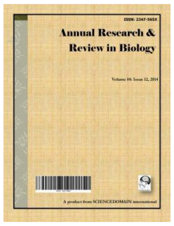

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Evaluation of Climate Variability Impacts on the Population of the Oil Palm Leaf Miner in Nigeria

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Authors' contributions

This work was carried out in collaboration between all authors. Author AT designed the study, wrote the protocol and interpreted the data. Authors AC and AT anchored the field study, gathered the initial data and performed preliminary data analysis. Author AC contributed figures 1 and 2. Authors AV and IB managed the literature searches and produced the initial draft. All authors read and approved the final manuscript.

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ABSTRACT

This paper evaluates climate change and variability from 1961-2010 and projections up to 2050 and its impacts on the oil palm leaf miner - *Coelaenomenodera elaeidis* (Coleoptera: Chrysomelidae), in the study area. The study involved direct field insect pest surveys and assessments at the Nigerian Institute for Oil Palm Research (NIFOR) main station. A complete randomized design (CRD) was utilized. The leaf miner was sampled during 2009-2010 in oil palm fields and records from previous surveys from 1976-1980 were utilized. Climate variability projections up to 2050 were evaluated and impacts on the leaf miner evaluated. Time series analysis was conducted using Minitab 14.0. Least square method was used to estimate the trend in the series and the trend equations. Computed models for temperature, rainfall and relative humidity were Yt = 30.6174+3.51E -02*t; Yt = 163.829 - 0.112521*t and Yt = 68.8473–230E -02*t respectively where t is time. On this basis, a forecast up to 2050 was generated indicating an upward trend in temperature and a downward trend in rainfall and relative humidity. Specific forecast indices for 2050 were: Temperature: 33.8°C; Rainfall: 153.70 mm; and Relative humidity:

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66.8%. The study has established an upward increase in temperature, attributed to climate change, with concomitant increase in leaf miner abundance between 1980 and 2010 The integration of weather forecasting with farmer action has great potential for control of insect pests in oil palm growing areas.

Keywords: Coelaenomenodera elaeidis; climate variability; oil palm; time series; forecast.

1. INTROUCTION

The leaf miner - *Coelaenomenodera elaeidis* (Coleoptera: Chrysomelidae), a hispid, is a serious defoliating pest of the oil palm. Leaf miner outbreaks are sporadic and difficult to predict. There is need for increased knowledge of the leaf miner and its dynamics to guide environmentally sustainable integrated pest management methods. A major ability of farmers to adapt to climate variability and change with respect to insect pest infestations will depend on knowledge of pest attacks in relation to climate variability and change. In order for farmers to move away from over reliance on pesticides, dependable tools to time pest management activities are needed. There is rapidly increasing understanding of how the climate is likely to change at the global scale under various emissions scenarios, however what is less well understood is the magnitude of future temperature, rainfall and relative humidity changes at the local level, and how these are influencing agro-biological systems [1].

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 [2]. The mean temperature for Nigeria is 27°C, in the absence of altitudinal modifications. Over the last few decades, there has been a general increase in temperature throughout Nigeria [3]. In Nigeria, climate change causes higher temperatures and relative humidity, which increases the likelihood of such stressors as pest infestations and diseases [4].

Agricultural pests severely constrain the productivity potential of global agriculture. 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 [5]. 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 [6]. A comprehensive study [7] places the combined pre-harvest loss from pests at 42 percent for the world's top eight food crops, with an additional 10 percent of potential food production lost to pests during post-harvest.

The adult beetle feeds on the lower surface of the leaflets leading to the partial drying up of the fronds [8]. 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 [9,10]. Accounts of the incidence, life cycle and damage of this pest have been given [11]. 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. The adults are tiny pale-yellow beetles which scoop and feed in longitudinal grooves on the lower-surface of leaflets, the females laying their eggs in pits at the ends of the grooves and covering these with mounds of debris. The larvae that hatch out, mine or tunnel within the leaflet tissue between the upper and lower epidermal layers. The larvae attain about 6.8 mm in length, with brownish thorax fused to the head. They mine longitudinally under the upper epidermis of leaflets of mature palms, except those below 3 years old. Their mined galleries attain 15 cm length and 1 cm breadth. Severely attacked palms look scorched from a distance, the young leaves remain green, while the others are grey-brown, and desiccated. The pupae are mobile and are visible in the center of the galleries, when the dried furrows are teased out. The adults are pale yellow with reddish wing cases. These adults in cases of severe attack can be observed flying within the crown, and show preference for migrating to the higher leaves. Heavily attacked trees may have up to 90% of the fronds defoliated which can result in about 50% loss in yields of fresh fruit bunch (ffb) over a two year period [12].

There is a clear need to advance knowledge on pest response to weather and climate variability. A key justification of this work is that the linkage between climate variability and pest response is poorly understood. This study contributes to the understanding of the insect pest-climate relationship in broad agricultural and food security terms.

This paper focuses on the sensitivity of the leaf miner to climate variability. The objectives include: Evaluation of climate change and variability from 1961-2010 and projections up to 2050; and Impacts of climate variability on *Coelaenomenodera elaeidis* in the study area.

2. MATERIALS AND METHODS

The study site is located at the main station of the Nigerian Institute for Oil Palm Research (NIFOR) near Benin, Edo State, Nigeria. It lies on the coordinates of latitude 6° 30' N and longitude 5° 40' E. It is located in the forest zone of South-West Nigeria. There are two seasons; wet and dry seasons. Average mean temperature is 26.6°C. 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. The river Okhuo flows southwards, towards the Northern part of the station. Fig. 1 shows geographical location of the study site.

