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Climate Change Impacts and Forecasts of Oil Palm Leaf Miner Populations

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Abstract

Agricultural production is very sensitive to climate change, and it suffers from periodic outbreaks of insect pests which cause considerable losses especially in the humid and sub-humid tropics which severely constrain the productivity potential of global agriculture under changing climate conditions. The oil palm leaf miner is a major pest of the oil palm. Mathematical relationships between the leaf miner insect stages and weather factors were developed for pest predictions and forecasting. Decadal variation in air temperature was characterized by wide differences between 1961 – 1970 and 2001 – 2010. The assessment of the sensitivity of leaf miner to variability in weather and climate conditions is important in view of evidence that show expansion of pest ranges as a result of climate variability impacts. The study has established an upward increase in temperature, attributed to climate change, with a concomitant increase in leaf miner abundance between 1980 and 2010. Larvae showed an increasing trend for the observed period. When this observation was correlated with the weather (temperature, rainfall, and relative humidity) during these periods, it could be inferred that there was proliferation as a result of weather changes. This was different from the decreasing trend observed during the 1976 – 1980 period. Pupae showed a decreasing trend for the observed period. Adults showed an increasing trend for the observed period. It could be inferred that adults were proliferating due to temperature increases and rainfall decreases. An incremental increase in temperature could help explain fluctuations in insect pest populations within and between years. Thus climatic conditions greatly influenced seasonal leaf miner populations. The climate forecast up to 2050 indicates an upward trend in temperature and a downward trend in rainfall and relative humidity. This followed the climate trend between 1961 and 2010. This study contributes to the understanding of the insect pest-weather relationship in broad agricultural and food security terms. A major advantage is the potential for limiting the spread of outbreaks through timely control of early pest infestations.

Keywords: Leaf miner; Climate change; Oil palm; Pest predictions; Forecasts.

1. Introduction

The oil palm (*Elaeis guineensis* Jacq.) is an important food and cash crop in Nigeria. Hartley [1], have reported the destructive insects of the oil palm and aspects of their control. The leaf miner, *Coelaenomenodera elaeidis* Mlk (Coleoptera: chrysomelidae) is a major pest of the oil palm and endemic through out the West African region [2]. The larvae are the main cause of damage, especially during swarming when several individuals can be found mining into the epidermis of the leaflets, leading to direct destruction or desiccation of the leaf or reduced photosynthetic surfaces [3]. C. *elaeidis* Mlk (Coleoptera: Chrysomelidae) feeds on the chlorophyll, water and nutrients from the leaf cells and the occurring foliar damage result in loss of oil palm yield. Palm oil has been a safe and nutritious source of edible oil for healthy humans for thousands of years [4]. The adult beetle feeds on the lower surface of the leaflets leading to the partial drying up of the fronds [5]. In severely affected plantations, the lower canopies of most palms appear scorched, grey-brown with desiccated rolled – in leaflets. Later, the withered laminae shatter, leaving the leaflets midribs only. Both the adult and larval forms of the leaf miner cause damage to the palm [6]. Morin and Mariau [7] and Hartley [1] gave accounts of the incidence, life cycle and damage of this pest. The developmental periods are: eggs, 20; larvae, 44; pupae, 12; adult to egg laying 18; total 94 days (about 3 months). The adult lives on the under-surface of the leaf for 3-4 months after egg laying. There are thus 3 to 4 generations of this pest in a year.

Weather refers, generally, to day-to-day temperature and precipitation activity, whereas climate is the term for the average atmospheric conditions over longer periods of time [8]. The mean temperature for Nigeria is 27^{o}C, in the absence of altitudinal modifications. Over the last few decades, there has been a general increase in temperature throughout Nigeria [9]. In Nigeria, climate change causes higher temperatures and relative humidity, which increases the likelihood of such stressors as pest infestations and diseases.

Seasonality is a common phenomenon among insects [10]. Insect abundance can change over time for a variety of reasons, including macroclimatic and microclimatic changes, and variation in the availability of food resources [11]. There is a clear need to advance knowledge on pest response to weather and climate variability.

Scientific evidence gathered over the last couple of decades suggests that climate conditions are changing rapidly and that this trend is likely to continue and even accelerate [12, 13]. These anticipated changes in climate baseline, variability, and extremes will have far-reaching consequences on agricultural production, posing additional challenges to meeting food security for a growing world population [14, 15].

Agricultural production is very sensitive to climate change and it suffers from periodic outbreak of insect pests which cause considerable losses especially in the humid and sub-humid tropics. Nigeria is particularly sensitive to climate change and variability largely due to our dependence on rain fed agriculture, widespread poverty, poor infrastructure, over exploitation of natural resources, limited institutional and technological capacity.

In many parts of Africa, climate is already a key driver of food security [16, 17]. Climate change and variability has been recognized as a major burden that restrains national development in the West African region from achieving desired economic and development goals. Vulnerability can be viewed as a function of the sensitivity of agriculture to changes in climate, the adaptive capacity of the system, and the degree of exposure to climate hazards [18]. Climate change is expected to impact both crops and livestock systems [19]. The rate of insect growth is greatly influenced by the physical environment, particularly temperature [20].

This study has assessed impacts of weather and climate variability factors on seasonal leaf miner abundance in Nigerian Institute for Oil Palm Research (NIFOR), Edo State, Nigeria. This paper contributes to the understanding of the insect pest-weather relationship in broad agricultural and food security terms.

2. Materials and Methods

2.1. Study Area

NIFOR: The site lies on the coordinates of latitude 6^0 33’ N and longitude 5^0 37’ E. The size is 2.95Ha consisting of 443 mature palms at 9m triangular spacing located at the main station of the Nigerian Institute for Oil Palm Research (NIFOR) near Benin, Edo State, Nigeria. The palms whose crown canopy had not formed a continuous layer and sunlight could still penetrate to the ground, were planted in the year 2000.

2.1.1. Climate

The site experiences two seasons; wet and dry seasons. Average mean temperature is 26.6 ^{0}C; average mean rainfall is 162mm; while average mean relative humidity is 77%. The station lies in the rainforest belt of Nigeria. The rainy season is from the month of April – October, while the dry season occurs between the months of November and March.

2.2. Sampling Technique

The study in NIFOR involved random sampling surveys for leaf miner on a plot planted in 2000 and comprised of 443 palms (2.95 hectares).

2.2.1. Arrangement on Palm Field

No pesticides were applied during the study period, purposely to simulate a natural ambience in the sample plot. A sampling intensity of 21 palms was used, selecting 1 palm per line. In shorter palms, fronds were pulled down by a stick, but in taller ones a ladder was used. A different palm was used at successive counts. Leaf miner counts were on the palm leaflets within the field plot. NIFOR palms are planted in a triangular pattern, so census lines ran in three directions. Access points were marked with reference to field boundaries and harvesting paths. Sampling was conducted monthly between 7 - 11am.

2.2.2. Insect Counts and Damage

Data was collected monthly from January 2009 – December 2010. It involved observing and counting of leaf miner and its natural enemies. The larval, pupal and adult stages of the *C. elaeidis* were counted. The independent variables were temperature, rainfall and relative humidity. The dependent variable was *Coelaenomenodera elaeidis* counts and its natural enemies. At each point, *C. elaeidis* were counted on fronds inclining at 45º (number 17 and 25 on the phyllotactic spiral) [21]. Leaf miner past population estimates were obtained from NIFOR entomology division from 1976 – 1980.

