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Impact of extreme weather events on coconut productivity in three climatic zones of Sri Lanka

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ABSTRACT

Coconut is a major plantation crop in Sri Lanka, a tropical island in the Indian Ocean. The highest coconut production is found in Gampaha, Kurunegala and Puttalam districts which belong to the wet, intermediate and dry zones respectively. An increase in the frequency of extreme weather events has been observed during the recent past. This study, the first of its kind, was undertaken to assess the impact of extreme events on coconut productivity. Meteorological and coconut productivity data were obtained for the period 1995–2015 from six estates, two estates representing each of the above-mentioned districts. Extreme events were defined using maximum daily temperature (T_{max}) and daily rainfall. The 90th percentiles of the daily distribution of rainfall and T_{max} in the reference period were used to define high rainfall and high temperature days respectively. The days with their rainfall below the 10th percentile were defined as low rainfall days. Regression analyses between coconut productivity and the number of extreme events during the first four months after flowering were performed. In the dry zone the number of high rainfall and high T_{max} days during the said period had a negative influence on productivity and the mean rainfall had a positive influence on productivity. In the intermediate zone the number of high rainfall events and the mean T_{max} of the same period had a negative impact on coconut productivity. In the wet zone, while the number of extreme weather events had no influence on the coconut productivity, the mean T_{max} during the first four months since flowering had a negative impact on coconut productivity.

1. Introduction

Changes in extreme weather events related to temperature and rainfall have been observed since about 1950 (IPCC, 2014). There has been a growing concern on the impact of extreme weather events on crop production, with the impending global issue of climate change.

Coconut (*Cocos nucifera*) is a tropical tree species and is dubbed as ‘the tree of life’ as it has a great variety of uses (Gomes and Prado, 2007). The livelihood of most people living in humid tropics depend on the coconut palm (Peiris et al., 1995). Indonesia, Philippines, India, Brazil, Sri Lanka and Thailand are the largest producers of coconut in decreasing order of importance (FAOSTAT, 2014).

1.1. Coconut in Sri Lanka

Coconut is one of the major plantation crops in Sri Lanka and is second only to rice in providing nutrition (Samita and Lanka, 2000). Coconut cultivation represents 21% of the agricultural land of the country and significantly contributes to Sri Lanka’s Gross Domestic Product (GDP), export earnings and employment (Fernando et al., 2007).

The highest coconut production of Sri Lanka, which is above 70% of the national production, comes from the Coconut Triangle (Fernando et al., 2007). The Coconut Triangle is formed by Gampaha, Kurunegala and Puttalam districts which belong to three climatic zones, Wet, Intermediate and Dry respectively. Given the change in weather patterns associated with climate change, it is anticipated that the coconut palms in different climatic zones might respond differently.

1.2. Coconut growth cycle

Growth cycle of a coconut bunch lasts for 38 months, from the initiation of the sinflorescence primordium to full maturity of the nuts (Peiris et al., 2008). Of the total period, pre-fertilization phase lasts for 27 months in which the inflorescence is covered by a spathe (Fig. 1). Fertilization and post-fertilization phases start with the spathe opening