2.1 Sampling Technique

The study involved direct field insect pest surveys and assessments at the NIFOR main station. Criterion for site selection was a plot 5-12 years of age. Data was collected monthly from January 2009 – December 2010. It involved observing and counting of *C. elaeidis*. No pesticides were applied during the study period to simulate a natural ambience in the sample plot. The field was selected after a reconnaissance survey of experimental plots in the NIFOR main station – fields 2, 13, 16, 37, 72, 47, 25, 26, 30, 37, 54, 46 and 34. Only field 54 was planted in the year 2000. Field 37 was planted in the year 1987. All others were planted in excess of 25 years. The study field 54 was made up of 443 palms (2.95 hectares). Formerly known as field 14, it was planted in the year 2000 and harvesting of fresh fruit bunch (ffb) began in 2005. It was divided into 7 blocks (1 – 31 palms; 2 – 58 palms; 3 – 68 palms; 4 – 68 palms; 5 – 72 palms; 6 – 63 palms and 7 – 83 palms). For mature palms, various census methods have been proposed [13-16]. In this study, the census system used sample counts within specified blocks. Since the palms were planted in a triangular pattern, census lines ran in three directions. Access points were marked with reference to field boundaries and harvesting paths. Census on the basis of damage by *C. elaeidis* was done monthly by walking the full length of a planted line, assessing damage on each palm and cutting 5 severely damaged leaflets from a palm frond with a harvesting knife and taken to the laboratory where the leaflets were opened up and immature stages of *C. elaiedis* counted. Sampling was conducted monthly between 7 am - 11 am. Insect sampling was done by the use of insect sweep net, direct handpicking and leaflet sampling.

2.2 Experimental Design

The experimental area was a total size of 2.95 Ha. A census of one palm per row was utilized, and a sampling intensity of 21 palms was used, selecting 1 palm per line. The larval, pupal and adult stages of the insects were counted. A complete randomized design (CRD) was utilized, since observations were made on experimental units that are homogenous. The independent variables were temperature, rainfall and relative humidity. The dependent variable was *Coelaenomenodera elaeidis*. At each point, pests were counted on fronds inclined at 45° (number 17 and 25 on the phyllotactic spiral) [17]. In shorter palms, fronds were pulled down by hand, but in taller ones a ladder was used. A different palm was used at successive census rounds.

2.3 Secondary Data Collection

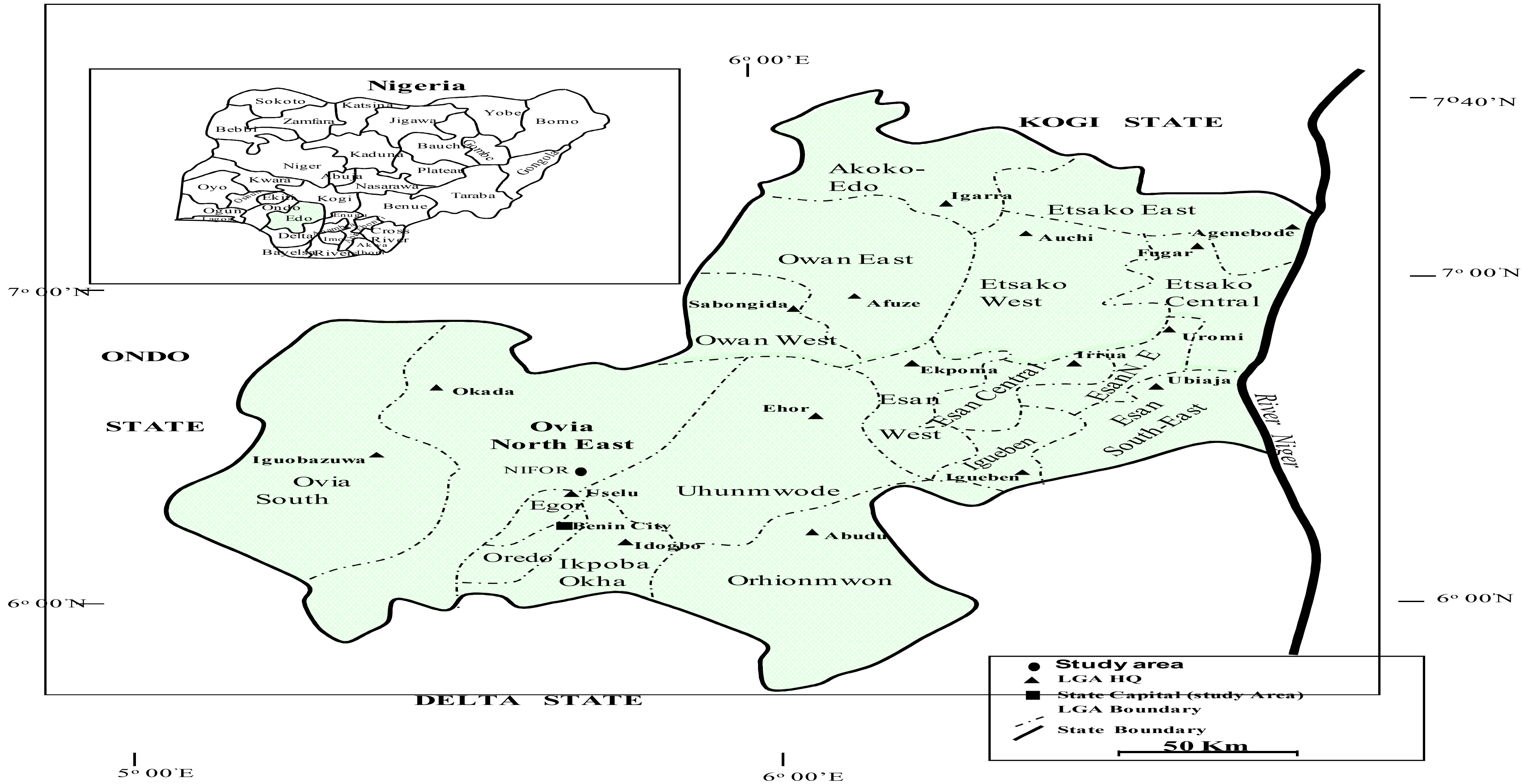
Leaf miner field data surveys from 1976-1980 were obtained from NIFOR Entomology division.

2.4 Climatological Data

Climatological data (temperature, rainfall and relative humidity) were obtained from NIFOR meteorological station. The weather station is within 1 km radius of the field. The data were monthly averaged records.

2.5 Statistical Analysis

Time series analysis was conducted using Minitab 14.0. Least square method was used to estimate the trend in the series and the trend equations.



Source: Governor's office Benin City, 2008.

