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Population dynamics of the fall armyworm moth on over the 2017/18 cropping season at Chiredzi Research Station in the south eastern Lowveld of Zimbabwe

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ABSTRACT

Fall armyworm (Spodoptera frugiperda) has been a pest of occasional importance in the agricultural sectors of the south eastern Lowveld since 2016 with sporadic outbreaks often developing rapidly in maize and sorghum, and resulted in severe defoliation. Fall armyworm adult moths were captured in pheromone trapsbaited with an insecticide strip containing 10% 2.2-dichlorovinyl dimethyl phosphate over a 12 month period at Chiredzi Research Station. Monthly catches collected daily from traps placed in the main irrigated block showed a population rise at the start of the summer season (August-October), a fall in November followed by a sharp rise in the last half of December. Fall armyworm moth distribution during these periods varied significantly, suggesting seasonal population patterns. These results represent an indication that the fall armyworm strain might have a substantially population dynamic in the agricultural vicinity of Chiredzi Research Station. Evidence from data collected suggest that the army worm moth was predominant during the onset of the summer periods. It further indicates that the worm can display a markedly different response to seasonal environmental cues.

Key words

Population dynamic, fall armyworm, damage, pheromone trap, forecast, yield

1. INTRODUCTION

The fall armyworm (*Spodoptera frugiperda*) is a species in the order of Lepidoptera. The term "armyworm" can refer to several species, often describing the large-scale invasive behaviour of the species' larval stage. It is regarded as a pest and can damage and destroy a wide variety of crops, which causes large economic damage. Its scientific name derives from *frugiperda,* which is Latin for *lost fruit*, named because of the species' ability to destroy crops (Croxton *et al.*, 1968). Because of its propensity for destruction, the fall armyworm's habits and possibilities for crop protection have been studied in depth. It is also a notable case for studying sympatric speciation, as it appears to be diverging into two species currently (Groot *et al*., 2010). Another remarkable trait of the larva is that they practice cannibalism. The fall armyworm (FAW), *Spodoptera frugiperda*, is native to the Americas and arrived in Africa in early 2016. Since its arrival, it has moved quickly and is now in over 25 African countries including Ethiopia, Kenya, Niger, Tanzania and Zimbabwe (FAO, 2017). The pest has the potential to cause significant damage and yield loss to over 80 plant species, including maize, rice, and sorghum. Already, it is estimated that it will cause over $3 billion in damage to maize throughout Africa in regions that are already food insecure (FAO, 2017).

The fall armyworm (*Spodoptera frugiperda* (JE Smith); *Lepidoptera*, *Noctuidae*) was first reported as present on the African continent in January 2016 (Goergen, 2016). Subsequent investigations have revealed the pest in nearly all of sub-Saharan Africa (SSA), where it is causing extensive damage, especially to maize fields and to a lesser degree sorghum and other crops. Currently, over 30 countries have identified the pest within their borders including the island countries of Cape Verde, Madagascar, São Tomé and Príncipe, and the Seychelles. The best evidence to date suggests that the FAW type introduced into Africa is the haplotype originating from south Florida (USA) and the Caribbean (Cook *et al*., 2017). The location(s), date(s), mode, and number of introductions are not known at present but anecdotal observation and the response of single-gene genetically modified Bt maize in South and East Africa suggests it has been present for at least several years (EUROPHYT, 2017). The generally hospitable agro ecological conditions for FAW in SSA suggest that FAW will establish as an endemic, multigenerational pest in Africa. Though new agricultural pests are periodically introduced into the African agricultural environment and pose some degree of risk, a number of characteristic factors make FAW a more devastating pest than many others:

Moths generally disperse about 500 km (300 miles) before oviposition, which is sufficient to move from seasonally dry habitats to wet habitats (Johnson, 1987). They fly downwind, above the boundary layer (the lowest part of the atmosphere, above which the wind direction and strength may be different), so the direction of movement depends largely on prevailing winds. When the wind pattern is right, moths move much larger distances: for example, 1,600 km (Rose *et al*., 1975). Clearly, FAW has the potential to spread rapidly across Africa: at least 500 km per generation, with a suitable wind. As yet, the literature review undertaken by CABI has found little evidence regarding what triggers adult dispersal, or indeed whether it is a feature of every generation.