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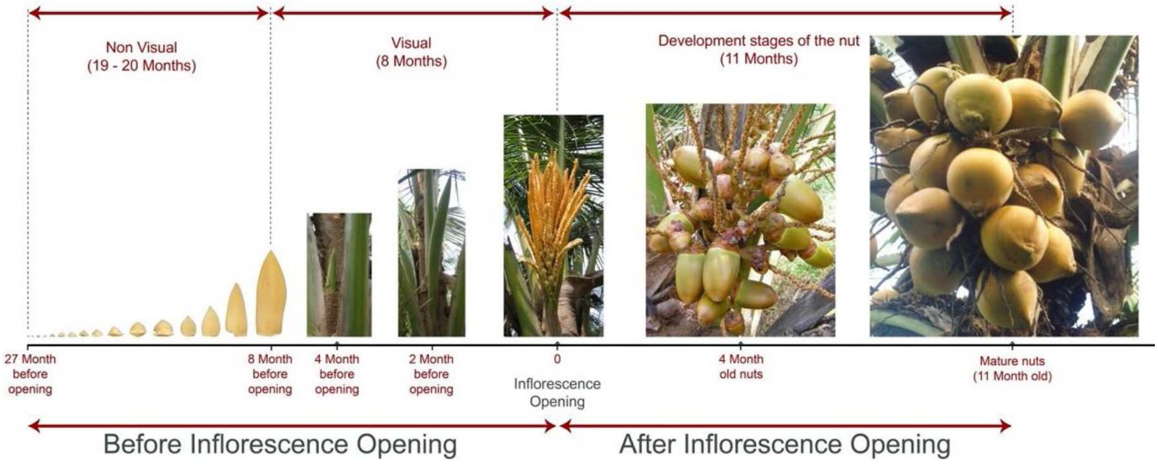


Fig. 1. Development stages of a coconut bunch (Source: Coconut Research Institute, Lunuwila, Sri Lanka).

and last for 11 months resulting in a mature bunch of coconuts (Fig. 1); (Ranasinghe et al., 2015). Of this, the first three months subsequent to inflorescence opening is said to be the period most vulnerable to climatic variation (Ranasinghe et al., 2015).

On average, one inflorescence opens every month of a year producing mature nuts ready to be harvested after 10–11 months. Harvesting coconuts in bimonthly intervals has become the most common harvesting practice in Sri Lanka amounting to 6 picks in a given year (Peiris and Peries, 1993).

Coconut yield depends on climatic variables such as rainfall, temperature and relative humidity in addition to other external factors such as pest attacks, diseases, crop management, land suitability and nutrient availability (Peiris et al., 2008). Optimum weather conditions for the growth of coconut include a well distributed annual rainfall of about 1500 mm, a mean air temperature of 27 °C and relative humidity of about 80–90% (Peiris et al., 1995).

1.3. *Climate/weather influence on coconuts' harvest*

Several studies in the past have analysed the impact of climatic or weather variation on coconuts. Peiris (1993) found a low correlation between yield and annual rainfall, either during the harvesting year or the preceding year, and he concluded that annual rainfall alone was not a good predictor of the yield. According to Peiris and Peries (1993) the effect of climatic variations such as temperature, rainfall and relative humidity in a given year is reflected in the coconut yield of the following year.

A study carried out by Peiris et al. (2008) shows how seasonal climate information is used to predict coconut production in Sri Lanka. Rainfall is identified as the principal element that influences the yield variability across different agro-ecological regions. Their study showed the relevance of comparing production data with rainfall data of the preceding year. The influence of climatic variables on nut production is more significant after opening of the inflorescence.

Although the impact of climate and weather on crop yields has been analysed in previous studies in Sri Lanka (Chithranayana and Punyawardena, 2014; Wijeratne and Anandacumaraswamy, 2007; Peiris and Peries, 1993; Peiris et al., 2008), India (Duncan et al., 2016) and China (Boehm et al., 2016) almost no research has been done on the impact of extreme weather events on crop yields.

1.4. *Extreme weather events and their impact*

Global climate is projected to change continuously due to various natural and anthropogenic reasons. This in turn would cause changes in the frequency and intensity of extreme weather events on a global scale (Trenberth et al., 2007). IPCC (2012) defines extreme weather events as "the occurrence of a value of a weather or climate variable above (or below) a threshold value near the upper (or lower) ends of the range of observed values of the variable". These values are generally defined with respect to a given reference period.