2.2.3. Climate Data

Climatological data (temperature, rainfall and relative humidity) were obtained from NIFOR meteorological station. The weather station is within 1km radius of the field. The data were monthly averaged records. Field microhabitat temperatures were recorded (15:00 hrs) using the maximum and minimum thermometer at the centre of the experimental plot.

2.2.4. Statistical Analysis

Means, standard deviation, variances, covariances, seasonal and climatic patterns for temperature, rainfall and relative humidity were computed. Time series analysis was conducted using Minitab 14.0. Least square method was used to estimate the trend in the series and the trend equation. Correlations were drawn between temperature data with the insect pest data collected so as to establish links between temperature changes and the formation of microhabitats in the oil palm plantation.

Multiple linear regressions were used to analyze the relationship between abundance of leaf miner and the following climatic variables: maximum and minimum temperature (°C), rainfall (mm) and relative humidity (%). For the analyses, climate variables from the month of collection (control variable) or from the month before the collection (delayed variable) were used.

3. Results

3.1. Leaf Miner - Weather Relationship: 1976 – 1980

Leaf miner – weather relationship for 1976-1980 is presented in table 1. Table 1 shows relationship ($P \leq 0.05$) between mean weather factors (temperature, rainfall and relative humidity) and leaf miner stages (larvae, pupae and adult) for 1976 - 1980. There was no recorded dominant variable during this period, and there was no detectable impact on leaf miner development.

Table-1. Relationship between mean Weather factors and Leaf miner stages (larvae, pupae, adult), for 1976 – 1980

Insect Stage	R^2	R	P-value	Climatic variable
Grouped leaf mine				
1976	0.419 0.045	0.647 0.212	0.204 0.943	Control Lagged
1977	0.384 0.298	0.620 0.546	0.251 0.393	Control Lagged
1978	0.063 0.086	0.251 0.293	0.908 0.859	Control Lagged
1979	0.176 0.216	0.419 0.465	0.651 0.560	Control Lagged
1980	0.025 0.168	0.158 0.410	0.975 0.669	Control Lagged

****Significance $P \leq 0.05$**
Control – Climatic variable from month of collection
Lagged – Climatic variable with a delayed month in relation to collection
R^2 – Coefficient of determination
R – Correlation coefficient

Table 2 shows relationship between mean weather factors (temperature, humidity and rainfall) and grouped leaf miner insect stages (larvae, pupae and adult) between 2009 and 2010. There was significant relationship ($P \leq 0.05$) in both the control (0.039) and lagged (0.029) in 2009.

Table-2. Relationship between mean Weather factors and Leaf miner stages (Larvae, pupae, adult) for 2009 – 2010

Insect Stage	R^2	R	P-value	Climatic variable
Grouped leaf Miner				
2009	0.714 0.715	0.845 0.846	0.014** 0.014**	Control Lagged
2010	0.193 0.301	0.439 0.549	0.612 0.387	Control Lagged

****Significance $P \leq 0.05$**

Summary statistics for temperature, relative humidity and rainfall between 1961 and 2010 is presented in table 3. The warmest period was D5 (2001-2010) with mean temperature of 32.16^{0}C. Variations in observed decadal temperature was highest in D5 (CV=7.11%) and lowest in D2 (CV=6.14%). Temperature increased by 1.56^{o}C between D1 (1961-1970) and D5 2001-2010). The period recording highest rainfall was D1 with mean rainfall of 164.9mm. Variations in observed rainfall across the years in each period was highest in D4 (CV=88.74%) and lowest in D2 (CV=80.0). Rainfall also decreased by 8.2mm between D1 and D5.

The most humid period was D4 (1991-2000) with mean relative humidity of 72.29%. Variations in observed humidity across the years in each period was highest in D5 (CV=17.75%) and lowest in D2 (CV=14.95%). Relative humidity decreased by 3.39% between D1 and D5.

Table-3. Summary Statistics for Average temperature, Relative humidity and Rainfall from 1961 - 2010

	Temperature (C)				Relative Humidity (%)				Rainfall (mm)			
	Mean	SD	Variance	CV (%)	Mean	Std	Variance	CV(%)	Mean	Std	Variance	CV(%)
D1:1961-1970	30.603	2.167	4.69	7.08	68.91	12.13	147.03	17.6	164.9	145.9	21290.62	88.48
D2:1971-1980	31.380	1.928	3.72	6.14	68.37	10.22	104.37	14.95	164.5	131.6	17320.28	80.0
D2:1981-1990	31.776	2.084	4.34	6.56	65.65	10.75	115.53	16.38	154.5	133.0	17683.84	86.08
D2:1991-2000	31.645	2.221	4.93	7.02	72.29	11.07	122.64	15.31	164.2	137.5	18900.20	88.74
D2:2001-2010	32.161	2.288	5.24	7.11	65.52	11.63	135.25	17.75	156.7	124.2	15418.62	79.26

Key:
D - Decade
Std. – Standard deviation
CV – Covariance

3.2. Climate Trends: 1961 - 2010

Trends of temperature, rainfall and relative humidity from 1961-2010 (50 years) are presented in figures 1 2 3. Generally, for all the plots, the time trends were varying and the series showed an increasing or decreasing trend.

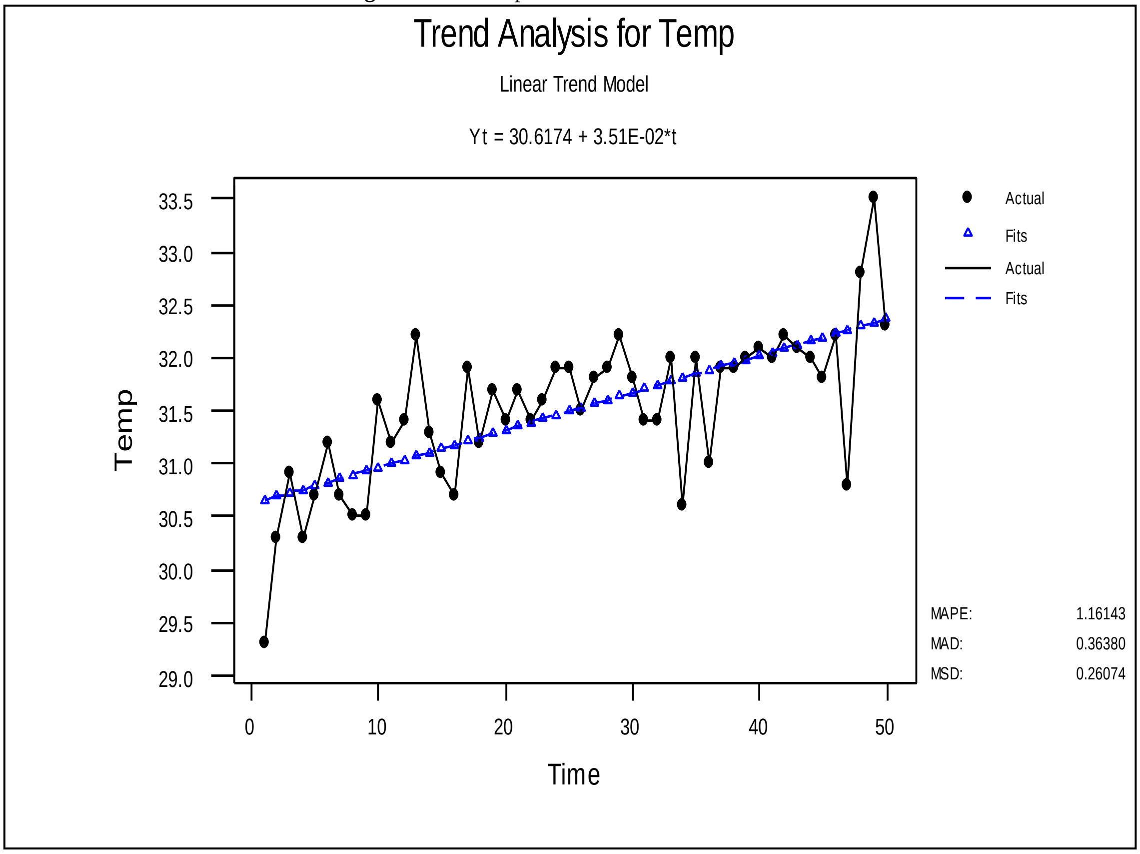
An increase in temperature can be observed (Fig. 1). Time series analysis on average monthly temperature is represented by the model:

Yt = 30.6174 + 3.51E -02*t

Where t = time

Yt = Temperature at any time forecast is needed

Fig-1. Trend of temperature between 1961 and 2010



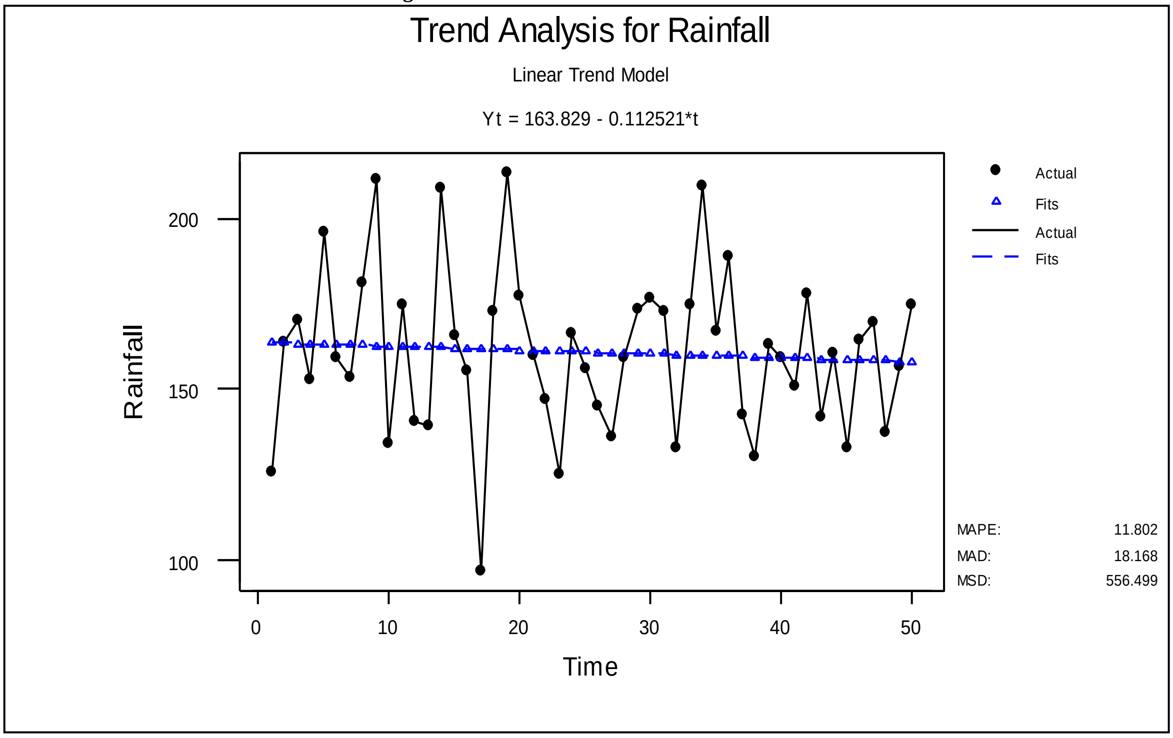
A gradual decrease in rainfall can be deduced (Fig. 2). Average amount of rainfall recorded decreased by 8.2mm between D1 (1961-1970) and D5 (2001-2010) using D1 as a baseline for comparison. The time series analysis represents average monthly rainfall volume. The trend model is represented by:

Yt = 163.829 - 0.112521*t

Where t = time

Yt = Rainfall at any time forecast is needed

Fig-2. Trend of rainfall between 1961 and 2010



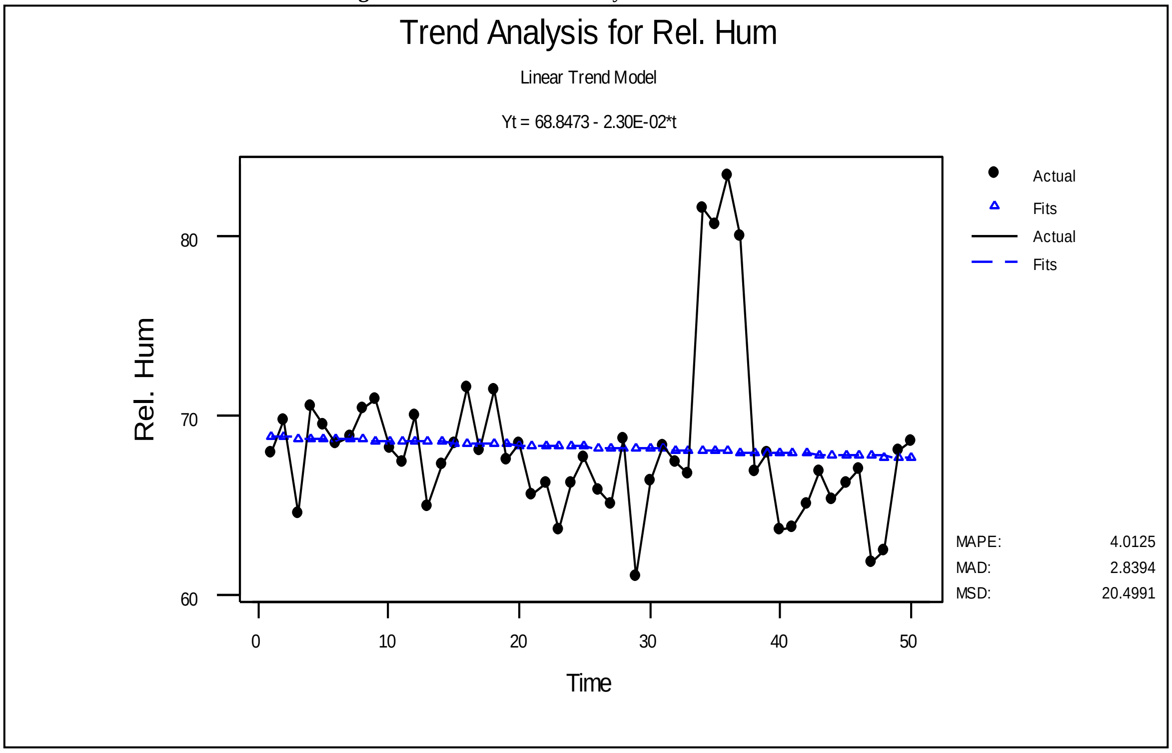
A gradual decrease in relative humidity can be deduced (Fig. 3). Average humidity decreased by 3.39% between D1 and D5. Time series analysis on average monthly relative humidity is represented by the model:

Yt = 68.8473 – 230E -02*t

Where t = time

Yt = Relative humidity at any time forecast is needed

Fig-3. Trend of relative humidity between 1961 and 2010



3.2.1. Leaf Miner Trends: 1976 -1980

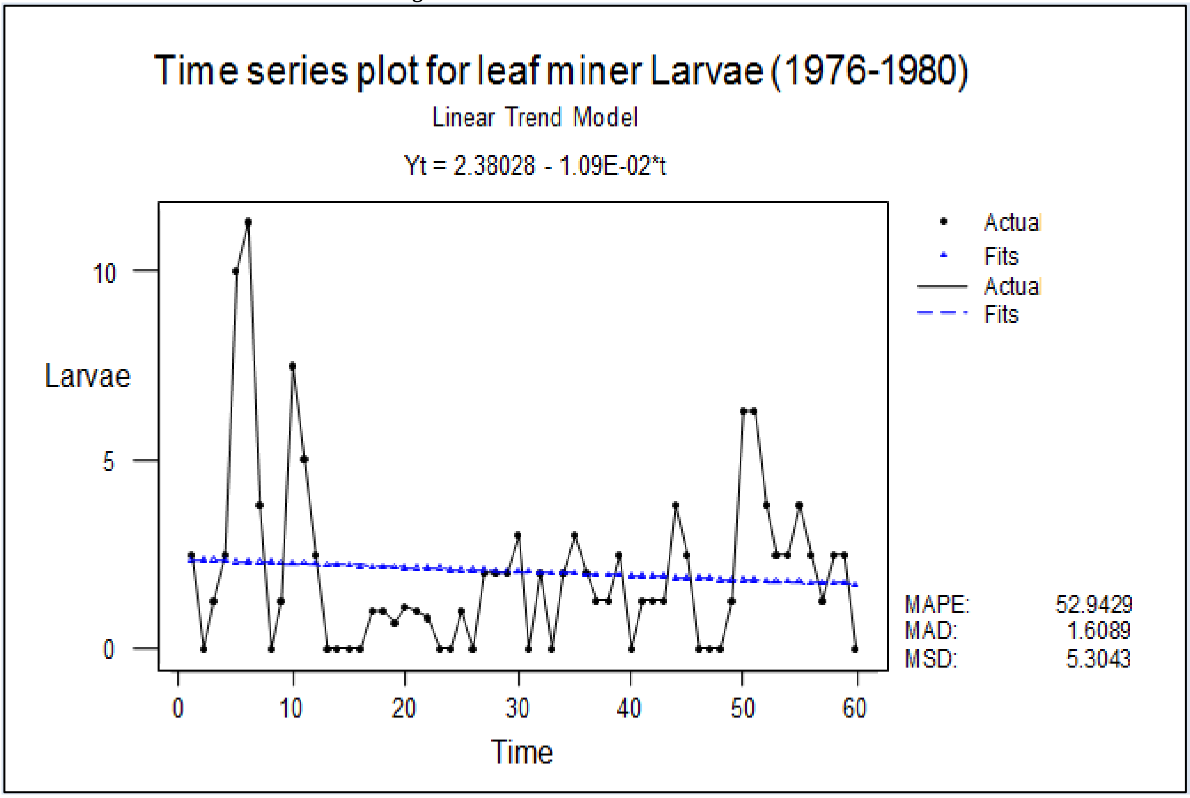
Trends of leaf miner (larvae, pupae, adult) from 1976 – 1980 are presented in figures 4 5 6. Generally, the time trends were varying showing increasing or decreasing trends. The trend line in larvae abundance shows an observed decrease (Fig. 4). The trend model is represented by the model:

Yt = 2.38028 – 1.09E – 02*t

Where t = time

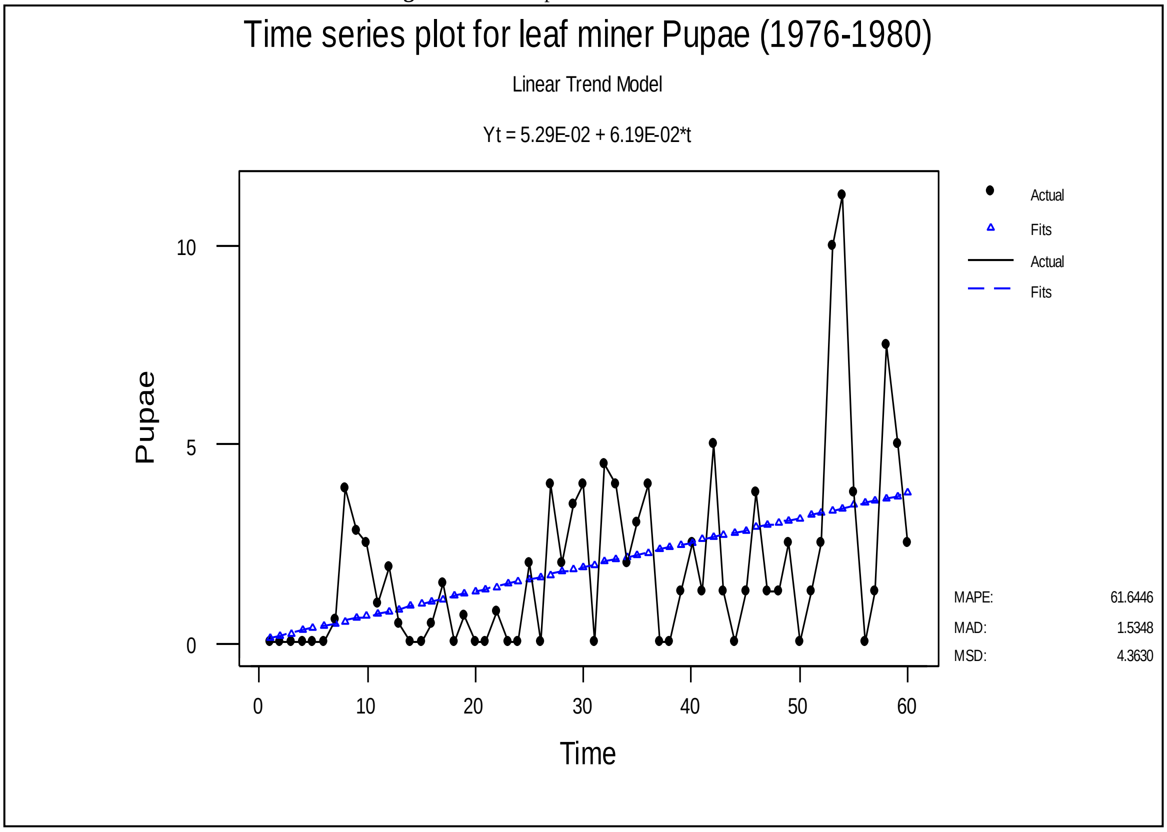
Yt = Larvae at any time forecasting is needed