Similarly, no studies have been found on whether part of each generation remains in situ, or whether the entire generation disperses. It seems likely that dispersal is triggered by the level of crowding experienced by the larvae, but this has not been tested. This makes it difficult to make robust forecasts of the likely pest problem in the next cropping cycle. Anecdotal observations from South America indicate that there is poor correlation in FAW populations from one crop season to the next *(Y. Colmanarez, pers comms.).* There may also be geographical or strain differences in this behaviour. It has been assumed that FAW disperse on wind-assisted flights until they are sexually mature and ready to mate (Rose *et al*., 1975), but we have not found any definitive studies on this aspect. However, this seems likely and would explain why males disperse alongside females. It is regularly intercepted in intercontinental trade (CABI, 2017, EUROPHYT, 2017). It has now appeared in Africa (Goergen *et al.*, 2016, Cock *et al.*, 2017) and is rapidly spreading throughout tropical and subtropical regions of the continent.

Reports related to the relationship between date and damage by FAW in commercial maize have been published in other countries, (Willink *et al*., 1983a, Willink *et al*., 1983b), and (Sosa, 2002a, Sosa, 2002b). Studies related with the population dynamics of FAW at Chiredzi Research Station, and how environmental factors affect this phenomenon were not previously reported at Chiredzi Research Station. Understanding the factors that influence the distribution and abundance of an insect is a fundamental issue of insect ecology and is a practical concern with insects that cause economic damage (Basksuf, 2003). Insect population dynamics have fundamentally different characteristics depending on the strength and form of exogenous (density-independent) versus endogenous (density-dependent) forces.

To date, development and implementation of a coordinated, evidence-based effort to control fall armyworm in at the station has faced a number of challenges. In particular, fall armyworm is a recently introduced pest. Therefore, scouting by farming communities and effective monitoring at the station, ward and district levels are limited. Farmers have differing perceptions on awareness and adaptations strategies (Esau *et al*., 2017). In addition to delaying recognition of the pest's movement through farming communities, this lack of surveillance, monitoring, and scouting capacity has delayed efforts to determine several key unknowns about fall armyworm populations on the farming communities and the dynamics of the pest's establishment and spread.

The lessons learned from the invasive pest should be identified quickly because they are important for monitoring and interception of this invasive pest as well as other future invasive pests. Thus the objective of this research work is to develop and come up with a coordinated, evidence based effort in the management of fall armyworm in the South eastern Lowveld of Zimbabwe.

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2. MATERIALS AND METHODS

2.1 Study location

The study was carried out at Chiredzi Research Station *(21^{0}01'S, 31^{0}33'E* 429 m above sea level*)* located in the South-Eastern Lowveld (agro-ecological region 5) of Zimbabwe. Its temperatures ranges from 29 – 39 ^{0}C and can reach up to 42^{0}C. The area receives rainfall totals of 450-650 mm year round. The low latitude of 1200-1500 ft *a.s.l* is an effective safeguard against frost in all but the extreme circumstances. Minimum temperatures tend to run low in winter and frost can occur in low lying areas. Triangle PE1 series such as shallow sandy clay soils dominate (Vincent and Thomas, 1960, Mugandani *et al*., 2012). Moth collection was done in the irrigated main block from mid-June 2017 to May 2018.

2.2 Pheromone Confirmation

Standard tricolour plastic trap (green top, yellow funnel, white bucket) baited with *an insecticide strip containing 10% 2.2-dichlorovinyl dimethyl phosphate* a commercially available fall armyworm pheromone were placed mid-June 2017 to May 2018 and collections were made on a daily basis. The trap was hung from a suspended pole or branch about 1.5 m above the ground.

The traps were checked on a daily basis by counting the number of fall armyworm moths inside by:

1. Opening the bucket trap by an anti-clockwise twisting of the low transparent bucket at the bottom of the trap while holding firmly the yellow funnel on top
2. Create a clean flat surface and invert the bucket to pour out the moths onto this surface
3. Remove any non-fall armyworm moths and insects that may have been caught in the trap
4. Carefully count the number of fall armyworm moths by putting counted ones to one side
5. If you in doubt as to whether the moth is fall armyworm, then compare a sample provided on a chart for ease of identification.