2. Methodology

2.1. *Sampling sites and data used*

Two sites belonging to each of the three climatic zones of Sri Lanka (dry, intermediate, wet) encompassing the coconut triangle (Figs. 2 and 3 and Table 1) were considered in this study. These six sites were selected based on the availability of long-term crop production data and meteorological data. Each estate has an average tree density of 64 palms per acre. The coconut plantations consisted of the same variety, *Sri Lanka Tall*, and were of the same age and had adopted similar management practices including the application of nitrogen (N), phosphorus (P), potassium (K), dolomite and poultry manure as fertilizer once a year, using coconut leaves and husks to retain moisture and chemicals to control Coconut Black Beetle and Coconut Red Weevil. All coconut palms are primarily rain-fed.

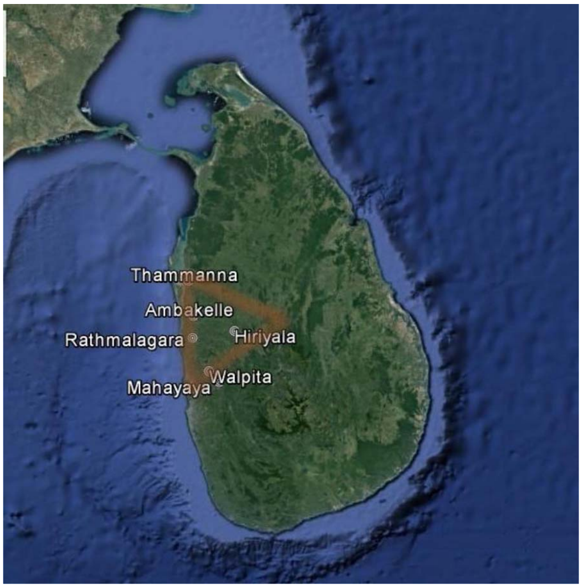


Fig. 2. Map of the sampling sites encompassing the coconut triangle.
Source: https://earth.google.com

Fig. 3. Sampling locations representing the three climatic zones of Sri Lanka: Ambakelle and Thammanna (Dry zone); Rathmalagara and Hiriyala (Intermediate zone); Walpita and Mahayaya (Wet zone).

Table 1
Predictors and their descriptions.

Predictor	Description
the	Number of high T_{max} events during the first four months after flowering
lre	Number of low rainfall events during the first four months after flowering
hre	Number of high rainfall events during the first four months after flowering
mr	Mean rainfall during the first four months after flowering
mt	Mean T_{max} during the first four months after flowering
p_{t-1}	Previous pick's productivity (one-month lag of productivity)

2.2. Production and meteorological data

Bimonthly harvest data of coconut were collected from the respective estates and Coconut Research Institute, Lunuwila. Daily rainfall and maximum daily temperature (T_{max}) data were obtained from the respective estates and the Department of Meteorology of Sri Lanka. A period of twenty-one years ranging from 1995 to 2015 was covered by this study.

2.3. Extreme weather events

High temperature days were defined as the days with their maximum temperature (T_{max}) exceeding the 90th percentile of the daily distribution in the reference period (1995–2015). *Heavy precipitation events* were the days with their rainfall exceeding the 90th percentile of the daily distribution in the reference period (Trenberth et al., 2007). Similarly a *low rainfall event* was defined as the days with their rainfall below the 10th percentile of the daily distribution in the reference period. These indicators were based on the definitions introduced in the IPCC's Fourth Assessment Report (Trenberth et al., 2007).

2.4. Statistical analyses

The bimonthly production (i.e. number of nuts) obtained from each estate was divided by the number of bearing palms of the respective estate to obtain values for productivity (nuts per bearing palm).

In evaluating the impact of extreme weather events, the coconut productivity of each bimonthly pick was analysed against the number of extreme weather events during the first four months after inflorescence opening.

In addition to the number of high T_{max}, low rainfall and high rainfall days, mean rainfall and mean T_{max} during the first four months after flowering were also calculated.

Step wise regression analyses were performed in Minitab (version 17) software for each zone to determine the best fitted model for the given predictor variables. The predictor variables and their definitions are indicated in Table 1.

