Journal of Entomology and Zoology Studies

Available online at www.entomoljournal.com

E-ISSN: 2320-7078
P-ISSN: 2349-6800
JEZS 2019; 7(5): 920-927

Received: 13-07-2019
Accepted: 15-08-2019

Aruna Balla
National Collateral Management Services Limited, Hyderabad, India

Bhaskar M
National Collateral Management Services Limited, Hyderabad, India

Prashant Bagade
National Collateral Management Services Limited, Hyderabad, India

Nalin Rawal
National Collateral Management Services Limited, Hyderabad, India

Corresponding Author:
Aruna Balla
National Collateral Management Services Limited, Hyderabad, India

Yield losses in maize (*Zea mays)* due to fall armyworm infestation and potential IoT-based interventions for its control

Aruna Balla, Bhaskar M, Prashant Bagade and Nalin Rawal

Abstract

Fall Armyworm, *Spodoptera frugiperda* (J.E. Smith), a polyphagous insect-pest, reported from over 50 countries across Africa and Asia in just about two years. It significantly damages maize, though over 350 host species have been reported. Its control has become a priority to scientists across continents. A study was undertaken in the Rangareddy district of Telangana to determine the effect of FAW and rainfall on yield. It was found that rainfall during critical crop growth stages showed a positive correlation of 0.595 with yield. To estimate yield during kharif 2018, rainfall data of previous twenty years was analysed. Yield during 2018 without accounting for FAW damage and during 2009 was estimated at 1.88 and 1.84 tons/ha, respectively. Further, yield losses due to FAW was estimated at 33%. Use of IoT-based technologies combined with IPM strategies will aid in tackling FAW. Taking control measures at vulnerable areas rather than as a general practice is a better alternative.

Keywords: Fall armyworm yield loss, IoT based pest monitoring, FAW interventions, remote sensing in agriculture

Introduction

Fall Armyworm (FAW), *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae), unarguably, one of the deadliest insect-pest, has been causing widespread damage particularly in Maize across Africa and Asia. Maize apart, its incidence has been reported from a wide range of host species such as Paddy [1], Sugarcane [2], Sorghum, Soybean, Millets, Vegetables, Cotton [3-5] etc. It is reported to have over 350 hosts [6] indicating the wide host range. FAW has been causing significant damage to crops resulting in huge economic losses since its appearance in Africa during 2016. Its wider adaptability, partly due to its ability to infect a wide range of species, is a cause of concern among scientists on ways to identify appropriate interventions for its effective and environmentally safe means of control. FAW is believed to have migrated from either United States of America or South America during early 2016 to Africa from where it moved to India (Figure 1), infecting over 50 countries across two continents in just over a period of two years. It has been predicted to invade other regions of the world such as Australia, China, Indonesia, Malaysia, Philippines and Thailand. [7] Among Asian countries, apart from India, Sri Lanka, Bangladesh, Myanmar, Malaysia, Vietnam, Thailand, China and Indonesia have already reported appearance of FAW. Figure 2 shows the spread of FAW in Africa and Asia since 2016. As of March 2019, it has been reported from 10 states in India - Andhra Pradesh, Bihar, Chhattisgarh, Gujarat, Karnataka, Maharashtra, Orissa, Tamil Nadu, Telangana, and West Bengal [8] since its first appearance in Karnataka during May 2018 [9]. However, there have been reports of its spread to other Indian states – Rajasthan, Arunachal Pradesh, Assam, Manipur and Mizoram. Favourable weather conditions play a major role in FAW dispersal and subsequent infestation.

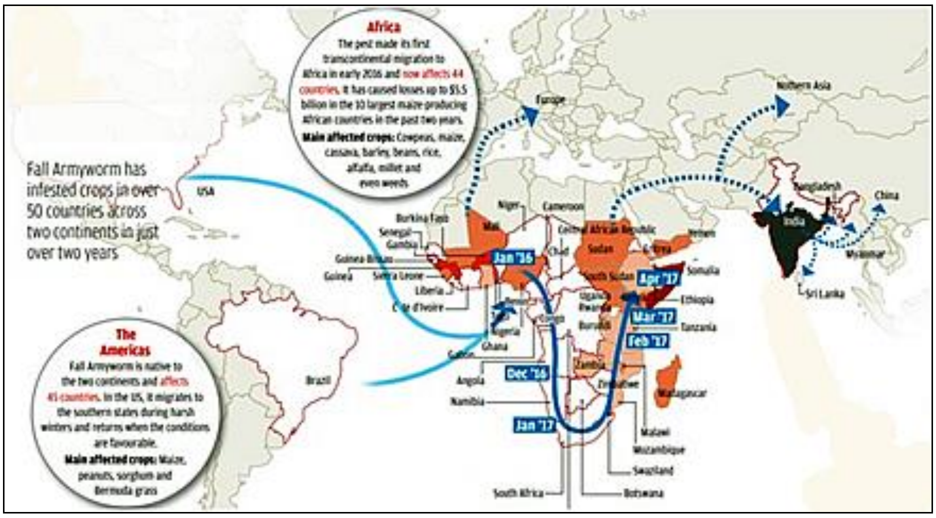

Fig 1: Migratory pattern of Fall Armyworm (Source: https://www.downtoearth.org.in)