The pheromone lure was usually replaced every 3–6 weeks to achieve optimum results, depending on temperature, humidity and pheromone components and release characteristics. Unopened pheromone dispensers were stored within an air-tight bag(s), tightly sealed glass containers or foil pouches, preferably inside a refrigerator or freezer to achieve up to two years shelf life. Pheromones degrade rapidly if exposed to bright light or high temperatures. Therefore, dispensers were kept inside their sealed packaging until ready to use. To activate the bucket trap, the lure is placed into the red rubber septum and then put the septum in the green coloured receptacle. The receptacle is then plugged into a hole on top of the green cap, which provides the roof of the bucket trap. The receptacle is then covered by a white lid. During lure replacement, the receptacle cap is simply removed and the rubber septa inserted into it.

2.3 Meteorological data collection

Daily temperature records were obtained from a meteorological station found at the station. Other records that were collected include monthly rainfall figures, wind speed as well as humidity.

2.4 Data analysis

Regression analyses were performed to determine the relationship between fall armyworm populations with temperature, wind speed, humidity and rainfall (Diez, 2001, Schliserman, 2001) by a stepwise approach. For the analyses, the mean of low and high temperatures, humidity, wind speed and mean rainfall during the sampling month, were used. From these data it was possible to estimate the month in which the environmental factors most affected the fall armyworm populations.

The Pearson correlation coefficient (CABI, 2017b, Dietrich, 1991 and FAO, 2017) was used to quantify the association between variables such that the relationship between an outcome variable (catches) and associating factors or confounding variables (rainfall, temperature, humidity and wind speed) can be tabulated.

Correlation coefficient ‘r’ was calculated using the following formula:

$$r = \frac{n\Sigma xy - \Sigma x \Sigma y}{\sqrt{\{n\Sigma x^2-(\Sigma x)^2\}\{n\Sigma y^2-(\Sigma y)^2}}$$

Where, *x* and *y* are values of variables, and *n* is size of the sample.

The value of correlation coefficient is interpreted in the following manner:

If ‘r’ is equal to 1, then there is perfect positive correlation between two values;

If ‘r’ is equal to -1, then there is perfect negative correlation between two values;

If ‘r’ is equal to zero, then there is no correlation between the two values.

3. RESULTS

3.1 Population dynamics of the fall armyworm moth in response to the environment over the 2017-18 season

The general trend of the distribution of the fruit fly across seasons indicate a rise in the total mean catches from August to September (Fig 1) coupled by a sudden drop in the months of October and November. This was followed by a sharp rise in the number of catches between November and December. However in January and February, the total number of catches remained low and rose again between May and June of the preceding season. December recorded the highest number of more than 200 catches over the trapping period, while low catches of below 10 moths per day were recorded in July, November and February.

3.2 Effect of temperature and humidity on adult fall armyworm moth catches

Due to rises in humidity and temperature, moth populations rose in the months of August and Sept. Moth populations dropped in September and November but temperature and humidity remained constant.A sharp rise of temperature (Fig 2) from 23 to 26 in the months of November and December resulted in a sharp rise in the number of catches from 9 to 232 over the trapping period.Moth populations drastically dropped in December, January and February.Populations rose again in February though temperature was dropping and moth populations remained on a rising mode over the preceding winter months.

3.3 Effect of rainfall and wind speed on adult fall armyworm moth catches

Despite low rainfall and wind speed in July, August and September, moth populations rose.A drop in moth population coincided with rainfall increase in September and November.Due to high rainfall (Fig 3) and low wind speed in January, moth populations dropped implying that wind responsible for migration of the fall armyworm moth. High rainfall total in December and January led to drops in the moth populations over the current months. Low rainfall and low wind speed as winter months approached led to increase in moth populations at the station

3.5 Correlation of fall armyworm moths to weather elements

A positive relationship (Fig 4) existed in the distibution of the fall armyworm moth between temperture (r =0.567) and wind speed (r = 0.643). Though weak, a positive relationship was also observed between rainfall (r =0.326) and humidity (0.463). This imply that all the weather elements had a positive influence in as far as the distribution of the moth over the season was concerned