The models obtained through the stepwise regression analyses were then refined considering the Variance Inflation Factor (VIF) of each predictor variable and correlation matrix to find out any multicollinearity among predictor variables. To find out any autocorrelation, the autocorrelation (ACF) and partial autocorrelation (PACF) functions of the residuals of the regression models were also studied. A time-lagged productivity (i.e. $\text{productivity}_{t\text{-}1}$ or the productivity of the previous year) was included as a predictor variable to account for the autocorrelation. The overall model performance was assessed using adjusted R-sq values.

2.5. Cross validation of models

Even though in time series forecasting most practitioners use out-of-sample (OOS) evaluation, regular cross-validation (CV) methods are possible when the models considered have uncorrelated errors (Bergmeir et al., 2018). Since the original models derived in this study showed uncorrelated error terms CV was used in the model validation. In the CV approach, the data set was divided into 2 parts: 80% of the data was randomly selected for fitting a regression model. The regression model thus derived was then used to predict coconut productivity values for the remaining 20% of the data. The predicted productivity values were plotted against the observed productivity values and an X = Y trend line was constructed to determine the acceptability and spread of values. The predicted residual error sum of squares (PRESS) and Relative Error (RE) were calculated to evaluate the strength of the model in predicting coconut productivity for the three climatic zones.

3. Results

3.1. Time series plots of extreme weather events

The time series plots of extreme weather events across all six estates (Fig. 4) revealed that the most frequent type of extreme events during the 21-year period was low rainfall days. Between the number of high T_{max} and high rainfall events, the former showed greater fluctuations as illustrated in Fig. 4.

3.2. Deriving model relationships

3.2.1. Dry zone

The initial regression model (R-sq adj = 24.95%) for the relationship between coconut productivity and predictor variables (Table 1) considering extreme weather events was as follows:

$$p = -7.00 - 0.04\ \text{hte} + 0.09\ \text{lre} - 0.31\ \text{hre} + 0.82\ \text{mr} \tag{1}$$

The model o–utput revealed that hre was highly correlated with at least one of the other predictors in the model (VIF > 5.00) as shown in Table 2.

The correlation matrix revealed highly significant correlation between hre and mr ($r = 0.858$, $p < 0.05$), lre and hre ($r = -0.832$, $p < 0.05$) and mr and lre ($r = -0.679$, $p < 0.05$).

The above multicollinearity issue was resolved when the variable lre was excluded in model fitting; the final regression model (R-sq adj = 22.58%) obtained is given in Eq. (2):

$$p = 7.50 - 0.03\ \text{hte} - 0.48\ \text{hre} + 0.87\ \text{mr} \tag{2}$$

The low VIF values obtained under the new model indicated that there is no further correlation among the predictor variables as shown in Table 2.

The ACF and PACF plots of the residuals of the regression model derived after the inclusion of the previous pick's productivity as a new predictor variable revealed that there is no more autocorrelation. This was further confirmed using the Durbin-Watson Statistic (d) which was found to be 1.89. It was found that there is no statistical evidence that the error terms are positively autocorrelated ($d > dU$, where $dU = 1.83$).

The new regression model after eliminating autocorrelation (R-sq adj = 65.65%) is given in Eq. (3):

$$p = 1.80 + 0.72\ p_{t\text{-}1} - 0.02\ \text{hte} - 0.15\ \text{hre} + 0.30\ \text{mr} \tag{3}$$

The low VIF values obtained under the new model indicated that there is no further correlation among the predictor variables as shown in Table 2.

The above model (Eq. (3)) shows that in the dry zone the number of high T_{max} and high rainfall extreme events during the first four months after flowering have a negative impact on the coconut productivity and the mean rainfall during the same period has a positive influence on the coconut productivity.

3.2.2. Intermediate zone

The final regression model (R-sq adj = 58.81%) obtained for the intermediate zone after removing any multicollinearity, autocorrelation and partial autocorrelation following the same steps as for the dry zone, is given in Eq. (4):

$$p = 35.00 + 0.69\ p_{t\text{-}1} - 0.04\ \text{hre} - 0.34\ \text{mt} \tag{4}$$

The above model (Eq. (4)) shows that in the intermediate zone the number of high rainfall extreme events and the mean rainfall during the first four months after flowering have a negative impact on the coconut productivity.