Fig-4. Trend of Larvae between 1976 and 1980



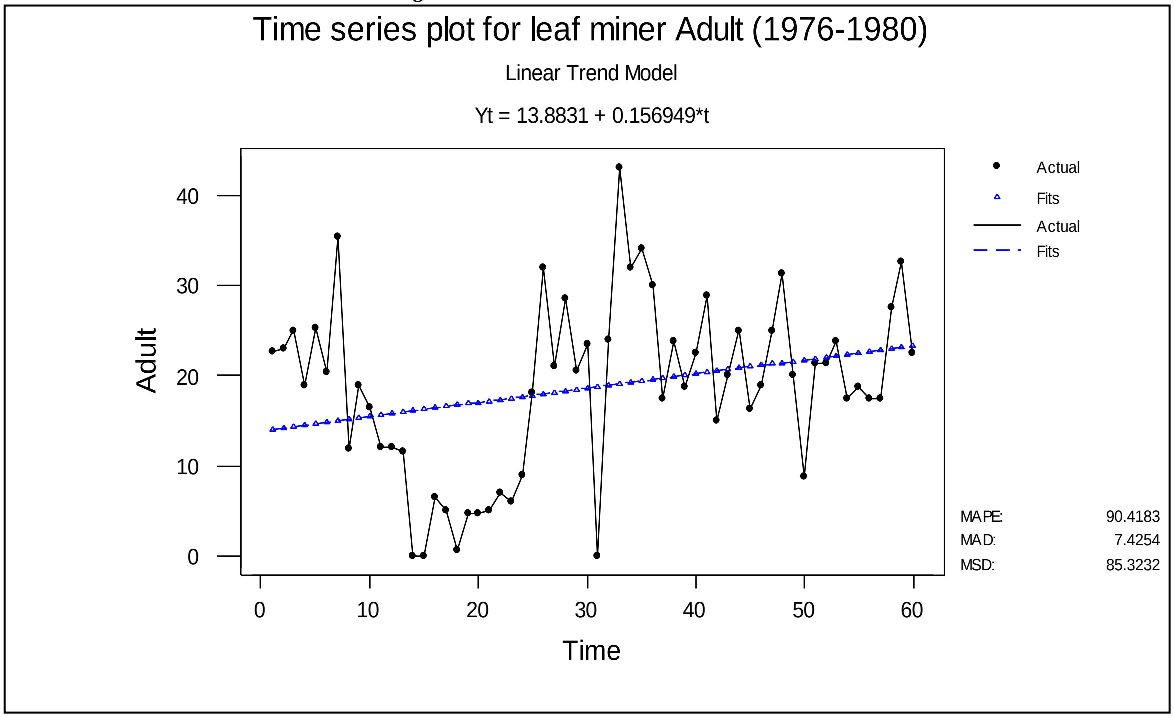
The trend line in pupae abundance shows an observed increase (Fig. 5). The trend is represented by the model:
Yt = 5.29E-02 + 6.19E-02*t
Where t = time
Yt = Pupae at any time forecasting is needed

Fig-5. Trend of Pupae between 1976 and 1980



The trend line in adult abundance shows an observed increase (Fig. 6). The trend is represented by the model:
Yt = 117.180 + 1.50646*t
Where t = time
Yt = Adult at any time forecasting is needed

Fig-6. Trend of adult between 1976 and 1980



3.2.2. Leaf Miner Trends: 2009 - 2010

Trends of leaf miner (larvae, pupae, adult) from 2009 – 2010 are presented in figures 7 8 9. Generally, the time trends are varying with no extremely increasing or decreasing trend.

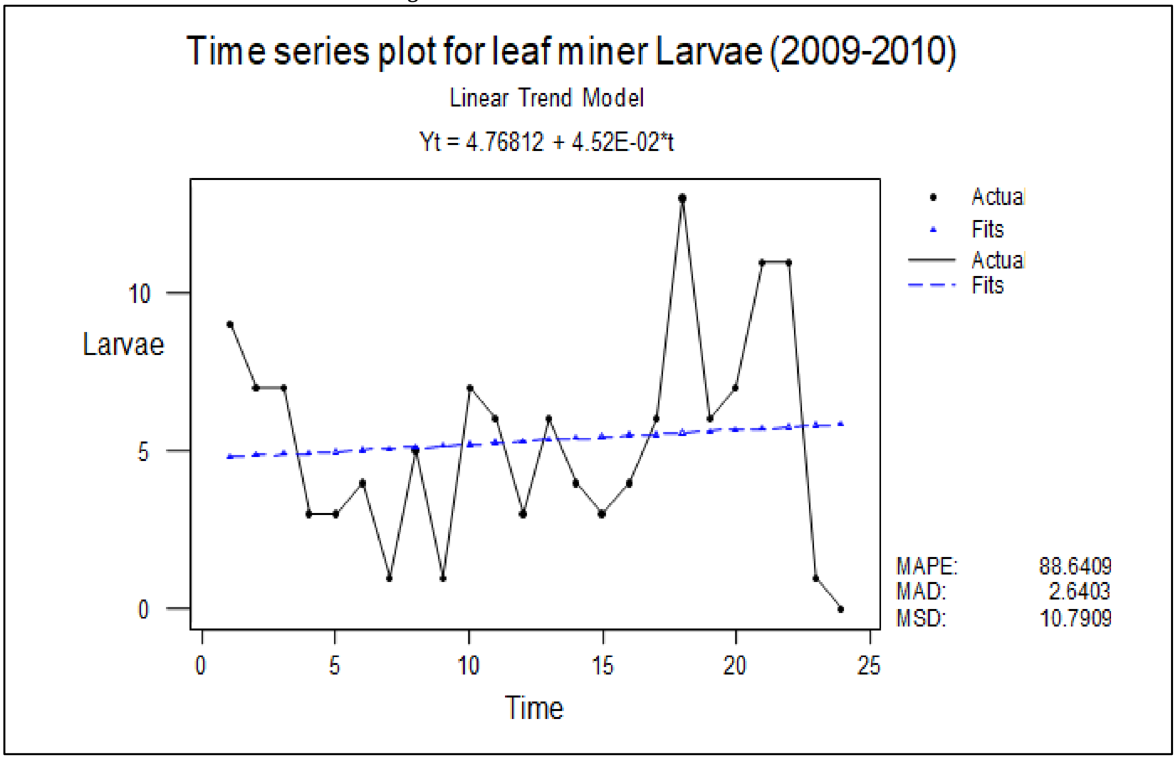
The trend line in larvae abundance shows an observed gradual increase (Fig. 7). The trend model is represented by the model:

Yt = 4.766812 + 4.52E-02*t

Where t = time

Yt = Larvae at any time forecasting is needed

Fig-7. Trend of larvae between 2009 and 2010



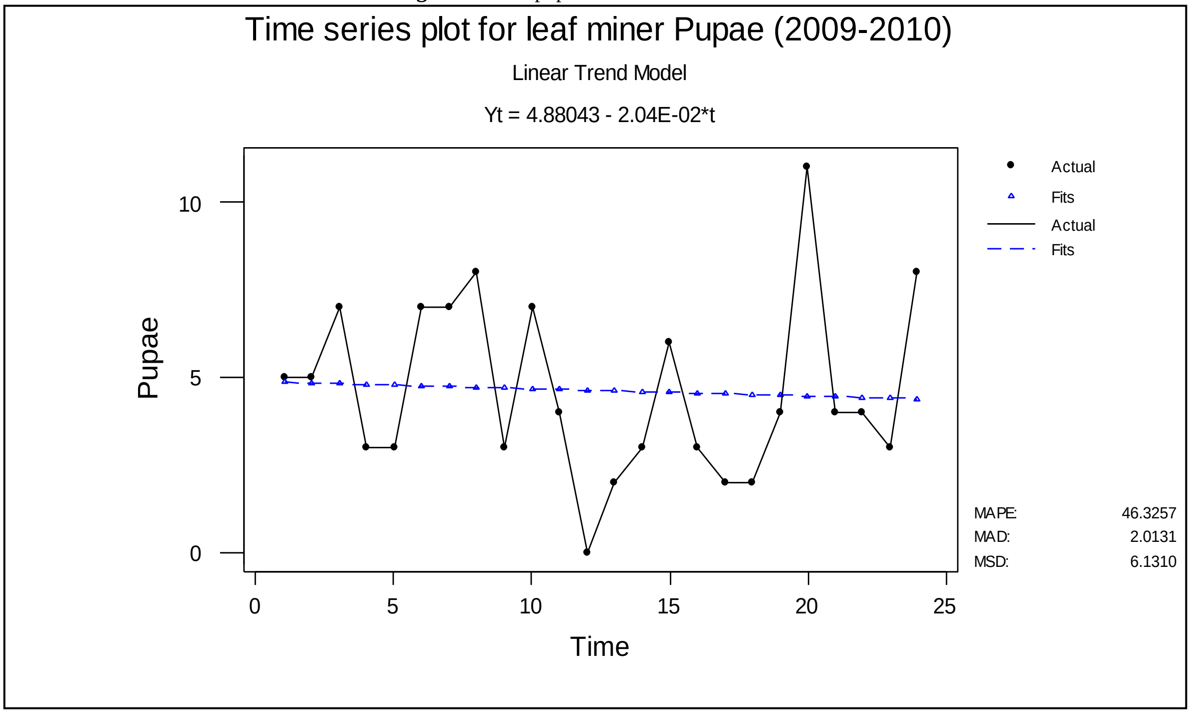
The trend line in pupae abundance shows an observed gradual decrease (Fig. 8). The trend model is represented by the model:

Yt = 4.88043 – 2.04E-02*t

Where t = time

Yt = Pupae at any time forecasting is needed

Fig-8. Trend of pupae between 2009 and 2010



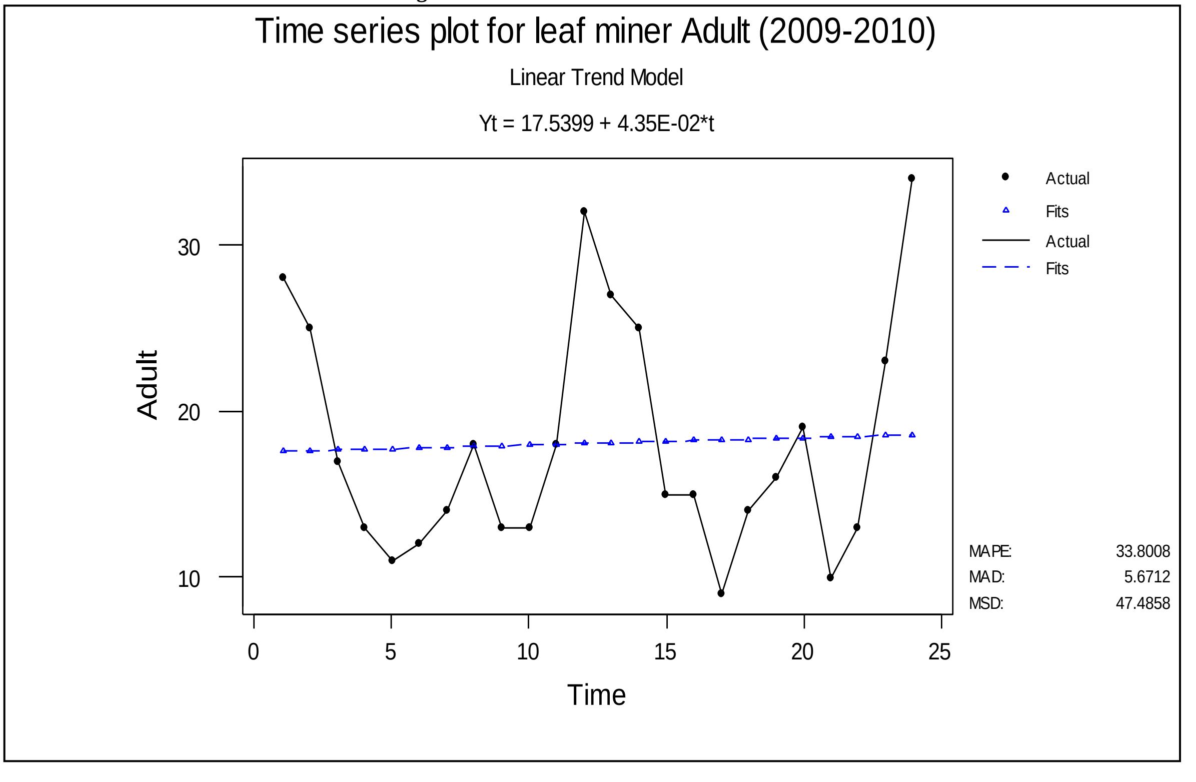
The trend line in adult abundance shows an observed increase (Fig. 9). The trend model is represented by the model:

Yt = 17.5399 + 4.35E-02*t

Where t = time

Yt = Adult at any time forecasting is needed

Fig-9. Trend of adult between 2009 and 2010



3.2.3. Climate Forecast Trends: 2011 -2050

Decadal forecast on yearly average temperature, rainfall and relative humidity from 2011-2050 is presented in table 4. It shows the average value of temperature, rainfall and relative humidity forecasted for the respective decade. It indicates increasing trends of temperature and decreasing trends in rainfall and relative humidity values through out the period under review. Specific forecast indices for 2050 are: Temperature: 33.6°C; Rainfall: 154.21mm; and Relative humidity: 66.9%.

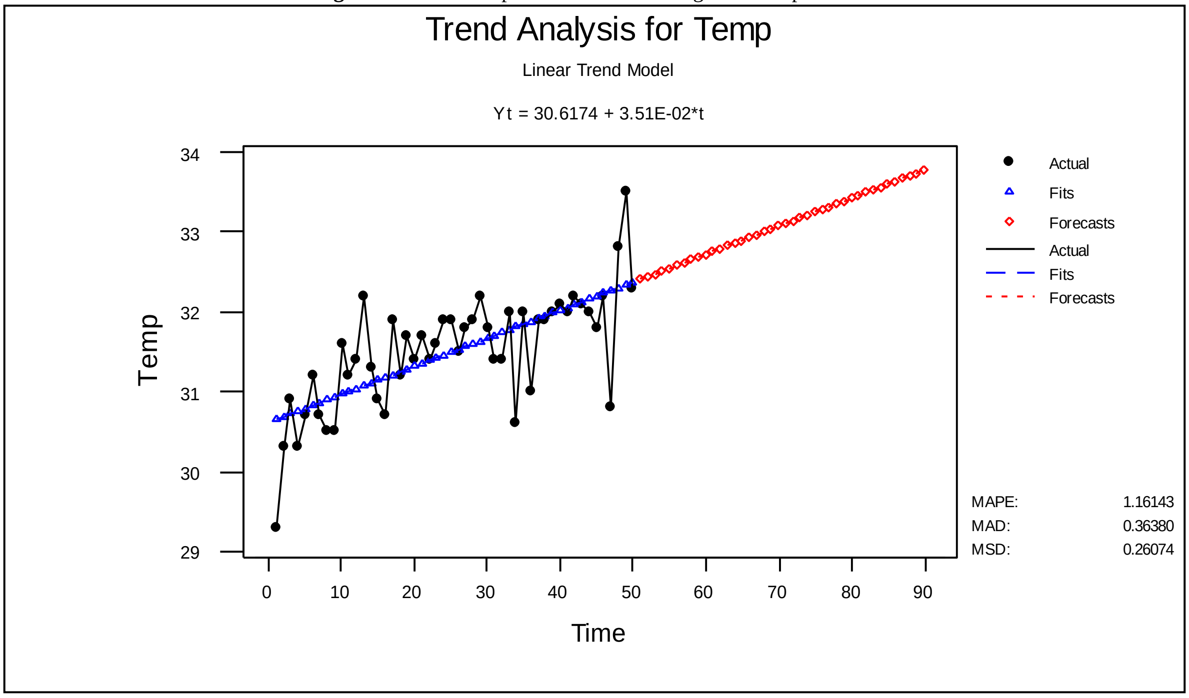
Table-4. Decadal forecast on yearly average temperature, rainfall and relative humidity from 2011-2050

