black pod disease ranged between 6 to 51% during monsoon season. Zuidema *et al*. (2005) stated that over 70% of the variation in simulated bean yield in cocoa could be explained by a combination of annual radiation and rainfall during the two driest months. Similar relations are observed in this study between cocoa DBY and weather (Table 4). The cumulative effect of changes in temperature, rainfall, humidity, evaporation, and sunshine hours has impact on the yield of cocoa. The slight yield increase in arecanut might be due to technical improvements such as better agronomic and crop protection measures. There are short comings like lack of detailed studies on phenology and single location in this paper, but it is a general trend applicable to humid tropics.

The correlations and regressions between yield and weather parameters clearly indicate differential response of arecanut and cocoa (Table 2, 3 and 4). The impact of rainfall was negative on arecanut and positive on cocoa, which might be due to differences in yielding pattern. The nut development stage in arecanut invariably faces heavy rains resulting in yield loss due to water stagnation, pests and diseases, but cocoa escapes heavy monsoon rains during pod development stage. Another significant aspect of variability was sunshine hours showing negative impact on arecanut and positive impact on cocoa (Table 2). As cocoa is a shade crop in arecanut plantations with only 40% of the incident radiation reaching the ground (Muralidharan, 1990), the positive relation between yield and sunshine hours indicates the need for higher sunlight availability to cocoa. Cocoa exhibits increased production under lowered light levels with optimal growth at 20 to 30% of full sunlight (Galyuon *et al*., 1996). Similarly, positive response of arecanut and negative response of cocoa to $RH_{forenoon}$ can be attributed to increased microclimatic humidity in arecanut plantation over atmospheric humidity.

Both arecanut and cocoa have similar evaporative demand in humid tropics (Abdul Haris *et al*., 1999; Bhat *et al*., 2007), but the response of cocoa to pan evaporation was positive and significant. Reduced evaporation in recent years might impact the transpiration losses through metabolic activities of these crops and in turn the productivity. Model simulations of the potential yield of tea in North East India predicted slight reduction in yield for each mm reduction in evapotranspiration (Panda *et al*., 2003). The sensitivity of cocoa to T_{max} and positive response of arecanut clearly explains the shade requirement of cocoa ruling out the possibility of sole cropping of cocoa in humid tropics. Minimum temperature clearly showed positive impact on both crops suggesting clear adaptability of these crops. Number of rainy days had no influence on both crops clearly indicating that the intensity and distribution of rainfall are important. Thus sudden change in weather variables might one of the reasons for stagnant productivity despite above optimum soil fertility status in farmer's fields (CPCRI, 2011 and 2012). Reduction in sunshine hours might have reduced the solar radiation and PAR and net photosynthesis. The impact of weather variability on growth and yield would be different for dicot and monocot perennials. Climate change impact assessment in plantation crops is big challenge as simulation models for many plantation crops are not available. Even though simulation model in perennial crop like cocoa (Zuidema *et al*., 2003) has been reported, the model is not yet validated for Indian conditions.

Adaptation strategies

Weather aberrations influence resource use efficiency, and incidence of pests and diseases. Management needs to fine tuned to weather changes with precision application of inputs. Identification of genotypes tolerant to various biotic and abiotic stresses is need of the hour. Suitable adaptation strategies can be selected from the already developed technologies. Successful technologies like nutrient and irrigation management, drip fertigation and cropping system approach in arecanut reduced the impact of weather changes during the last decade. This is obvious from high and uniform yield levels at Institute compared to stagnant yields at national level (Fig. 3). Drip fertigation is a better adaptation strategy under changing climate scenario in humid tropics as it resulted in higher yields during 2002-2006 (Bhat *et al*., 2007). Drip irrigation also sustained yield levels of arecanut in 2002 despite low rainfall. In the same year, yield loss of 13 -14.5% is reported in farmer's plantations (Jose *et al*., 2004). In case of cocoa, delayed flowering is a concern as it might result in yield reduction. But, drip fertigation at 75% NPK to cocoa improved the yield levels in initial stages (Sujatha and Bhat, 2013a). Developing strategies to counteract climate change might be difficult for cocoa compared to arecanut as weather variations result in delayed flowering and outbreak of certain pests and diseases. Hence, it can be inferred that climate is also playing an important role for stagnant trend of productivity in arecanut and declining trend in cocoa growing areas.

CONCLUSIONS

A comprehensive analysis of 43-yr weather data from 1970-2012 revealed that humidity and temperature increased, while other variables like total rainfall, sunshine hours and evaporation decreased in humid tropics in India. The results imply that weather has a definite role in influencing the yield of arecanut and cocoa. The correlations between weather variables and yield was either positive or negative or without any relation. There was differential response of arecanut and cocoa to weather variability. The results give scope for developing suitable strategies in tune with negative or positive responses of these two crops. The results reveal that the crop productivity remains highly dependent on weather, which can affect both the quantity and quality, despite advances in technology and the widespread prevalence of irrigation facilities in arecanut belt.

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