3.2.3. Wet zone

The regression model (R-sq adj = 47.92%) obtained for the wet zone after removing multicollinearity, autocorrelation and partial autocorrelation, as performed in the dry zone, is given in Eq. (5):

$$p = 110.00 + 0.55\ p_{t\text{-}1} - 1.20\ \text{mt} \tag{5}$$

The above model (Eq. (5)) shows that in the wet zone the mean T_{max} during the first four months after flowering has a negative impact on the coconut productivity. A statistically significant relationship between extreme weather events and productivity could not be found in the wet zone.

The model relationships derived for the three climatic zones reveal that the impact of extreme weather events on coconut productivity varied with each zone as indicated in Table 3.

3.3. Cross validation of models

The model relationships derived between coconut productivity and the number of extreme weather events for each of the three climatic zones was cross validated to evaluate the performance of the models. The mean relative error of the regression model developed for the dry, intermediate and wet zones were 27.4%, 29.6% and 24.5%,

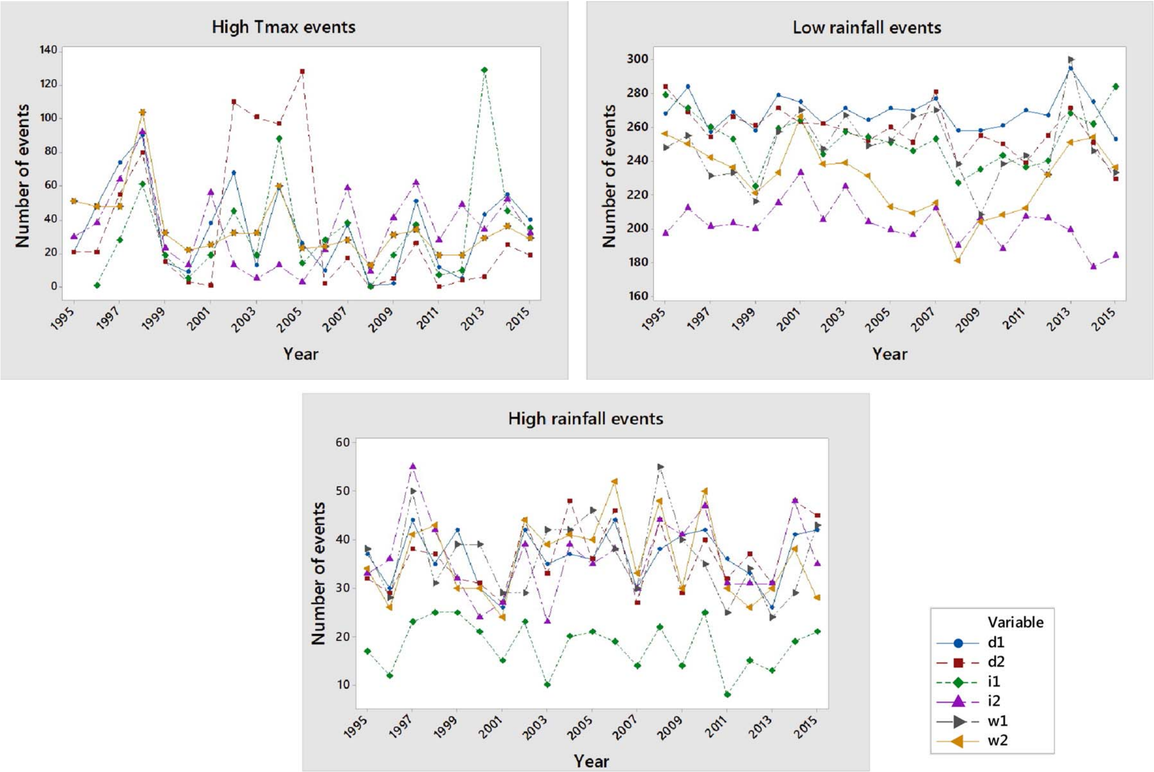


Fig. 4. Time Series plots of extreme weather events across the six sites (d1, d2 – dry; i1, i2–intermediate; w1, w2–wet).