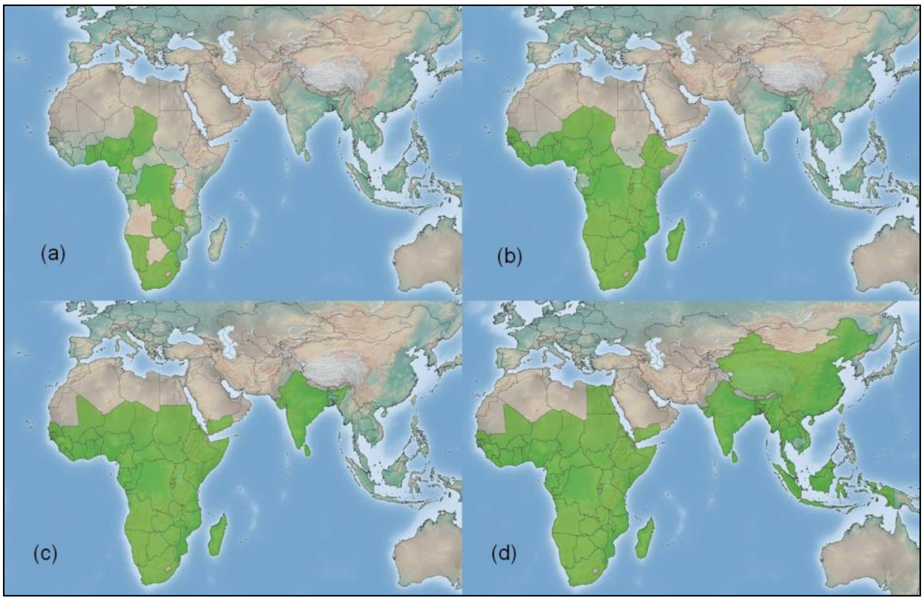

Fig 2: Spread of Fall Armyworm since 2016 in Africa and Asia. [a] 2016, [b] 2017, [c] 2018, [d] June 2019. (Source: Centre for Agriculture and Bioscience International, CABI)

Considering the economic losses being caused by FAW and the widespread damage resulting from its infestation across countries, it is imperative that effective interventions be identified and implemented. Food and Agriculture Organization (FAO) has declared FAW as food security threat in the African continent indicating the importance of finding effective solutions for controlling FAW. A pilot study was undertaken during kharif 2018 in Rangareddy and Nagarkurnool districts of the state of Telangana, India to estimate yield losses in Maize. Since FAW was not a threat at the time of initiation of the study, it was not intended to estimate losses specifically due to FAW. But as the season progressed, FAW emerged as a potentially major threat to Indian corn after causing huge losses across Africa. Due to its emerging importance, yield losses attributable to FAW were estimated as a secondary objective. Currently, scientists are trying to figure out the best control mechanisms against FAW. Though potential chemical and biological controls are available, it is important to establish economic threshold limits prior to adopting such options. Due to the fact that favourable weather conditions are essential for the FAW to cause damage, effective interventions can be monitoring of weather conditions and crop health using IoT-based technologies such as Remote sensing, GIS etc to aid integrated pest management practices. This article discusses the yield losses in maize in the Rangareddy district of Telangana state and potential use of IoT-based interventions that can be implemented to monitor spread of FAW so that effective and economical control measures can be initiated with due consideration for environmental safety.

2. Materials and Methods

2.1 Study area: The Rangareddy district (Figure 3), spreads approximately 16°-30′ and 18°-20′ North altitude and 77°-30′ and 79°-30′ East longitudes. It is bound by Medak district in north, Nalgonda district in east, Mahaboobnagar district in south and Gulbarga district of Karnataka on the west. A large portion of the district is composed of high-grade laterite soils. The main river of the district is Musi, which rises in the Ananthagiri hills near Sivareddipet village. The climate in the district is characterized by hot summer and is generally dry except during the Southwest monsoon season. The average rainfall in the district is 543 mm, bulk of which is received through the Southwest monsoon during June to September. Red soils are predominant in the district followed by black cotton soils.