Decade (D)	Temperature (°C)	Rainfall (mm)	Relative humidity (%)
D6 (2011-2020)	32.6	157.58	67.7
D7 (2021-2030)	32.9	156.46	67.3
D8 (2031-2040)	33.3	155.33	67.0
D9 (2041-2050)	33.6	154.21	66.9

Forecast trends of temperature, rainfall and relative humidity from 2011-2050 (40 years) are presented in figures 10 11 12.

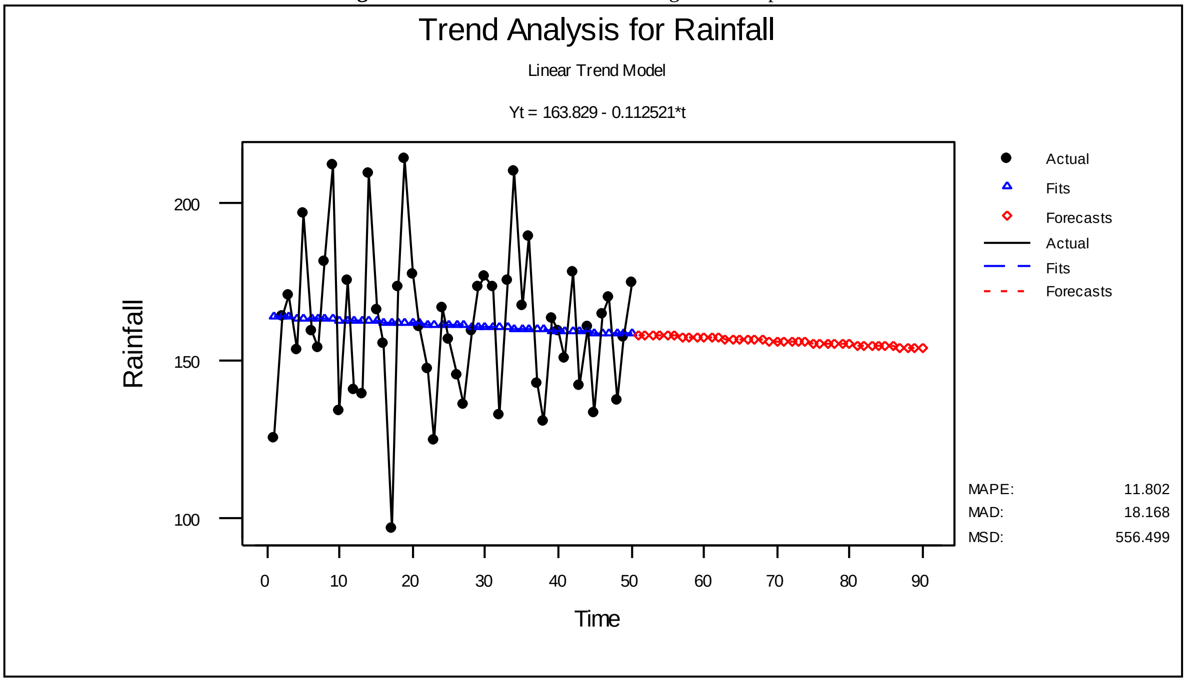
Average temperature forecast (Fig. 10) for 2050 (D9) is 33.6°C showing a 1.4°C increase in average temperature between D5 (2011-2020) and D9 (2041-2050).

Fig-10. Trend of Temperature with forecast generated up to 2050



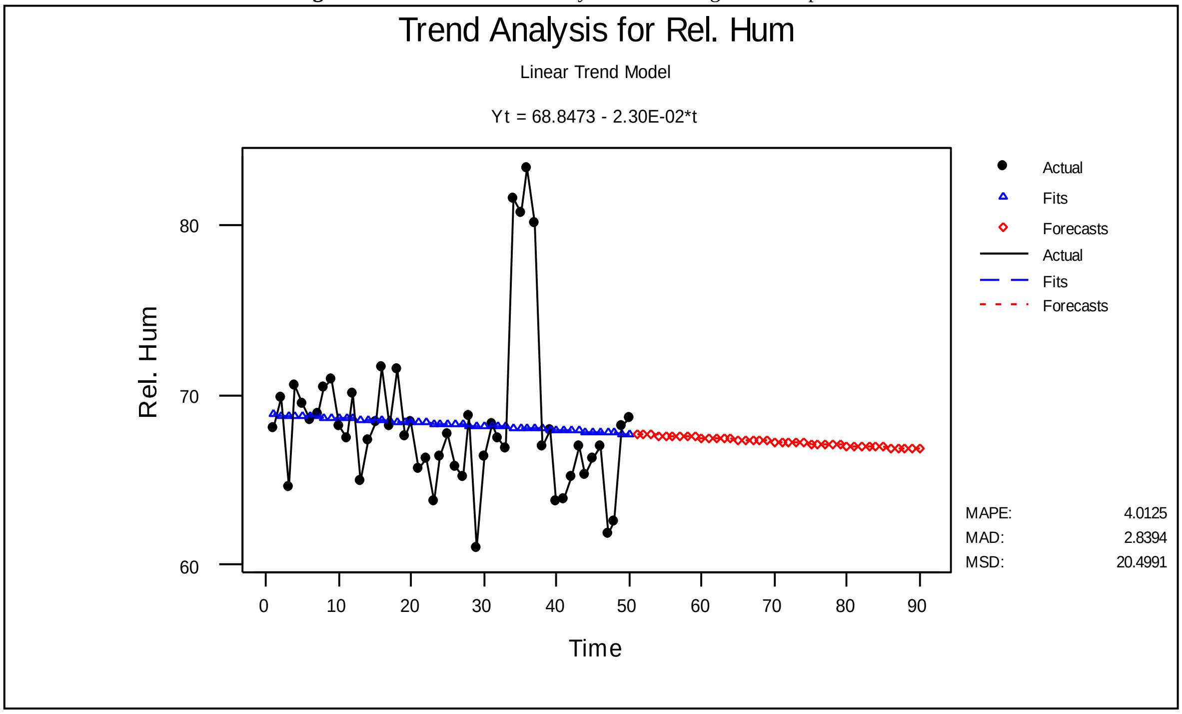
Rainfall forecast obtained (Fig. 11) shows an average amount of rainfall for D9 (2041-2050) to be 154.21mm showing a 2.47mm decrease in average amount of rainfall between D5 and D9.