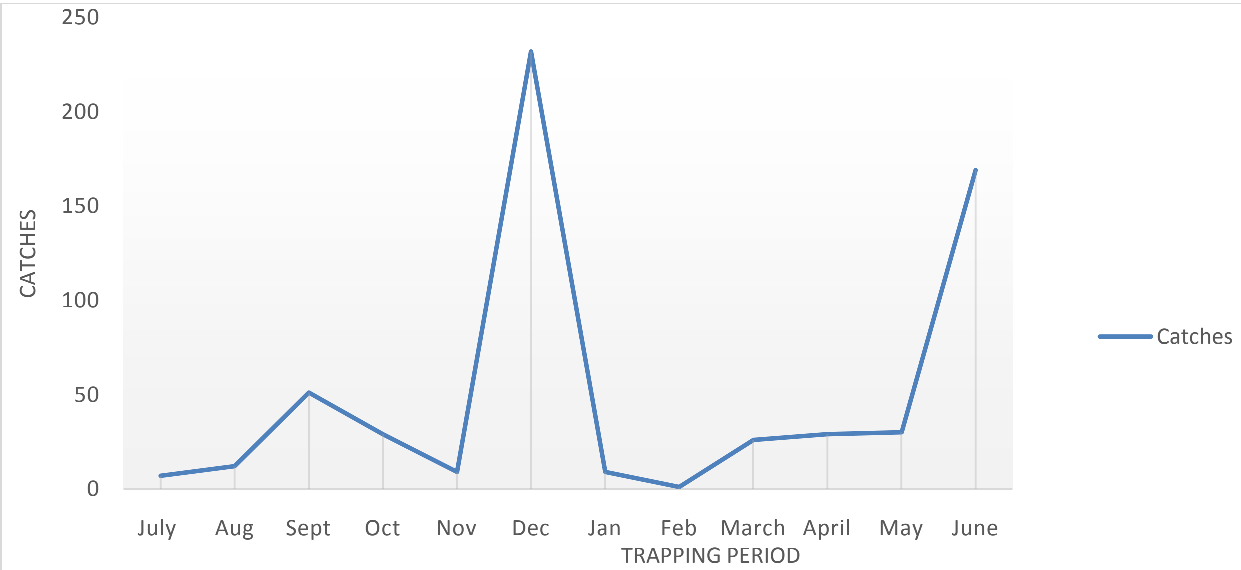

Fig 1: Monthly population dynamics of the adult fall armyworm moth over the 2017-18 season