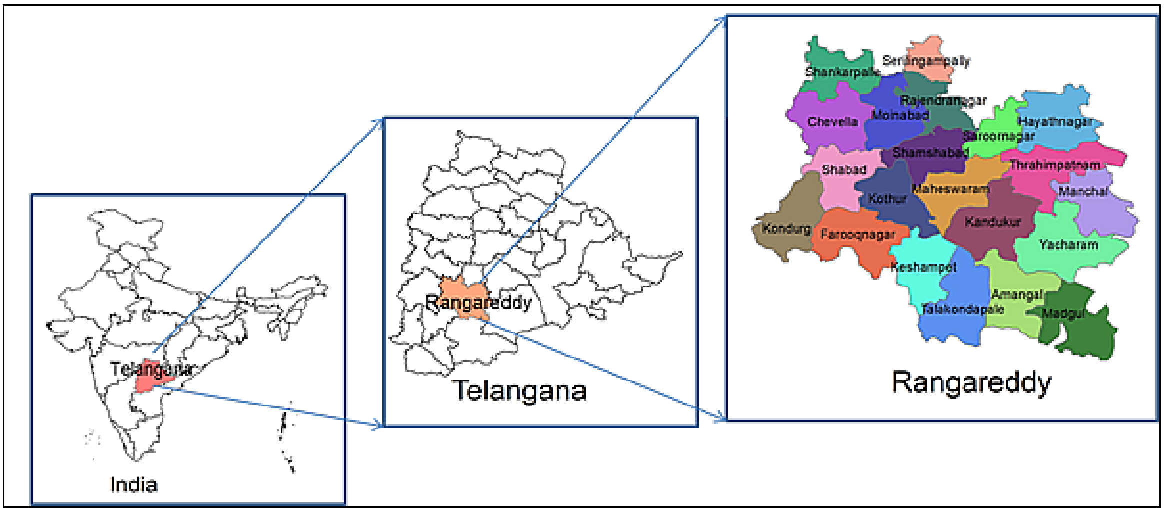

Fig 3: Study area

2.2 Rainfall pattern Analysis: Rainfall data was sourced from Indian Meteorological Department (IMD) gridded rainfall data based on average rainfall during the years 1960 – 2010. Average rainfall was estimated by writing a code in statistical software RExcel® from IMD's gridded historical data. Further, matching of rainfall trend was performed by comparing the rainfall pattern against that of previous twenty years. Pearson correlation analysis were performed on the data sets of rainfall occurred during southwest monsoon period, i.e., June through September of year in study with that of historical rainfall trends during the same period. Yields in rainfed areas were estimated on the basis of both "best match" and primary data obtained from field surveys. Apart, average yield during normal rainfall receiving years is also calculated and compared with the "best match year" rainfall. Methodology adopted in this study is depicted in Figure 4.

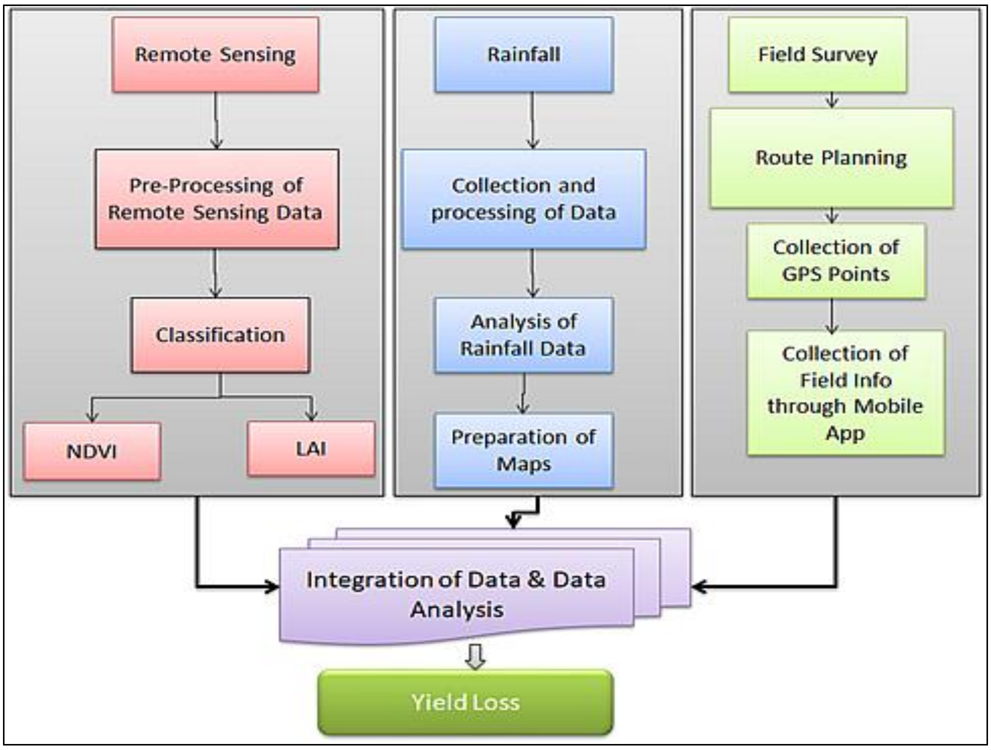

Fig 4: Flow chart of the methodology

2.3 Remote Sensing: The most commonly used index to assess the vegetation condition is the Normalized Difference Vegetation Index (NDVI). It along with and leaf area index (LAI) are primary indices that have been used for mapping and monitoring drought and assessment of vegetation health and productivity. Crop monitoring at regular intervals of crop growth is necessary to take appropriate measures and to know the probable loss of production due to any stress factor. The crop growth stages and its development are influenced by a variety of factors such as available soil moisture, date of planting, air temperature, day length, soil condition etc. These factors are responsible for the plant conditions and their productivity. The crop yield is dependent on many factors such as crop variety, water and nutrient status of field, influence by weeds, pest and disease infestation, weather parameters. The spectral response curve is dependent on these factors. The growth and decay in the spectral response curve indicates the crop condition and its performance. For example, the spectral reflectance in the visible region will be higher in water stressed crop than the non-stressed. The vegetation indices like NDVI and LAI will be lower for stressed and higher for non-stressed crop.

