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Monitoring of damage and distribution of invasive fall armyworm, *Spodoptera frugiperda* (J.E. Smith) (*Lepidoptera: Noctuidae*) on maize crop in Karo, North Sumatera, Indonesia

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Abstract. The fall armyworm (FAW), *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) is an invasive pest from America and has recently become an important pest in Indonesia. In their new environment, these pests have very high migratory and adaptive skills, as well as aggressive feeding habits. The aim of this research was to monitor the distribution, percentage of attacks, and damage caused by *S. frugiperda* on maize fields in the Karo District of North Sumatra Province. The study was conducted using a survey method at various altitudes and the sample unit was determined using the diagonal method. Each sample unit has a size of 2 × 2 m^2. The age of maize crop used as the sample is 2-4; 5-6; 7-8; 9-10; and 11 weeks after planting (wap). Symptoms of attack, number of larvae population, and percentage of FAW attack were observed directly on plants. The results showed that FAW spread evenly at various altitudes, with the highest population at an altitude of 500-1,000 m.a.s.l at the age of 2-4 wap with a larval population density of 14.20 individual/unit sample. The highest percentage of attack was found at an altitude of 500-1,000 m.a.s.l, namely 82% at 2-4 wap. The highest attack on leaves occurred at an altitude of 500-1,000 m.a.s.l (70.6%) at the age of 2-4 wap.

1. Introduction

Karo Regency is one of North Sumatra Province's maize growing centers. Maize productivity in North Sumatra Province is estimated to reach 1,960,423.85 tons in 2019, with Karo Regency contributing one of most, with a total corn production of 767,304.59 tons, or 39.1 percent of the province's total maize production [1]. Furthermore, the National Statistical Agency (NSA) [1] indicated that the Karo Regency area is at an altitude of 200-1,620 m.a.s.l, with air temperatures ranging from 15.6 to 23°C. Karo Regency's agro-climatic features make it an ideal location for maize plant growth. Corn plant expansion

in the region has a favorable impact on regional economic growth in the form of business unintended consequences.

Maize is widely utilized in Indonesia as a rice substitute or as a rice mixture, and it plays an essential role in determining the effectiveness of the processed food sector [2]. Around 2-3 percent of total corn production is anticipated to be used for home consumption, with the remainder going to the agricultural business for animal feed, corn oil, and biofuel components. However, throughout the previous few decades, national maize production has tended to decrease, and market demand has not stagnated. The same situation occurred in Karo Regency due to the presence of many pests and abiotic and biotic elements that affected the maize crop's productivity directly and indirectly. Plant growth and development are influenced by abiotic elements such as climate change (rainfall, light, temperature, and humidity), changes in soil characteristics (physical and chemical), and altitude [3]. Similarly, biotic elements such as plant pest organism attack, particularly from the pest and disease group, have a major impact on maize yield [4,5].

The Fall Armyworm (FAW), *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae), is one of the region's newest invasive pests. This pest has spread to various regions of the world, from West and Central Africa in 2016 to Asia in 2018 [6,7]. Because it is supported by several intrinsic factors, including the ability to fly over hundreds of kilometers, and the ability to adapt well to its new environment. In addition, it may also be carried by means of transportation that transport agricultural commodities across countries, therefore, *S. frugiperda* can spread quickly to several neighboring countries or other regions[8,9]. In Lampung, FAW was first recorded invading maize crops in 2019 [10]. The Center for Forecasting Plants Pests Organisms (CFPPO) reported FAW in maize crops in 29 regions in April 2020.

S. frugiperda affects maize plants at all stages of development, from vegetative to generative [11]. The vegetative phase had the highest amount of destruction [10]. Crop problems can occur from damage to leaves and cobs, resulting in lower regional and national corn yield. Previous studies showed that at the age of 5 weeks after planting (wap), the highest attack of FAW on two types of sweet corn and sticky rice was 33.72 % and 34.74 %, respectively [12]. The FAW life cycle lasts 32-46 days, including an egg stage of 2-3 days, a larval stage of 14-19 days, and a pupa stage of 9-12 days [13].