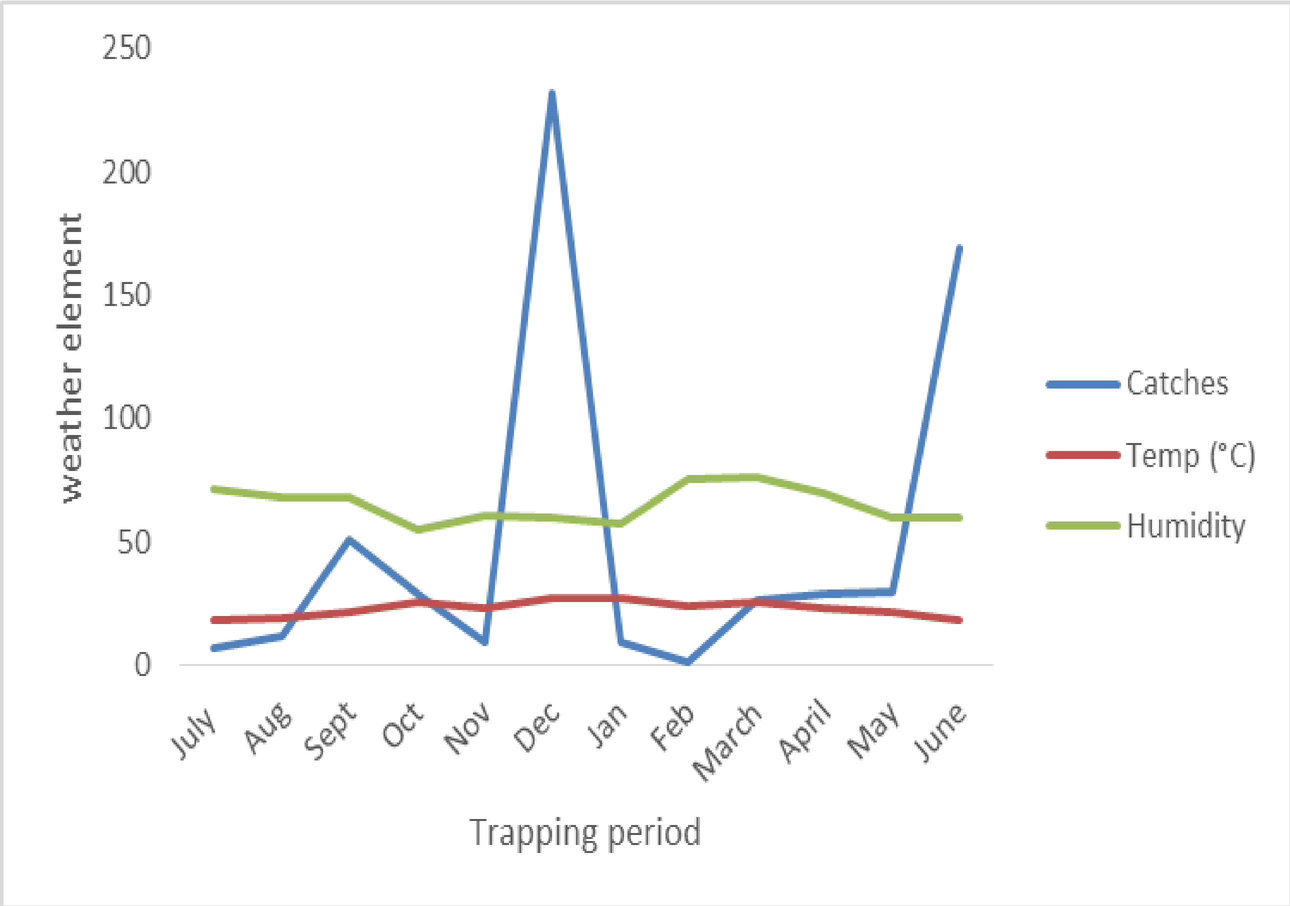

Fig 2: Effect of humidity and temperature on population dynamics of the fall armyworm over the season.

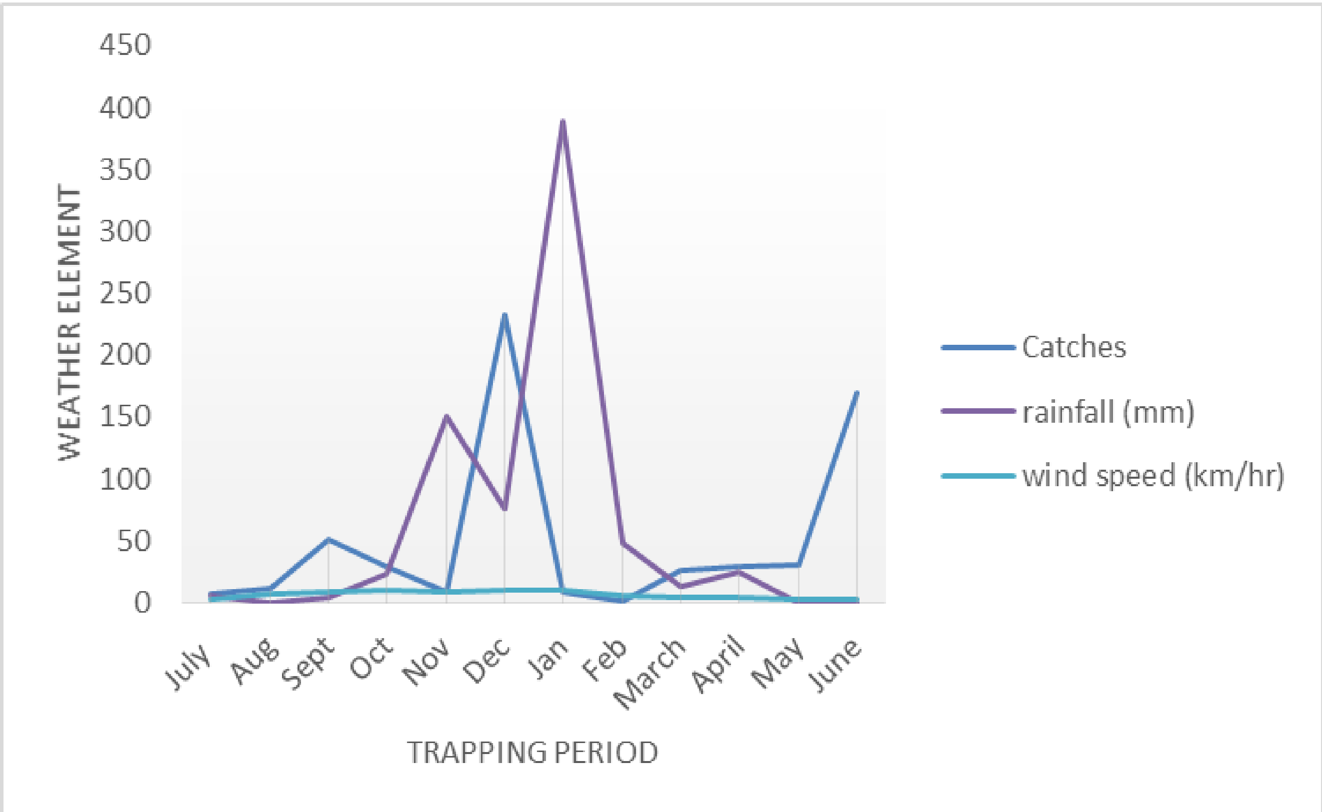

Fig 3: Effect of rainfall and wind speed on population dynamics of the fall armyworm over the season.