Map of Edo State Showing NIFOR

Fig. 1. Geographical location of study site

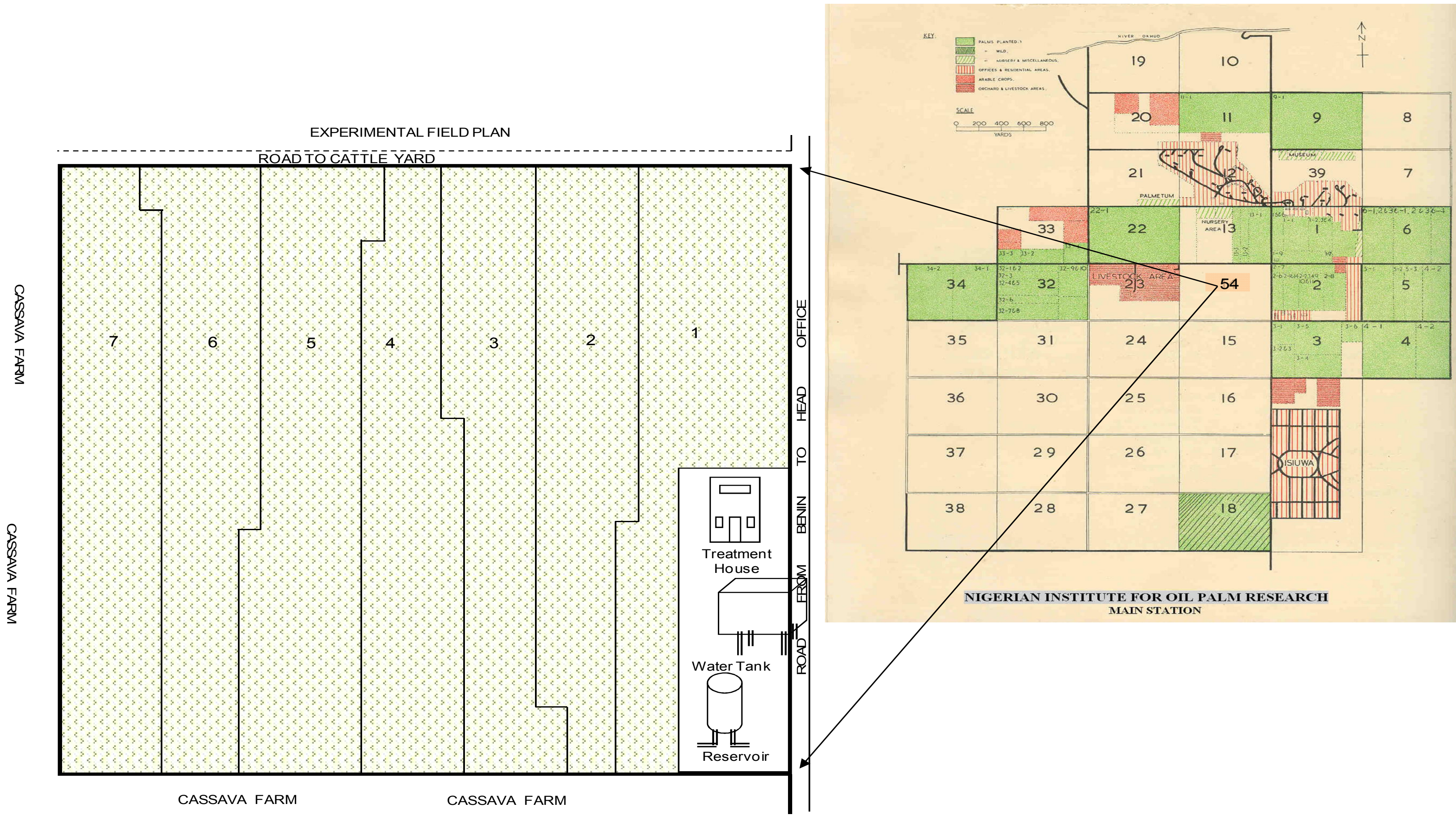


Fig. 2. Schematic diagram of experimental plot

3. RESULTS AND DISCUSSION

3.1 Climate Trends: 1961 – 2010

Trends of temperature, rainfall and relative humidity from 1961-2010 (50 years) are presented in Figs. 3-5. Generally, for all the plots, the time trends are varying and the series show increasing or decreasing trends.

3.1.1 Temperature

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 [18].

Time series analysis on average monthly temperature is represented by the model (equation 1):

Yt = 30.6174 + 3.51E -02*t

Where t = time

Yt = Temperature at any time forecast is needed

3.1.2 Rainfall

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 [19]. 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 [20].

A gradual decrease in rainfall can be deduced (Fig. 4). 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 (equation 2) is represented by:

Yt = 163.829 - 0.112521*t

Where t = time

Yt = Rainfall at any time forecast is needed

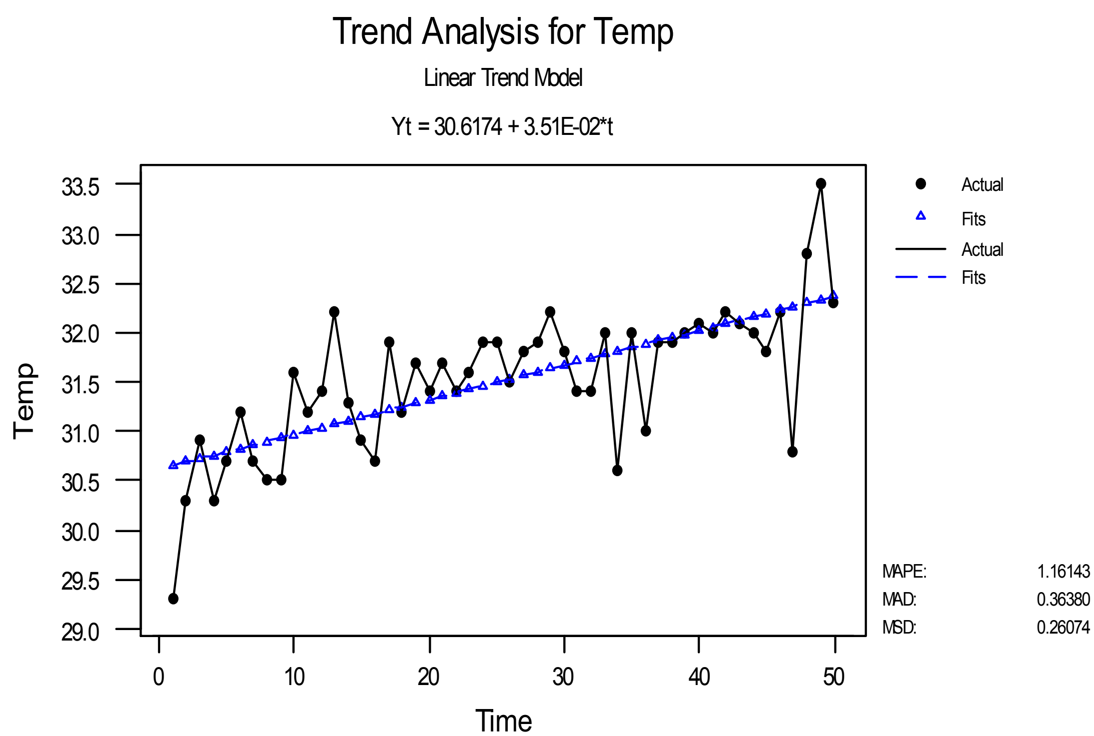


Fig. 3. Trend of temperature (°C) between 1961 and 2010

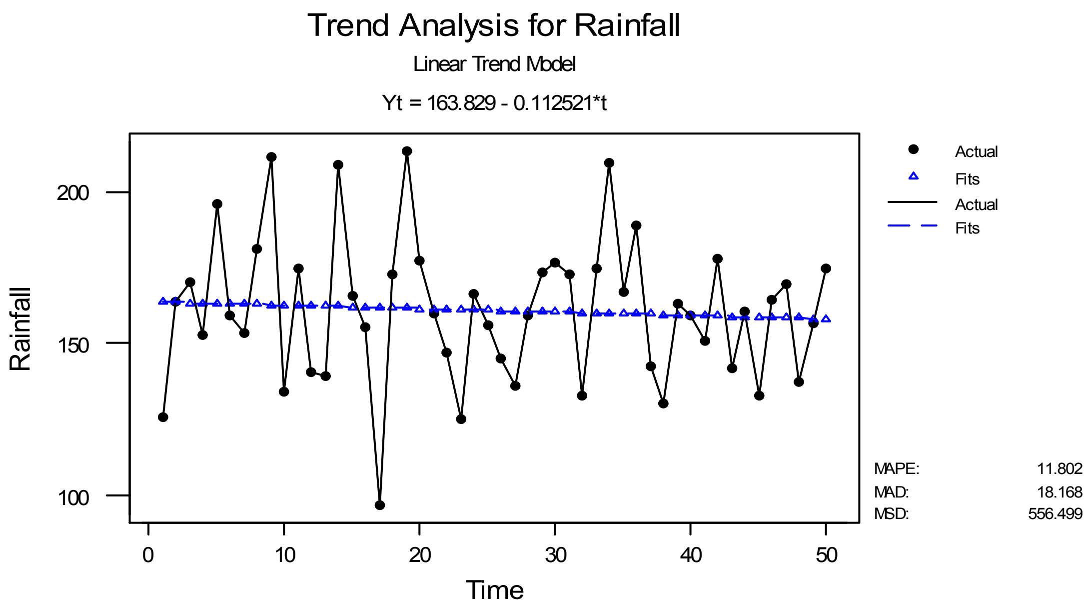


Fig. 4. Trend of rainfall (mm) between 1961 and 2010

3.1.3 Relative humidity

Relative humidity is an environmental factor which may affect different aspects of insect life [21].

A gradual decrease in relative humidity can be deduced (Fig. 5). Average humidity decreased by 3.39% between D1 and D5. Time series analysis on average monthly relative humidity is represented by the model (equation 3):

Yt = 68.8473 – 230E -02*t

Where t = time

Yt = Relative humidity at any time forecast is needed

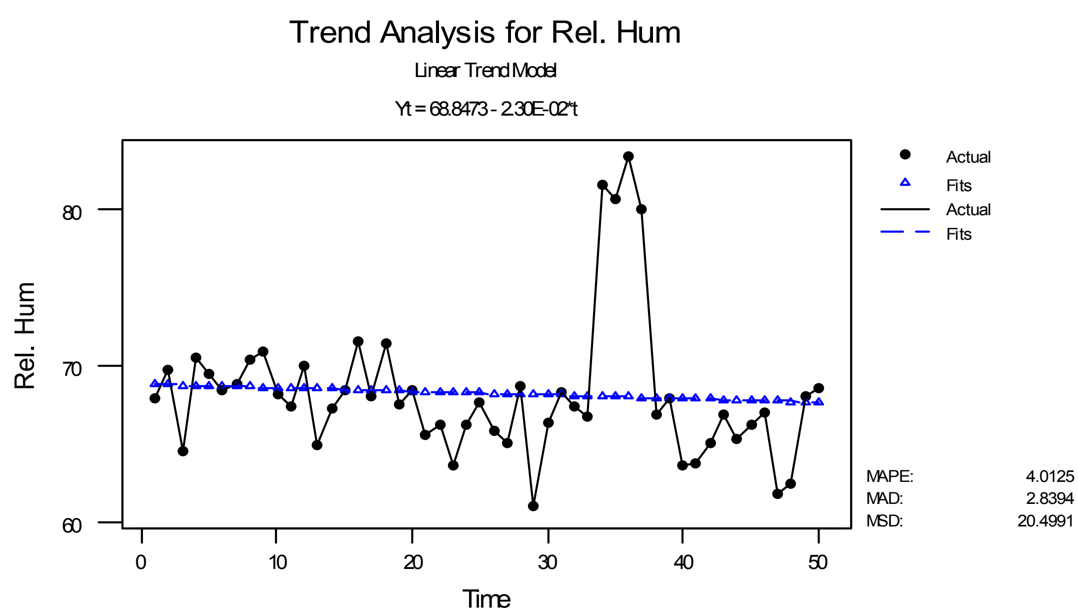


Fig. 5. Trend of relative humidity (%) between 1961 and 2010

3.2 Leaf Miner Trends: 1976 -1980

Trends of leaf miner (larvae, pupae, adult) from 1976 – 1980 are presented in Figs. 6 – 8. Generally, the time trends are varying with no large increasing or decreasing trends.