Table 2
Coefficients of the predictor variables of the regression model of Eqs. (1), (2) and (3) of the dry zone.

Equation	Predictor variable	Coef	SE Coef	T-Value	P-Value	VIF
1	hte	−0.0376	0.0110	−3.41	0.001	1.13
	lre	0.0908	0.0311	2.92	0.004	3.54
	hre	−0.3070	0.0886	−3.47	0.001	6.88[a]
	mr	0.819	0.1100	7.45	0.000	3.90
2	hte	−0.0291	0.0108	−2.70	0.008	1.05
	hre	−0.4803	0.0668	−7.20	0.000	3.79
	mr	0.866	0.1100	7.85	0.000	3.81
3	Constant	1.8160	0.5980	3.04	0.003	
	p_{t-1}	0.7196	0.0416	17.31	0.000	1.22
	hte	−0.0154	0.0072	−2.13	0.034	1.06
	hre	−0.1501	0.0484	−3.10	0.002	4.48
	mr	0.3032	0.0804	3.77	0.000	4.56

[a] VIF > 5.00; Coef = Coefficient.

Table 3
Summary of impact of extreme weather events on coconut productivity in the three climatic zones.

Climatic Zone	Variables and their influence on productivity (positive/negative)	R-sq adjusted value (%)
Dry	High rainfall (negative) High Tmax (negative) Mean rainfall (positive)	65.65
Intermediate	High rainfall (negative) Mean T_{max} (negative)	58.81
Wet	Mean T_{max} (negative)	47.92

respectively. The scatter plots of observed productivity versus predicted productivity values for each climatic zone illustrate the performance of the respective models as indicated in Fig. 5.

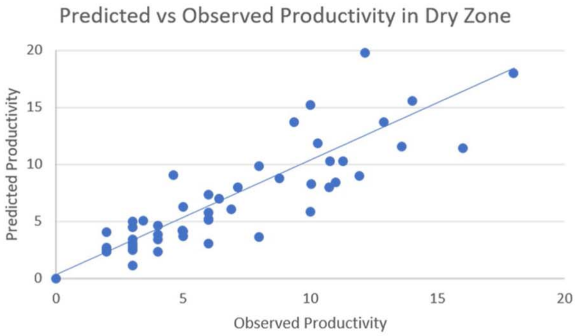
4. Discussion

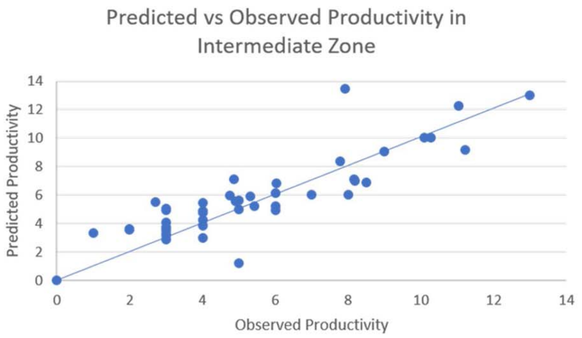
This is the first study, to our knowledge, to assess the impact of extreme weather events on coconut productivity. Previously studies have been conducted to investigate any possible link between weather parameters and coconut productivity, but none have been done specifically on extreme weather events.

Extremely high rainfall is found to cause button shedding in coconut plantations in India as revealed in a study carried out by Petch and Gadd (1923). Therefore, this may have been the cause for reduction in coconut productivity in the dry zone. Additionally it is possible that exposure of male flowers to high temperature could have a negative influence on pollen production as shown by Burke et al. (2004) with their analysis on cotton pollen germination. In a similar study carried out in India, Prasada Rao, (2016) showed that extremely dry conditions cause a decline in coconut productivity, which has implications on the country's economy.