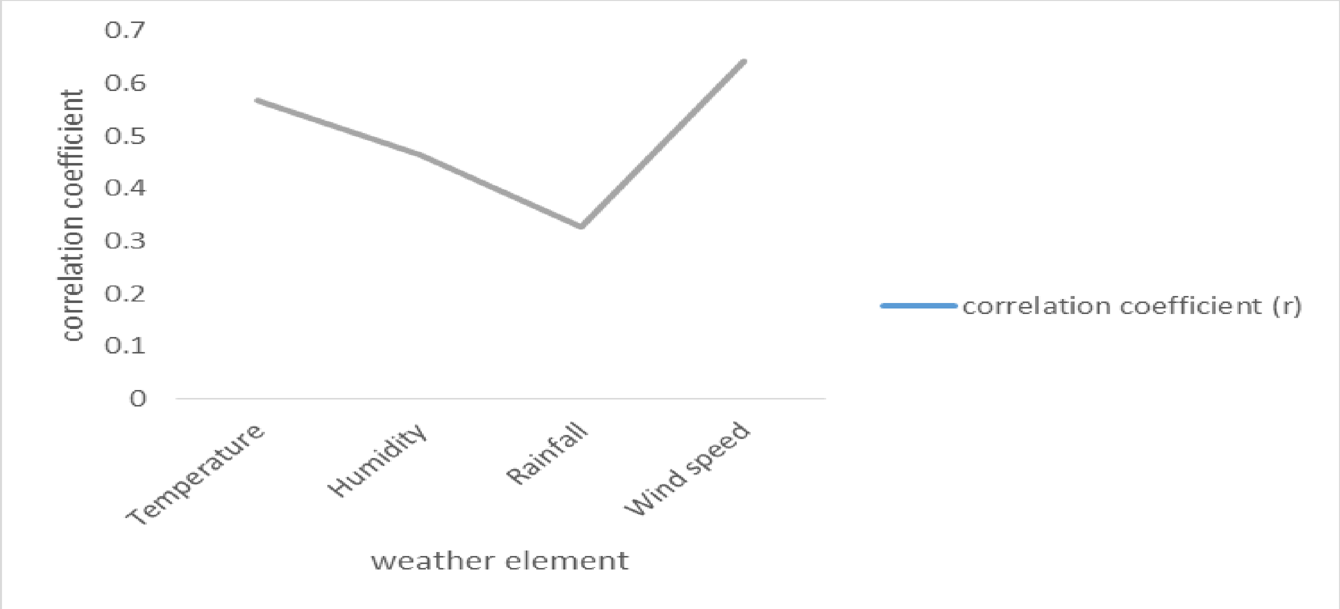

Fig.4 Correlation of fall armyworm moths to weather elemen

4 Discussion

There has been an upward and downward surge in the number of fall armyworm adults that were trapped over the season. Fall armyworm populations were maintained at an average of 12 catches during the winter months of July and August (Fig 1). This is in line with the findings of (Nagoshi *et al*., 2012) who observed fall armyworm infestations occurring throughout the season due to the intolerance of the species to winter freezes and hot months. This infestation pattern may be explained by overwintering of the moth at Chiredzi Research Station, followed by annual re-invasions of its geographic surroundings through successive long-distance flights during the winter and summer periods. There were periodic down surges of the fall armyworm catches over the season. Populations fell in August, November, January and February. This may signify fecundity of the worm since most females will be laying out eggs, hence reduced flights to look for partners. Temperature affects larval development, food consumption, and adult female longevity and fecundity, and that developmental times are temperature-dependent (Diez, 2001). This was also observed by Gong *et al*., 2019 when they observed reproductive experiences of *Eothenomys miletus.*