3.2.1 Larvae

The trend line in larvae abundance shows an observed gradual decrease (Fig. 6). The trend model is represented by the model (equation 4):

Yt = 2.38028 – 1.09E – 02*t

Where t = time

Yt = Larvae at any time forecasting is needed

3.2.2 Pupae

The trend line in pupae abundance shows an observed increase (Fig. 7). The trend is represented by the model (equation 5):

Yt = 5.29E-02 + 6.19E-02*t

Where t = time

Yt = Pupae at any time forecasting is needed

3.2.3 Adult

The trend line in adult abundance shows an observed increase (Fig. 8). The trend is represented by the model (equation 6):

Yt = 117.180 + 1.50646*t

Where t = time

Yt = Adult at any time forecasting is needed

3.3 Leaf Miner Trends: 2009 – 2010

Trends of leaf miner (larvae, pupae, adult) from 2009 – 2010 are presented in Figs. 9 – 11. Generally, the time trends are varying showing increasing or decreasing trends.

3.3.1 Larvae

The trend line in larvae abundance shows an observed gradual increase (Fig. 9). The trend model is represented by the model (equation 7):

Yt = 4.766812 + 4.52E-02*t

Where t = time

Yt = Larvae at any time forecasting is needed

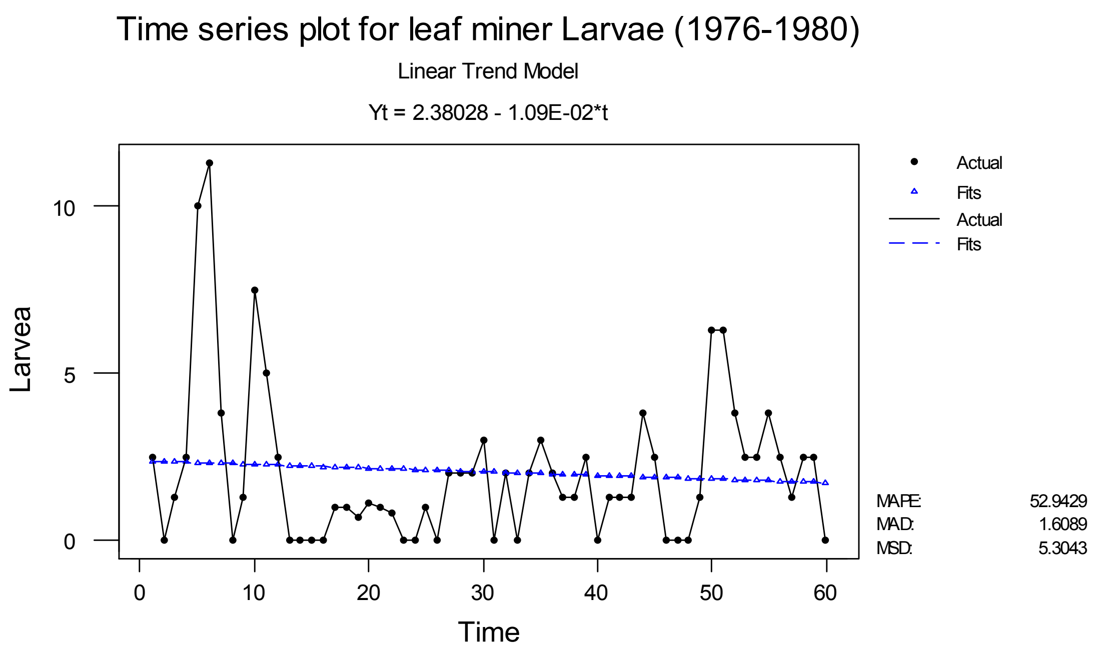


Fig. 6. Trend of Pupae between 1976 and 1980

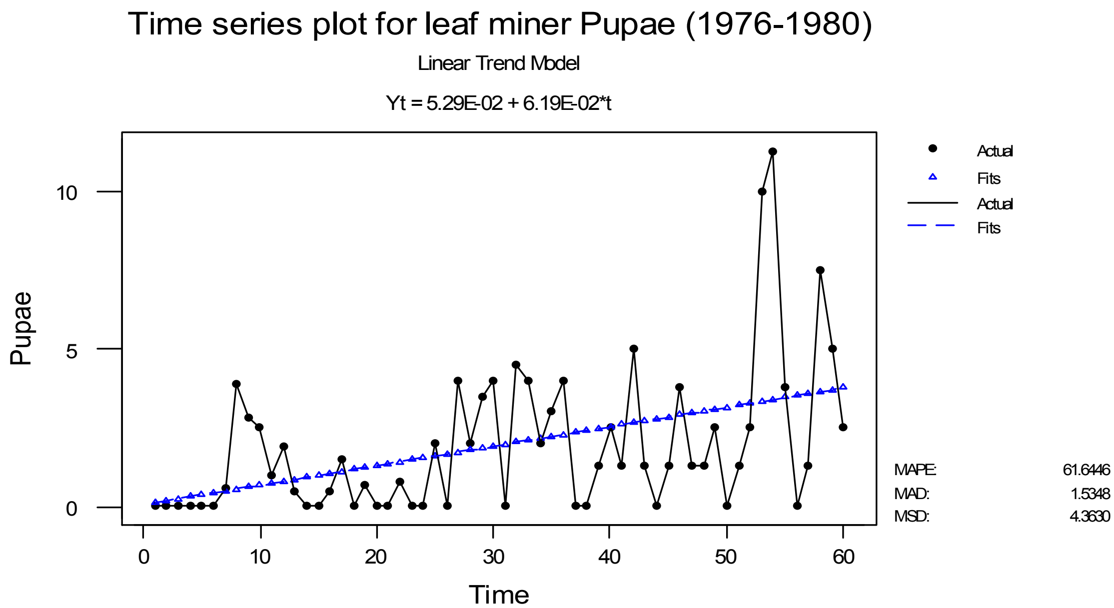


Fig. 7. Trend of Pupae between 1976 and 1980

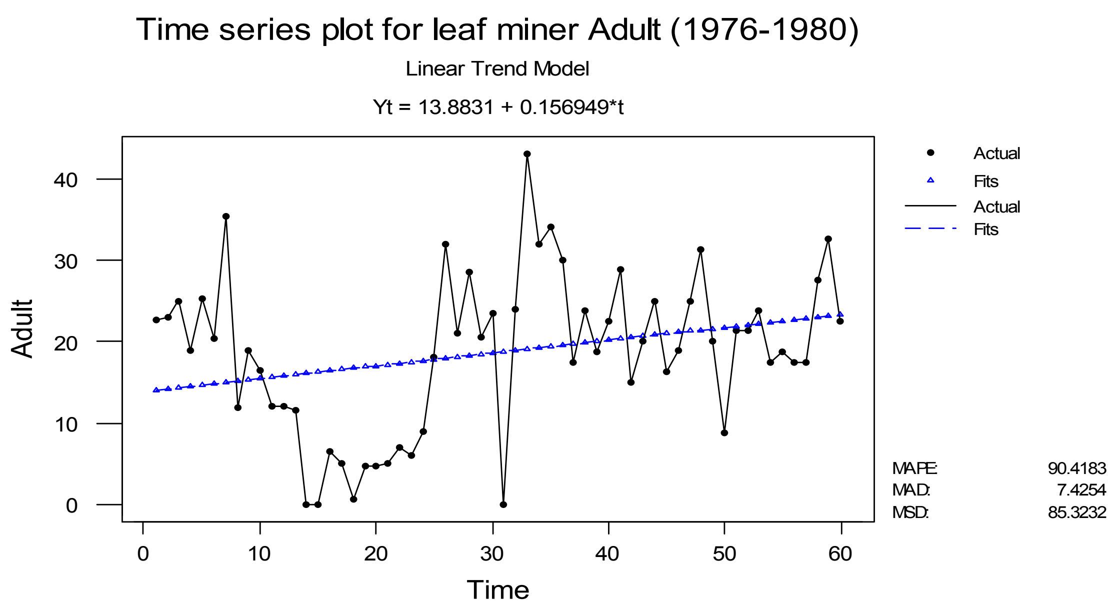


Fig. 8. Trend of adult between 1976 and 1980

3.3.2 Pupae

The trend line in pupae abundance shows an observed gradual decrease (Fig. 10). The trend model is represented by the model (equation 8):

$$Yt = 4.88043 – 2.04E\text{-}02*t$$

Where t = time

Yt = Pupae at any time forecasting is needed

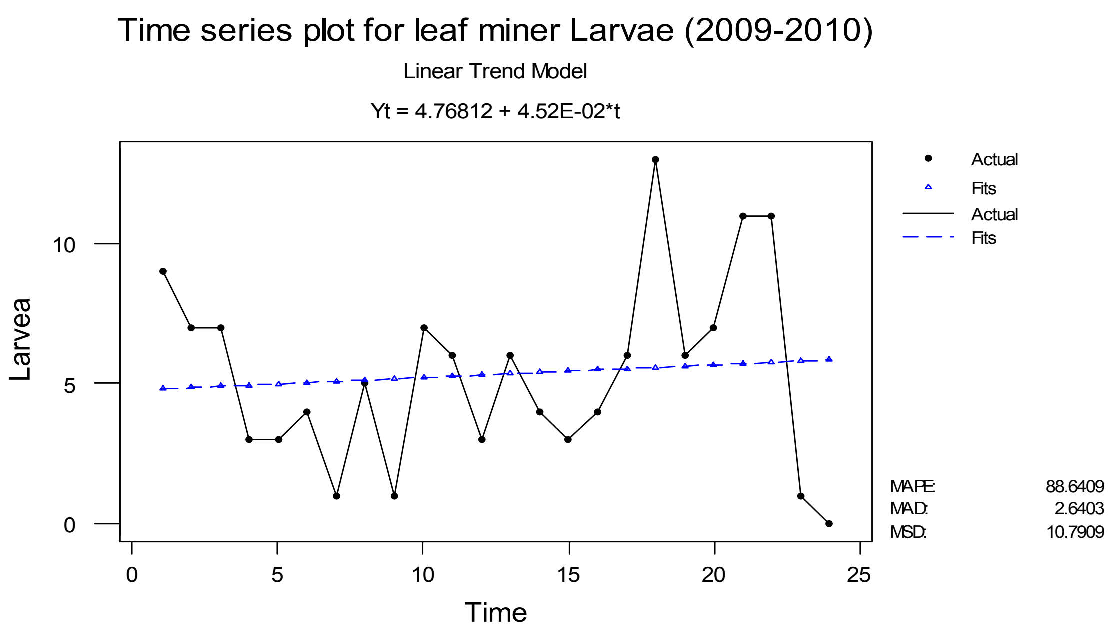


Fig. 9. Trend of larvae between 2009 and 2010

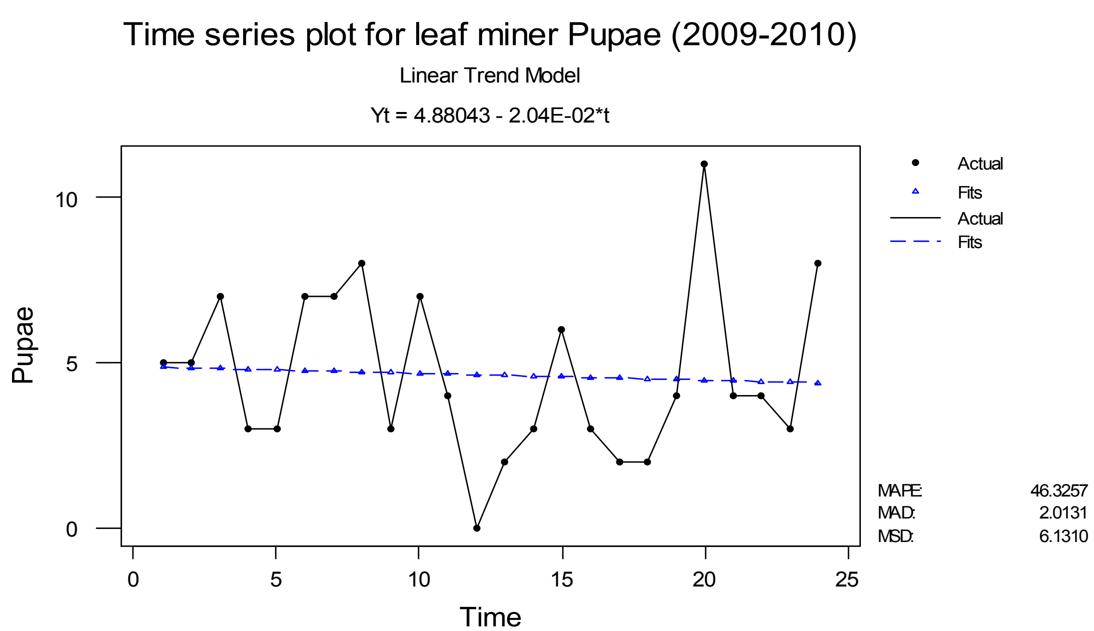


Fig. 10. Trend of pupae between 2009 and 2010

3.3.3 Adult

The trend line in adult abundance shows an observed increase (Fig. 11). The trend model is represented by the model (equation 9):