Normalized Difference Vegetation Index quantifies vegetation by measuring the difference between near-infrared (which vegetation strongly reflects) and red light (which vegetation absorbs). NIR and red channels are used in NDVI calculation, formula for which is given below:

$$NDVI = \frac{(\text{NIR} - \text{Red})}{(\text{NIR} + \text{Red})}$$

Healthy vegetation (chlorophyll) reflects more near-infrared (NIR) and green light compared to other wavelengths. But it absorbs more red lights. The result of this formula generates a value between -1 and +1. A low reflectance (or low values) in the red channel and high reflectance in the NIR channel will yield a high NDVI value and vice versa. Overall, NDVI is a standardized way to measure healthy vegetation. Higher NDVI values result in healthier vegetation.

Leaf area index (LAI), the total one-sided green leaf area per unit of ground surface, is an important structural property of vegetation. Because leaf surfaces are the primary sites of energy and mass exchange, important processes such as canopy interception, evapotranspiration, and gross photosynthesis are directly proportional to LAI. It is a critical parameter in many agriculture related studies like crop health and yield estimation studies. The vegetation canopy structure, including the LAI, directly influences the radiative transfer process of sunlight in vegetation and, therefore, determines the radiometric characteristics of the top of the canopy (TOC), such as reflectance. Remote-sensing methods estimate the canopy LAI based on its relationship with TOC radiometric information, such as the statistical relationship between the TOC reflectance and the LAI, or from the outputs of physical canopy radiative transfer models.

Surface Soil Moisture (SSM) is the relative water content of the soil surface describing how wet or dry the soil is in its topmost layer, expressed in percent saturation. It is measured by satellite radar sensors and allows insights in local precipitation impacts and soil conditions. SSM is a key driver of water and heat fluxes between the ground and the atmosphere, regulating air temperature and humidity. Moreover, in its role as water supply, it is vital to vegetation health. Vice versa, SSM is very sensitive to external forcing in the form of precipitation, temperature, solar irradiation, humidity, and wind. Thus, it is both an integrator of climatic conditions and a driver of local weather and climate, and plays a major role in global water-, energy- and carbon-cycles. Knowledge on the dynamics of soil moisture is important in the understanding of processes in many environmental and socio-economic fields, e.g., its impact on vegetation vitality, crop yield, droughts or exposure to flood threats. Soil Moisture is recognized as an Essential Climate Variable (ECV) by the Global Climate Observing System (GCOS).

2.4 Image collection and processing: Moderate Resolution Imaging Spectroradiometer (MODIS) satellite images obtained at a resolution of 250m were used for determining NDVI. These images were acquired on 28th of each month starting from June to October 2018. The MOD15A2H Version 6 (MODIS) was used for obtaining images at a resolution of 500m and were used for determining Leaf Area Index (LAI) and Fraction of Photosynthetically Active Radiation (FPAR). These images were acquired on June 26th, July 28th, August 29th, September 30th, and October 24th, 2018. Images acquired from Soil Moisture Active Passive (SMAP) satellite were used for obtaining soil moisture data. These images were acquired on June 26th, July 28th, August 29th, September 30th, and October 24th, 2018.

3. Results and Discussion:

Crop yield, to a great extent, depends on the amount and spread of rainfall. Optimum levels of soil moisture during critical stages of crop growth, usually result in better crop yields provided other factors such as diseases and insect-pests do not cause significant damage. Month-wise rainfall during southwest monsoon season of 2018 in Rangareddy district compared with normal rainfall amounts are given in Table 1. From the table it is evident that during the month of June, rainfall was normal during both 2009 and 2018. While rainfall amounts during the critical crop growth periods of July and September in both the years were either "deficit" or "large deficit", possibly resulting in lower crop yields. Since the spread of rainfall is a critical component in affecting crop yield, rainfall deviations on a weekly basis during the entire crop growing season were determined. Figure 5 shows the deviations in rainfall compared to normal along with stages of maize crop. Water stress conditions were observed during most of the crop growing season including critical stages of germination to emergence and grain filling resulting in significantly lower yields compared to average yield in the district.