Fig-11. Trend of rainfall with forecast generated up to 2050



Average relative humidity forecast (Fig. 12) for D9 (2041-2050) is 66.9% showing a 1.38% decrease in average relative humidity between D5 (2011-2020) and D9 (2041-2050).

Fig-12. Trend of relative humidity with forecast generated up to 2050



4. Discussion

The effect of climate change in Nigeria is already contributing to extreme weather events: amount of rainfall, proliferation of pests, crop diseases and high temperature effects. Insects have been noted to respond to various levels of ultra violet light [22]. Major impacts on food production will come from changes in temperature, moisture levels, ultraviolet (UV) radiation, CO_2 levels, pests and diseases [23]. Control measures require extensive high quality information on climate, agricultural, environmental and social systems affected by climate, with a view to carrying out realistic vulnerability assessments and looking towards the near future [24]. Climate change can increase incidence of pests and consequently decrease crop harvest yields. The proliferation of pests can hinder storage because of temperature increase. Many publications concerned with the ecological consequences of global climate change focused upon the response of organisms to past climatic changes, or were based on models to predict future impacts [25]. Each specie of insect has a range of temperature within which it can survive. This range is referred to as the tolerable zone [26]. Most insects have an upper temperature tolerance between 40 and 50^0C, and no known insect can survive temperatures in excess of 63^0C [27]. Insects are able to function faster and more efficiently at higher temperatures. They can feed, develop, reproduce, and disperse when the climate is warm, though they may live for a shorter time [28]. Existing studies suggest that direct effects of temperature are likely to be larger and more important than any other factor [29]. Little is published about the direct effects of changing precipitation patterns on insects, although much can be surmised, particularly of rainfall as an enhanced mortality factor (e.g. [30, 31]. Time series analysis provides a method for estimating population trends and associated variances [32].

4.1. Decadal Weather Variation from 1961 - 2010

In many tropical systems, fluctuations in temperature, rainfall, and wind regimes represent the strongest seasonal changes altering the environment to an extent which matches the importance of temperature in many temperate areas [33]. In the dry season, temperatures were high while rainfall and relative humidity were low. The onset of the rains caused a decrease in air temperatures while rainfall and humidity levels increased considerably. Thus climatic conditions greatly influenced seasonal leaf miner populations.

Decadal variation in air temperature was characterized by wide difference between 1961 – 1970 and 2001 – 2010. An incremental increase in temperature could help explain fluctuations in insect pest populations within and between years. Existing studies suggest that direct effects of temperature on insects are likely to be larger and more important than any other factor [29, 34-36].

The rainfall pattern showed a decline in decadal mean rainfall between 1961- 1970 and 2001 – 2010. Rainfall was characterized by lower precipitation in the dry season months of November to February than the other months of the year. The highest mean monthly precipitations were recorded in the months of July, August and September, while the lowest precipitation levels were recorded in December and January. The moisture content in the habitat of an insect directly determines whether or not an individual survives. All forms of environmental moisture (atmospheric humidity, rain, dew, soil moisture, snow, hail and surface water) influence the water balance of insects [37]. Little is published about the direct effects of changing precipitation patterns on insects, although much can be surmised, particularly of rainfall as an enhanced mortality factor [30, 31].

Humidity was closely related to rainfall pattern with a decline in decadal mean rainfall between 1961- 1970 and 2001 – 2010. Maximal values were recorded in the rainy season when moisture content of the air was highest. Relative humidity is an environmental factor which may affect different aspects of insect life [38].

Temperature variation followed decadal incremental increase of 1.56^{o}C between 1961 and 2010. Rainfall (8.2mm) and relative humidity (3.39%) decreased respectively between the same periods. These variations could be attributed to climate change. However, seasonal maximum temperature variations were higher in the dry season (1.75^{o}C) than in the rainy season (1.15^{o}C). Seasonal rainfall pattern showed observed variations in both the dry and rainy seasons. Seasonal relative humidity pattern followed the rainfall pattern with higher variation in the rainy season. Seasonal variations could influence timing of pest control measures.

4.1.1. Leaf Miner Trends: 1976 -1980

A crucial issue in ecology is to determine how environmental variations associated with global climate change and variability, especially changing temperatures, affects trophic interactions in various ecosystems.

4.1.1.1. Larvae Trends: 1976 -1980

Larvae showed a gradually decreasing trend for the observed period. When this observation was correlated with the weather (temperature, rainfall and relative humidity) during these periods, it could be inferred that there was no proliferation as a result of weather.

4.1.1.2. Pupae Trends: 1976 -1980

Pupae showed an increasing trend for the observed period. No feeding occurs at this stage.

4.1.1.3. Adult Trends: 1976 -1980

Adult analysis shows an increasing trend for the observed period.

At this stage, the adults emerge from the leaflet mines into the environment. It could be inferred that adults are more sensitive to environmental conditions, and are more likely to proliferate than other leaf miner developmental stage. In general, most studies have concluded that future climate change is likely to produce an increased challenge to agriculture.

4.1.2. Leaf Miner Trends: 2009 - 2010

The assessment of the sensitivity of leaf miner to variability in weather conditions is important in view of evidence that show expansion of pest ranges as a result of climate variability impacts. The study has established an upward increase in temperature, attributed to climate change, with concomitant increase in leaf miner abundance between 1980 and 2010. Larvae showed an increasing trend for the observed period. When this observation was correlated with the weather (temperature, rainfall and relative humidity) during these periods, it could be inferred that there was proliferation as a result of weather. This was different from the decreasing trend observed during the 1976 – 1980 periods. Pupae showed a decreasing trend for the observed period. No feeding occurs at this stage. Adults showed an increasing trend for the observed period.

It could be inferred that adults were proliferating due to temperature increase and rainfall decrease.

4.1.3. Climate Forecast Trends: 2011 - 2050

The climate forecast up to 2050 indicates an upward trend in temperature and a downward trend in rainfall and relative humidity. This followed the climate trend between 1961 and 2010.

In this study, temperature forecast is projected to increase by 1.4^{0}C by 2050 based on trend analysis using 2001 – 2010 as baseline values. This implies further proliferation of the leaf miner by 2050. The leaf miner could experience increased rate of development in the context of climate change. By 2050, some areas in sub-Saharan Africa (SSA) are predicted to have up to 10% less annual rainfall [39]. The magnitude of projected rainfall changes for 2050 in IPCC [40] is small in most African areas, but can be up to 20% of 1961–1990 baseline values. In this study, rainfall forecast is projected to decrease by 2.47mm in 2050 based on trend analysis using 2001 – 2010 as baseline values. Decrease in rainfall levels would lead to increased leaf miner abundance.

In this study, relative humidity forecast is projected to decrease by 1.38% in 2050 based on trend analysis using 2001 – 2010 as baseline values. A decrease in relative humidity would increase temperature and promote growth of the leaf miner.

5. Conclusion

The development of forecasting systems to manage outbreaks of the leaf miner is important and based on integrating meteorological and entomological data into a conceptual model that relates the probability of occurrence of outbreaks to a particular series of events which can be monitored. A major advantage is the potential for limiting the spread of outbreaks through timely control of early infestations.

Environmental change issues are rapidly increasing in relevance for pests of agriculture. Oil palm – pest interactions will change significantly with climate variability and change leading to impacts on pest abundance.

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