Yt = 17.5399 + 4.35E-02*t

Where t = time

Yt = Adult at any time forecasting is needed

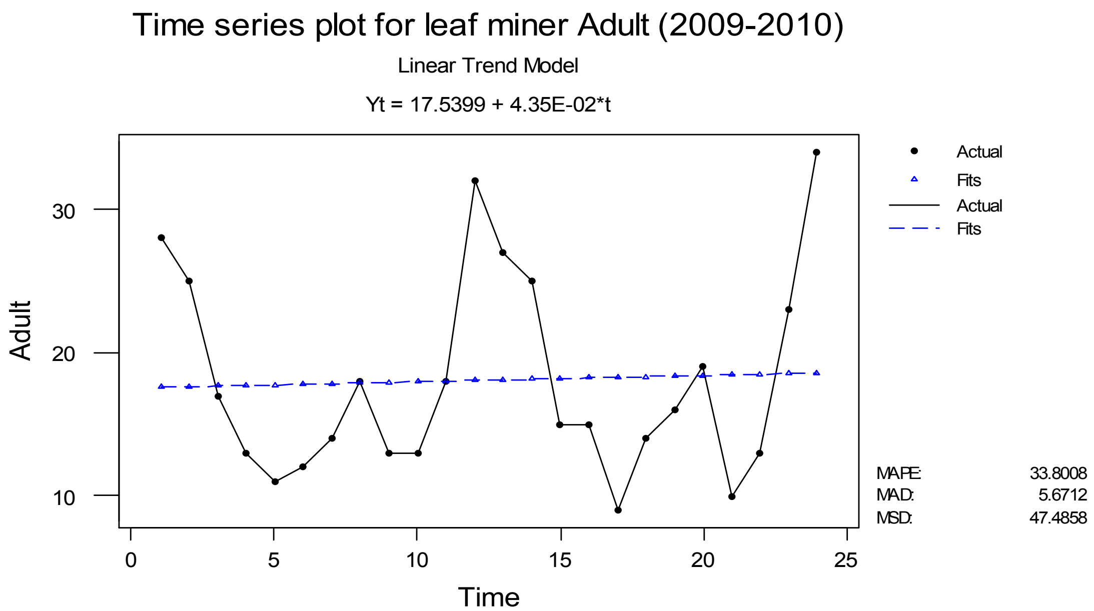


Fig. 11. Trend of adult between 2009 and 2010

3.4 Climate Forecast Trends: 2011 - 2050

Decadal forecast on yearly average temperature, rainfall and relative humidity from 2011-2050 is presented in Table 1. 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: 154.21 mm; and Relative humidity: 66.9%.

Forecast trends of temperature, rainfall and relative humidity from 2011-2050 (40 years) are presented in Figs. 12-14.