Table 1: Rainfall statistics during kharif 2018 (Source: India Meteorological Department)

Month & Year →	**June**		**July**		**August**		**September**		**Cumulative**	
	2009	**2018**	**2009**	**2018**	**2009**	**2018**	**2009**	**2018**	**2009**	**2018**
Actual (mm)	111.5	103	53.1	102.7	317.1	130.9	96.4	50.3	578.1	386.9
Normal (mm)	93.2	93.2	148.7	148.7	143.7	143.7	158.1	158.1	543.7	543.7
Departure (%)	19.6	10.5	-64.3	-30.9	120.7	-8.9	-39.0	-68.2	6.3	-28.8
Category #	N	N	LD	D	LE	N	D	LD	N	D

N – Normal; D – Deficit; LD – Large Deficit; E – Excess; LE – Large Excess.

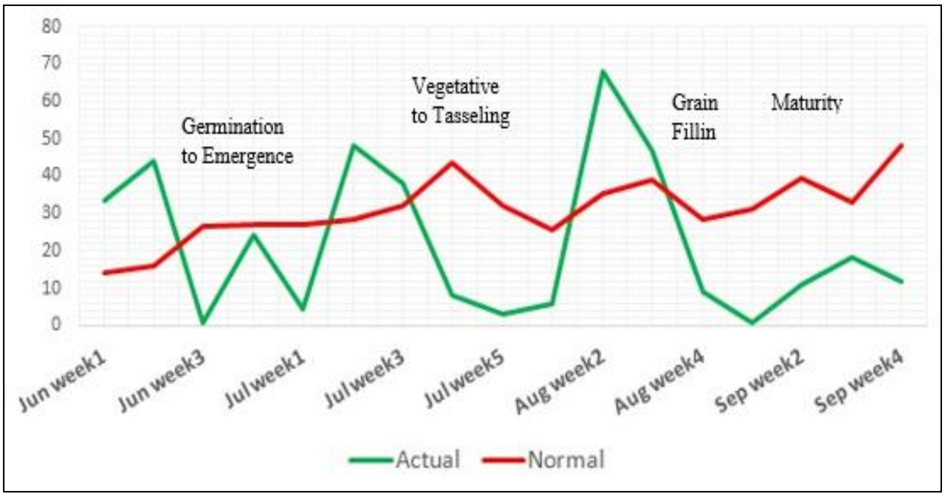

Fig 5: Weekly rainfall departures from normal during kharif 2018 in Rangareddy district

In Rangareddy district, maize yields are normally about 3 tons/ha. However, during kharif 2018, as per the model developed by National Collateral Management Services Limited (NCML), it was estimated at 1.26 tons/ha (Table 2). The drastic reduction of over 50% is attributable to two important factors – Rainfall deficiency and Fall Armyworm infestation. To determine whether the yield reduction is only due to deficient rainfall or other factors including FAW infestation, rainfall pattern analysis of last twenty years was performed. Rainfall pattern of 2018 showed a very close match with that of 2009 (Figure 6). Rainfall amount during 2009 and 2018 was recorded as 578.11 and 386.9 mm respectively while maize yields during corresponding years were 1.84 tons/ha and 1.26 tons/ha (2018 yield as estimated by NCML). Effect of rainfall on yield was analysed by determining correlation coefficients (r^2) between cumulative rainfall and yield after excluding outliers. A data point is considered as an outlier if its value is outside Mean ± 1 x Standard deviation. While calculating cumulative rainfall, if a data point in any month is found to be an outlier, data from remaining months was also not considered in calculation of cumulative rainfall as it would have already influenced the yield. Usually, sowing occurs during June but depends upon the onset of monsoon and availability of sufficient soil moisture. But, crop critical period starts about two weeks after sowing when availability of sufficient soil moisture results in normal crop growth while deficiency in rainfall would lead to stunting resulting in yield reduction. Since the stages of germination and emergence could vary between the months of June and July, cumulative rainfall of these two months was used for calculating r^2 value. It showed a r^2 value of 0.23 with yield indicating positive effect of rainfall on yield, though not to a high degree since yield is a complex parameter and depends on many factors. As can be seen from Figure 5, grain filling stage is another critical stage of the crop growth which requires sufficient soil moisture and falls during the month of September. Correlation between rainfall amount during September and yield showed a r^2 value of only 0.067 indicating that the amount of rainfall during September didn't had much effect on yield. Also, availability of soil moisture from August rainfall would have provided required moisture for normal crop growth. However, as predicted, combined rainfall of July and September showed r^2 value of 0.595 with yield indicating that rainfall during the critical stages of crop growth is linked positively with yield. As expected, correlations between yield and cumulative rainfall is found to be very low (0.085) since yield is a very complex parameter and is influenced by a variety of factors including their timing. Nevertheless, rainfall amount and spread are the most important factors for yield.

Yield losses of 28 – 40% were reported by Cakir [10] depending upon growth stage of the crop and up to 93% during prolonged water stress conditions. Similarly, Ghooshchi et.al. [11], reported yield losses of up to 42% due to water deficit.