Lack of moisture during pupal stages appears to have little direct effect on survival or development rates. However, indirect effects of moisture are likely more important for fall armyworm population sizes than direct effects. This is because abundance tends to peak during rainy seasons, particularly in drier sites, possibly because of increased host plant growth. On the other hand, infestation rates are highest in maize deprived of irrigation for the longest, likely because plant moisture stress favours insect development (Reynolds *et al*., 2005)

Although the trapping data generated during the one year survey at Chiredzi Research failed to establish any particular site as the "parental source'' of fall armyworm migrants entering uninfested areas of the Station, there appears to be no question that favourable wind currents were conducive to the spread of the fall armyworm into and from the area. Meteorological analyses show at least one distinct area in terms of mean wind direction-the south-eastly winds, thus movements can be ascribed to relative beneficial atmospheric transport conditions from the south which depended on the direction of winds in the South eastern Lowveld of Zimbabwe. This is in line with several studies that investigated how synoptic wind patterns affect the frequency, intensity, and displacement of migratory flights of noctuid moths (Chapman *et al*., 2008, Pair and Westbrook, 1995).

Such studies demonstrated that weather transport systems are the most important climatic factors governing fall armyworm abundance at a migratory destination (Westbrook, 2008), that the direction of migratory flight is highly correlated with wind headings (Westbrook and Sparks, 1986), and that migratory pathways can be modelled using projections of air transport trajectories (Westbrook and Sparks, 1986). The meteorological data collected indicated a significant change in wind speed at Chiredzi Research Station as from September, October, November and December 2017. This resulted in a rise in the number of catches as from the month of September to December. There was also a rise in the number of moths between May and June 2018. This is in line with (Westbook and Sparks, 1986) who observed habitation being influenced by atmospheric circulation that provided a less transport potential to enhance movement of migrating fall armyworm moths. Thus with suitable wind pattern, moths can move much larger distances, (Rose *et al*., 1975). Fall armyworm thus, has the potential to spread rapidly across Africa: at least 500 km per generation, with a suitable wind." (CABI, 2017)

Studies at Chiredzi Research station have demonstrated integrated effects of temperature and moisture as significant on their vital rates, developmental time and fecundity (Westbrook and Sparks, 1986). This is also in line with (Jin, 1979), who observed rainfall, maximum, and minimum relative humidity being positively associated with armyworm moth catches. A rise in catches were observed from August to September, and this period was coupled by a precipitation of 4.3mm. This is also in line with studies on serious outbreak of the 3rd-generation armyworm larvae which concluded that low temperature and frequent rainfall could have created favourable conditions for the breeding of the 2nd-generation adults and suitable hosts for the 3rd-generation larvae (Westbrook and Sparks, 1986).

Rainfall may have influenced the microclimate especially the humidity substantially, and the humidity could affect armyworms directly in multiple ways (Sharma *et al*., 2002).

The effects of rainfall and humidity on armyworm individuals and populations at Chiredzi Research Station have been reported in many researches (for example *Zhang et al*., 2012, Jin *et al*., 1964, Jin *et al*., 1965, Salato et al., 2017, Tucker ad Pedgley, 1983, Drake and Farrow, 1988). This was also seconded in Jin's experiments, which observed that fecundity, egg development, hatching rate, larval survival, and larval development were shown to be positively impacted by high relative humidity (Zhang *et al*., 2012). Low humidity makes the egg shell a more difficult obstacle for larvae to chew their way out. Higher humidity in air or soil directly brings about higher survival rates of the 1st, 2nd, and 4th instar larvae (Willink *et al*., 1993a). Therefore, humidity might be an important factor affecting the formation of the initial population. Low humidity also reduces vigour of larvae and hence reduces their ability to cause damage. The duration of larval stage is inversely correlated to humidity, so larvae can reach their foraging peak earlier with higher humidity (Sharma *et al*., 2002).

5. CONCLUSIONS

These results present an indication that the fall armyworm strain have a substantially population dynamic in the agricultural vicinity of Chiredzi Research Station starting on the onset of the rain season. Evidence from data collected suggest that the army worm moth was predominant during the onset of the summer periods. It further indicates that the worm can display a markedly different response to seasonal environmental cues such as temperature, wind speed and direction as well as humidity.

6 RECOMMENDATION

Farmers should implement control measures for the management of the fall armyworm from the onset of the rain season. They must also bear in mind that the worm can tolerate cooler conditions posed by the winter season of which it remains a pest of economic importance in cereal production in the South eastern Lowveld of Zimbabwe.

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