Based on this information, this study was intended to investigate the distribution and percentage of attacks of *S. frugiperda* on maize crops in Karo Regency, North Sumatra. This study is critical since the data on the subject are few, particularly on the spread of FAW pests in Karo Regency, which is a physically suitable location for the development of maize in North Sumatra. The findings of this study are helpful to promote decision-making in controlling the FAW pests in North Sumatra.

2. Materials and methods

2.1. Study area

The research was carried out in December 2020 - March 2021 with location details presented in table 1.

Table 1. Plant sampling sites at various altitudes in Karo Regency, North Sumatra.

Altitude (m.a.s.l)	Research site/Subdistrict	Coordinate point
>1,000	Pertibi Tembe	2˚56’22”, 98˚28’5”
	Pertibi Lama	2˚56’48”, 98˚28’27”
	Cinta Rayat	3˚11’41”, 98˚28’27”
	Serumbia	3˚7’36”, 98˚25’49”
	Kandibata	3˚5’22”, 98˚26’25”
	Kuta Gerat	3˚4’59”, 98˚25’39”
	Barung Kersap	3˚2’32”, 98˚24’14”

500-1,000	Singgamanik	3˚5’53”, 98˚19’52”
	Selakkar	3˚5’15”, 98˚19’23”
	Sukababo	3˚3’13”, 98˚19’41”
	Mbetung	3˚1’54”, 98˚16’11”
	Kem-kem	3˚3’22”, 98˚13’22”
	Kuala	3˚3’32”, 98˚12’58”
	Lau Kapur	3˚3’48”, 98˚12’49”
	Simolap	3˚3’58”, 98˚12’6”
<500	Lau Peranggunan	3˚3’52”, 98˚7’52”
	Mardinding	3˚14’3”, 98˚0’22”

Note: m.a.s.l : Height or altitude above mean sea level.

2.2. Sampling

This study used a survey method with a sample location determined purposively [14,15] at three altitudes, namely <500; 500-1,000; >1,000 m.a.s.l. While the determination of the sample unit was using the diagonal method (Figure 1). The age of the corn plants observed at each sample point were plants aged 2-4; 5-6; 7-8; 9-10; and 11 weeks after planting (wap). The number of plants observed at each sample point was 20. Variables observed included attack symptoms, number of larval populations, and percentage of FAW attacks on plant samples through direct observation in the field.

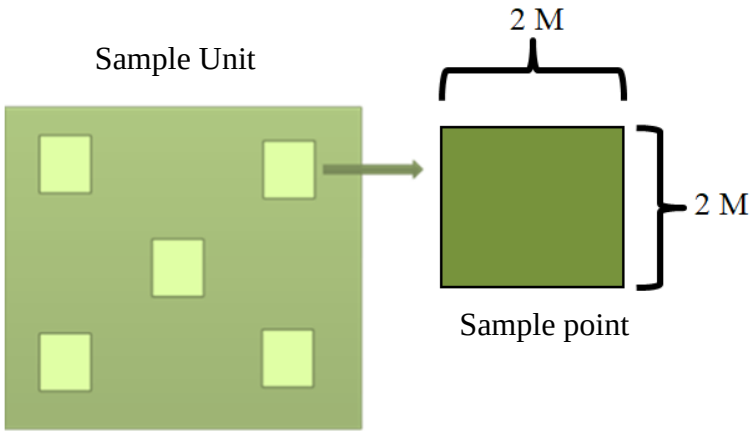

Figure 1. Sample unit with diagonal method (modified from Le [16]; MOST [17]; Peters et al. [18]).

2.3. Research procedure

2.3.1. Distribution of FAW. Observations on the distribution of FAW were carried out at three altitudes in several sub-districts in Karo Regency, namely <500; 500-1,000; and >1,000 m.a.s.l. The variables observed included the population of larvae in the observation plots that were observed directly. The results of the observations are accompanied by notes on the location, time of observation, and the number of larvae found.

2.3.2. Larvae population density. The number of larvae collected in the observation sites at each location, at each age level of the plant, at each altitude was used to determine FAW population density. Temperature and humidity levels were also measured.