Table 2: Month-wise rainfall and Maize yields during kharif of 1998 to 2018 in Rangareddy district

Year	Rainfall (mm)#					Yield (Tons/Ha)^
	Jun	Jul	Aug	Sep	Cumulative JJAS	
1998	63.18	253.50	281.00	201.01	798.69	2.42
1999	59.90	162.57	88.54	105.24	416.26	1.92
2000	235.44	127.52	308.04	85.73	756.74	1.96
2001	157.92	52.04	188.23	175.96	574.16	2.03
2002	117.30	71.21	192.89	46.20	427.60	2.62
2003	84.42	207.51	231.28	102.18	625.39	4.23
2004	45.89	191.99	61.52	113.41	412.81	2.62
2005	71.52	296.04	137.13	212.82	717.52	3.58
2006	72.88	116.49	160.10	170.71	520.18	2.78
2007	150.53	116.47	195.99	223.86	686.84	4.42
2008	96.37	109.09	359.07	163.52	728.04	2.47
2009	111.47	53.09	317.11	96.44	578.11	1.84
2010	155.22	276.22	255.36	188.98	875.78	1.93
2011	54.82	189.11	185.40	37.21	466.54	1.73

2012	131.29	192.59	114.77	116.51	555.16	3.83
2013	115.56	226.82	143.82	209.26	695.46	3.46
2014	51.52	137.59	273.46	100.59	563.16	2.88
2015	130.94	71.23	130.27	129.21	461.66	3.79
2016	165.23	194.78	182.79	314.60	857.40	3.14
2017	198.82	123.04	159.46	138.83	620.16	2.16
2018	103.00	102.70	130.90	50.30	386.90	1.26*

Source: Indian Meteorological Department (IMD)
^ Source: Ministry of Agriculture and Farmers Welfare
* Estimated by National Collateral Management Services Limited

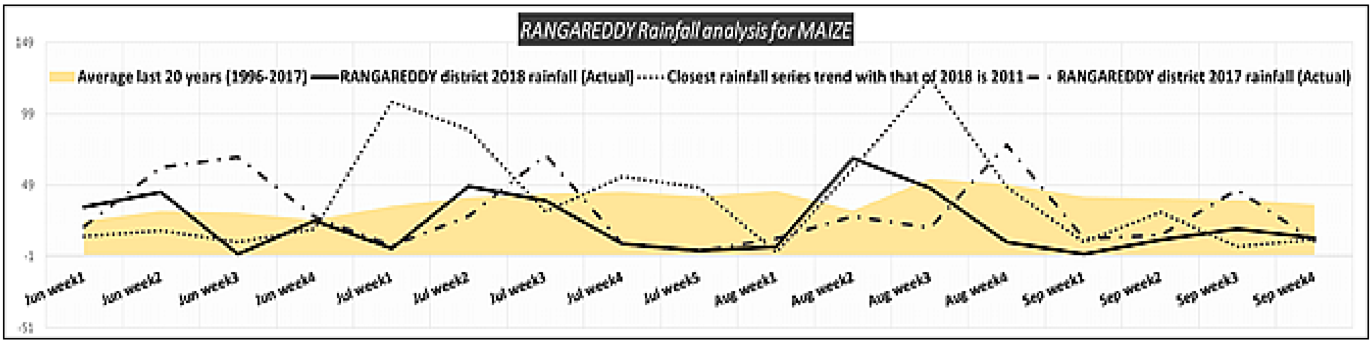

Fig 6: Rainfall pattern analysis

Combined rainfall during the months of July and September of 2009 and 2018 are 149.53 and 153 mm, respectively. Since the rainfall pattern and amounts are almost same during these two years apart from a good correlation between these parameters, it is predicted that the yield would also be similar. Such predicted yield was at 1.88 tons/ha assuming absence of significant losses due to insect-pests including Fall Armyworm compared to 1.84 tons/ha during 2009. Further, yield was estimated at 1.26 tons/ha using the yield estimation model. The reduction is attributable to damage due to FAW since no other significant insect-pest or disease damage was observed. From these observations, yield loss of 33% is attributed to FAW infestation. Due to its recent introduction in India, no yield loss estimates are available in India. further studies would be required to determine yield losses that can result from FAW. However, a study [12] from Zimbabwe reported yield losses of 32 – 48% in maize due to FAW. Losses in the range of 22 to 67% were reported from Ghana and Zambia [13] while Ethiopia and Kenya reported yield losses of 32% and 47% [14], respectively. Our findings are similar to these studies reported from Africa. Though the results of this study are based on data from one district and from only one season, based on various reports available across the countries, it can be safely interpreted that FAW has been causing significant yield losses. However, further refinement in the models would be required to determine yield losses with higher precision.

IoT-based technologies such as remote sensing and GIS were used for monitoring Normalized Difference Vegetation Index (NDVI) and Leaf Area Index (LAI) which gives an indication of the crop health condition. These parameters were analysed along with soil moisture during crop growing season. Figure 6 shows the images obtained through remote sensing.