A study carried out by Abeywardena and Mathes (1971) showed that two-thirds of the button nuts fell during the first four months subsequent to inflorescence opening. Extreme weather events such as high rainfall and high temperature are possible causes of this. In the current study, we found a statistically significant impact of the extreme weather events on coconut productivity in the dry and intermediate zones. In a study carried out by Nainanayake et al. (2008) it was revealed that a majority of flower and fruit abortions were observed in coconut plantations in the dry and intermediate zones of Sri Lanka. Possible reasons for this include decreased quality of pollen and female flowers due to exposure of flowers to extremely dry weather.

The time series plots of number of low rainfall, high rainfall and high T_{max} days reveal that the most frequent type of extreme weather event are low rainfall days. The increased number of low rainfall days in the years 1997, 2002, 2006, 2009, 2014 and 2015 could be linked with the prevalence of an El Nino Southern Oscillation (ENSO) phenomenon in the respective years (Legler, 1998). This fact was reiterated by a study carried out by Zubair et al. (2008) which reveals that there is





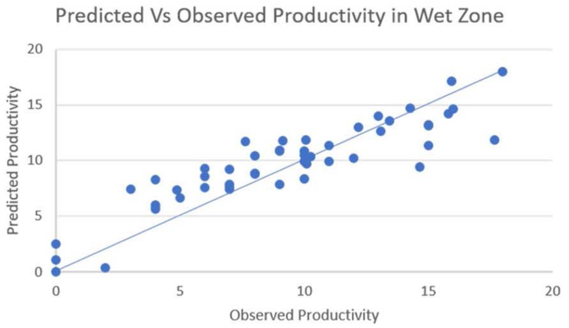


Fig. 5. Predicted vs Observed productivity (number of coconuts per bearing palm) plots in the Dry, Intermediate and Wet zones.

decreased rainfall during El Nino events.

We selected the maximum temperature (T_{max}), instead of mean temperature, as the parameter to determine high temperature events, as the pollen viability is said to depend on T_{max}. Most laboratory experiments and studies in the past eg: Peiris and Thattil, (1997) have also considered T_{max} values instead of mean temperature.

One of the biggest challenges in carrying out this study was the difficulty in obtaining productivity data and meteorological data for a twenty-year period due to lack of well documented, digitized data. This limited the possibility of selecting more than two sites per climatic zone.

This study reinforces the importance of being aware of the implications of climate change on crop productivity. The findings of this study can contribute to the coconut plantation sector in Sri Lanka. Those involved in this sector including the superintendents of the estates as well as the labourers appear to be aware of the changing climate, who already have adopted soil moisture conservation methods such as mulching, burying coconut husks and growing cover crops.

5. Conclusion

The impact of extreme weather events on coconut productivity varied with each climatic zone. A statistically significant relationship between extreme weather events and coconut productivity was seen in the dry and intermediate zones. It was revealed that high rainfall extreme events during the first four months after inflorescence opening had a negative influence on productivity in the dry and intermediate zones. High temperature extreme events during the first four months after inflorescence opening had a negative impact on coconut productivity in the dry zone. A statistically significant relationship between extreme weather events and coconut productivity was not found in the wet zone.

These findings further confirm the fact that climatic variability impacts coconut productivity to varying degrees depending on the climatic zone. This study is the first of its kind to investigate the impact of extreme weather events on coconut productivity across the three climatic zones of Sri Lanka and contributes to the existing literature on climate change. It also sets the precedence for the importance of expanding current research on extreme weather events and their impact on the agricultural and plantation sectors.

The model relationships derived for each zone can be used to make predictions on coconut productivity. This would in turn benefit those involved in the coconut plantation sector by enabling them to take necessary measures to adapt to the changing climate. We hope that the findings of this study will help policy- and market decision making in relation to export agriculture in Sri Lanka.

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