3.4.1 Temperature

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

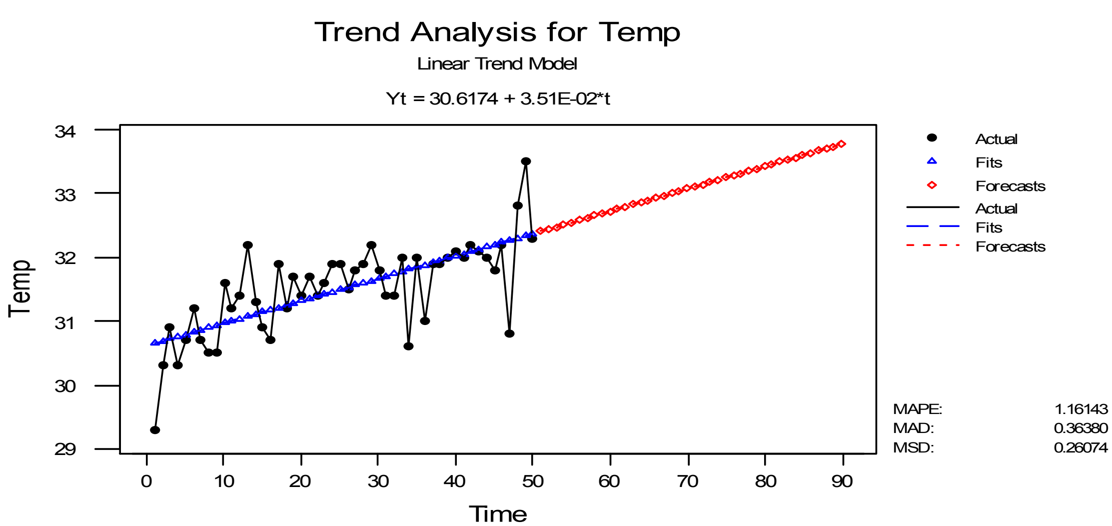


Fig. 12. Trend of temperature (°C) with forecast generated up to 2050

3.4.2 Rainfall

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

3.4.3 Relative humidity

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

Table 1. 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

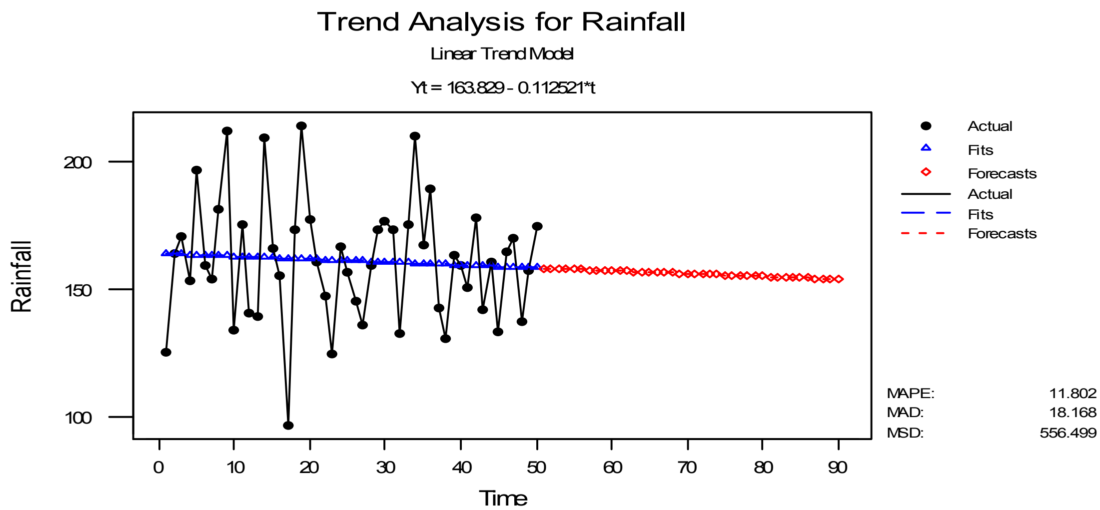


Fig. 13. Trend of rainfall (mm) with forecast generated up to 2050

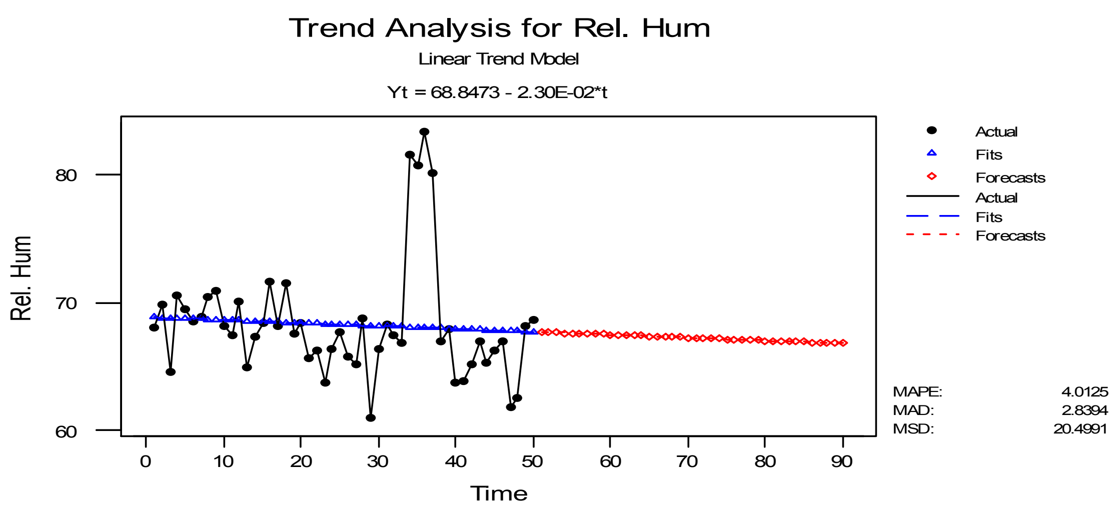


Fig. 14. Trend of relative humidity (%) with forecast generated up to 2050

4. CONCLUSION

The oil palm plays a dominant role in supporting rural livelihoods and economic growth over most of Southern Nigeria. Given the heavy dependence of livelihoods on natural resources in Nigeria, efforts should be directed to implementing effective and longer-term agro-meteorological programmes to adapt production systems to climatic resources. The broad effect of global change on the leaf miner would be mainly due to land-use change resulting from establishment of oil palm plantations. The consequences of climate variability and change affect the leaf miner and could have significant effects on its distribution and abundance. Prediction of climate change on the leaf miner is complicated because of the interactions between the insects and trees. This overall response is dependent on the impacts of climate change on the leaf miner – palm tree – natural enemy relationship. However, in this study, predictions were made on past and present leaf miner abundance. Given the population base of the leaf miner, increases in temperature could create favorable conditions for population growth and thus substantial oil palm yield losses.

The forecast up to 2050 indicates an upward trend in temperature and a downward trend in rainfall and relative humidity. This follows the climate trend between 1961 and 2010. Studies of effects of weather and climate on ecology and evolution at the population level are numerous [22-26].

Fossil records suggest that previous episodes of rapid global warming led to increased levels of insect herbivory [27]. Similarly, insect herbivory levels are currently increasing [28]. The reasons adduced for this include lower plant defenses and higher plant nutritional value in the presence of increased CO_2 and O_3 [29] and altered seasonal synchrony between plants, insect herbivores and their natural enemies [30,31]. The results reported in IPCC [32,33] suggest temperature changes over the coming decades for Africa of between 0.2 and 0.5ºC per decade, with the greatest warming in interior regions. Rising temperatures were observed between 1961 and 2010 with 2001 – 2010 being the warmest period. In this study, temperature forecast is projected to increase by 1.4ºC by 2050 based on trend analysis using 2001 – 2010 as baseline values. This could imply further proliferation of the leaf miner by 2050. The study has established an upward increase in temperature, attributed to climate change, with concomitant increase in leaf miner abundance between 1980 and 2010.

The water available on earth continually cycles through the atmosphere, oceans, and terrestrial environments, mainly, through evaporation, transpiration and precipitation. During the 1979 - 1980 periods, there was no dominant weather effect on the leaf miner. However, the 2009 - 2010 periods has shown rainfall to be the dominant variable implying that its decrease could contribute to increase in abundance of the leaf miner. By 2050, some areas in sub-Saharan Africa (SSA) are predicted to have up to 10% less annual rainfall [34]. The magnitude of projected rainfall changes for 2050 [34] 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 2.47 mm in 2050 based on trend analysis using 2001 – 2010 as baseline values. High rainfall could also lead to disruption in leaf miner breeding and mortality, and decrease in rainfall levels leads to increased leaf miner abundance.

Generally, high relative humidity provides a moist environment and favors increase in insect pests and diseases. Relative humidity is an environmental factor which may affect different aspects of insect life [35]. 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 the growth of the leaf miner. The study contributes to the current global climate debate about the need for countries to curb carbon dioxide emissions and agree on policies to reduce global temperatures.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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