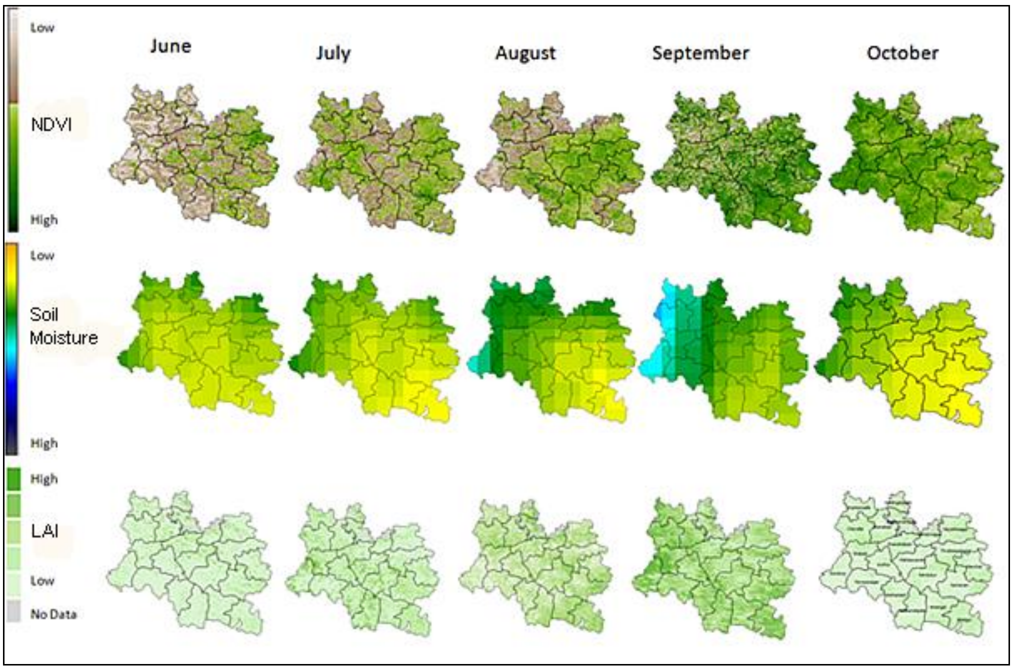

Fig 7: Satellite images showing NDVI, LAI, and Soil Moisture during kharif 2018

Satellite images of NDVI, LAI, and Soil moisture acquired during southwest monsoon season of 2018 are shown in Figure 7. Intensity of green colour is proportional to NDVI. From the figure it is clear that there has been a gradual increase in the intensity of green colour from June to September. It is due to the fact that crop sowing occurs during the month of June and there will be gradual increase in vegetation in the subsequent months. The crop is usually harvested in the month of October when ideally greenness would decrease. Upon closer observation of October month's NDVI, image shows that though there is an increase in the green area, the intensity has decreased. It indicates that lighter green colour are the newly sown crop areas and the dark green areas seen in the month of September have been harvested. Similar pattern is observed for LAI also as the leaf area increase gradually after sowing till maturity at which time the greenhouse will be reduced as indicated by almost complete absence of greenness in October 2018 image. Yellow colour in the image represents lower levels of soil moisture content. While gradual increase is represented by green and cyan colours. The satellite images indicate a clear increase in soil moisture content from June to September 2018. However, in the image obtained during October 2018, there is a clear decrease in soil moisture content as can be seen by lack of cyan colour and also reduced green colour as compared to yellow areas.

Currently, FAW can be controlled, with varying degree of success, by adopting different approaches according to many available reports. These include chemical pesticides, biological controls, natural enemies, "Push-Pull" companion cropping [15], cultural & landscape management approaches [16] and use of pheromone traps. Though the effectiveness of various control options is being evaluated, it is important to develop effective interventions that are environmental-friendly for controlling FAW. Since lot of research has been done on the harmful effects of chemical pesticides on human health, it is advisable to be diligent on their usage. It is ideal to minimise the use of pesticides and opt for non-chemical based controlling options. At all costs indiscriminate use of pesticides should be avoided. It would be effective to predict migration of the pest based on weather forecasting. Crop monitoring using IoT-based technologies such as Remote sensing and GIS will help to determine the crop health which will serve as an indicator on any pest infestation. Such obtained information, after processing, can be combined with IPM strategy and issued as advisories through NGOs, KVKs etc for effective control FAW. Necessary control options can be exercised based on these advisories for an effective control of FAW. It is important to note that the IoT-based technologies are not an alternative to the control mechanisms but aid in taking controlled and need-based actions.

4. Conclusions

It can be concluded from the study that Fall Armyworm is a destructive pest which causes drastic yield losses in Maize during favourable weather conditions. Excessive application of synthetic pesticides without regard for environment and human health is neither advisable nor sustainable. To prevent indiscriminate use of pesticides / insecticides for controlling the damage, it is advisable to monitor weather conditions for initiating control measures in infestation-prone areas since FAW can cause damage only under favourable conditions. Apart, use of IoT based technologies such as Remote sensing, GIS etc can be utilised for monitoring crop health so that control measures can be taken up in vulnerable areas rather than as a general practice. FAW management must be driven by considering agro-ecological conditions, cropping systems, socio-economic conditions etc since it involves an integrated approach. Hence, exploitation of these technologies along with weather monitoring and forecasting, in conjunction with IPM strategies, will aid in effective intervention for controlling FAW infestation.

5. Acknowledgements

Authors would like to express their gratitude to Mr. Ankur Gupta for performing statistical analysis. They would also like to acknowledge the support provided by NCML's management for undertaking this study.

6. References

1. Sarfaraz Ali, Zakkia Masroor, Mohammad Danish Masroor. First record of the fall armyworm, *Spodoptera frugiperda* (J. E. Smith, 1797) (Lepidoptera: Noctuidae), an evil attack on paddy in Magadh, Bihar (India). International Journal of Emerging Technologies and Innovative Research, 2018; 5(12):546-549.
2. Ankush Chormule, Naresh Shejawal, Sharanabasappa, Kalleshwaraswamy CM, Asokan R, Mahadeva Swamy HM. First report of the fall Armyworm, *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera, Noctuidae) on sugarcane and other crops from Maharashtra, India. Journal of Entomology and Zoology Studies. 2019; 7(1):114-117.
3. Pogue MA. World revision of the genus *Spodoptera* Guene´e (Lepidoptera: Noctuidae). Memoirs of the American Entomological Society. 2002; 43:1-202.
4. Chapman JW, Williams T, Martõ Ânez AM, Cisneros J, Caballero P, Cave RD. Does cannibalism in *Spodoptera frugiperda* (Lepidoptera: Noctuidae) reduce the risk of predation? Behavioral Ecology and Sociobiology. 2000; 48:321-327. doi: 10.1007/s002650000237.
5. CABI. Datasheet. *Spodoptera frugiperda* (fall armyworm). Invasive Species Compendium, 2016. http://www.cabi.org/isc/datasheet/29810 (Date of access: 05/07/2019).
6. Ramesh Babu S, Kalyan RK, Sonika Joshi, Balai CM, Mahla MK, Rokadia P. Report of an exotic invasive pest the fall armyworm, *Spodoptera frugiperda* (J.E. Smith) on maize in Southern Rajasthan. Journal of Entomology and Zoology Studies. 2019; 7(3):1296-1300.
7. Early R, González-Moreno P, Murphy ST, Day R. Forecasting the global extent of invasion of the cereal pest *Spodoptera frugiperda*, the fall armyworm. 2018. NeoBiota.
8. EPPO Reporting Service No. 03 – 2019. Num. article: 2019/053.
9. Sharanabasappa, Kalleshwaraswamy CM, Asokan R, Mahadeva Swamy HM, Maruthi MS, Pavithra HB *et al*. First report of the fall armyworm, *Spodoptera frugiperda* (J.E.Smith) (Lepidoptera, Noctuidae), an alien invasive pest on maize in India. Pest Management in Horticultural Ecosystems. 2018a; 24:23-29.
10. Cakir R. Effect of water stress at different development stages on vegetative and reproductive growth of corn. Field Crops Research. 2004; 89:1-16.
11. Ghooshchi F, Seilsepour M, Jafari P. Effects of Water Stress on Yield and Some Agronomic Traits of Maiz [SC 301]. American-Eurasian J Agric. & Environ. Sci. 2008;

4(3):302-305.

12. Baudron F, Zaman-Allah MA, Chaipa I, Chari N, Chinwada P. Understanding the factors conditioning fall armyworm (*Spodoptera frugiperda* J.E. Smith) infestation in African smallholder maize fields and quantifying its impact on yield: a case study in Eastern Zimbabwe. Crop Protection. 2019; 120:141-150.
13. Day R, Abrahams P, Bateman M, Beale T, Clottey V, Cock M *et al*. A. Witt. Fall armyworm: impacts and implications for Africa. Outlooks Pest management. 2017; 28:196-201.
14. Kumela T, Simiyu J, Sisay B, Likhayo P, Mendesil E, Gohole L *et al.* Farmers' knowledge, perceptions, and management practices of the new invasive pest, fall armyworm (*Spodoptera frugiperda*) in Ethiopia and Kenya. Int. J. Pest Management, 0874 2018, 1-9.
15. Midega CAO, Pittchar J, Pickett JA, Hailu G, Khan ZR. A climate-adapted push-pull system effectively controls fall armyworm, *Spodoptera frugiperda* (J.E. Smith), in maize in East Africa. Crop Protection. 2018; 105:10-15.
16. Prasanna BM, Joseph Huesing E, Regina Eddy, Virginia MP. Fall armyworm in Africa: A Guide for Integrated Pest Management, First Edition. Mexico, 2018.