2.3.3. Attack percentage of FAW. The observations were aimed at the number of affected plants in each observation plot from a number of plants observed in accordance with predetermined provisions. The percentage of infected plants in the sample unit was determined using the equation from Putrasamedja et al. [19] namely:

$$P = \frac{a}{b} x\ 100\% \quad (1)$$

Remarks:
P = Percentage of affected plants (%)
a = number of affected plants
b = the number of plants observed

2.3.4. Attack intensity
FAW attack intensity refers to Prabaningrum and Moeksan [20] :

$$I = \frac{\Sigma(n \times v)}{N \times Z} x\ 100\% \quad (2)$$

Remarks:
I = Attack intensity (%)
Z = highest scale value (9)
N = the number of plants observed
n = number of plants with the same value of v (damage)
v = plant damage scale value

The attacks level category was determined based on Table 2. by assessing each damage to the affected plant through the attack level category with a scale value of 1-5 [20]:

Table 2. Determination of the damage level to corn leaves caused by *S. frugiperda.*

No.	Category	Plant Age (WAP)		
		Category I 0-2	Category II 2-4	Category III >4
1	Slight	0 - 10%	0 - 20%	0 - 40%
2	Moderate	11 - 20%	21 - 40%	41 - 60%
3	Heaviness	21 - 40%	41 - 60%	61 - 75%
4	Very heavy	41-85%	61 - 85%	76 - 85%
5	No result	>85%	>85%	>85%
6	Economic threshold	15%	30%	50%

The determination of the attack level category is adjusted based on the damage to the leaves of the corn plant (Figure 2):

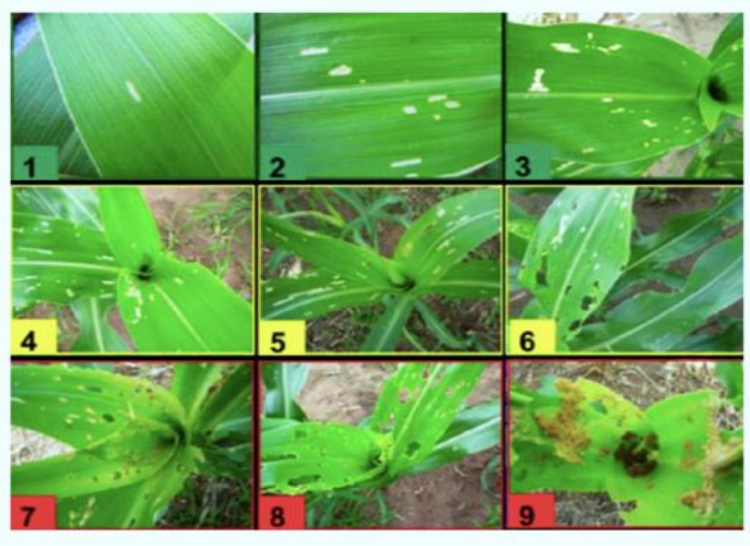

Figure 2. Pest attack categories based on the level of leaf damage [21].

2.4. Data analysis

The data obtained were documented and tabulated using Ms. Excel 2019 (Microsoft, USA). Pest population distribution data is presented in the form of images using GraphPad Prism software (GraphPad, San Diego, USA), while population density data and the percentage of FAW attacks are presented in table form.

3. Results and discussion

3.1. Distribution of FAW on maize crop in Karo Regency

The results showed that the distribution pattern of FAW in Karo Regency occurred at all altitudes from <500 m.a.s.l to > 1,000 m.a.s.l (Figure 3). Figure 3 shows that the distribution of FAW pests was found to be evenly distributed in maize planted at locations with an altitude of < 500 masl, 500-1,000 masl, and > 1,000 m.a.s.l.

Field findings, on the other hand, indicate that FAW distribution in the lowlands is more dominating than in the highlands. According to Syarkawi et al. [22], the altitude factor, as well as the temperature and humidity of the surrounding environment, has an impact on the spreading of invasive pests. FAW spreads as random in the field, following the spread of the host plant [23]. Insects' abilities to locate food, escape predators, and perhaps be moved away by the wind are influencing the dispersal pattern [14]. According to Du Plessis et al. [24], ambient temperature plays an essential impact in the FAW invasion process, particularly the adverse environmental aspects for its growth phase.

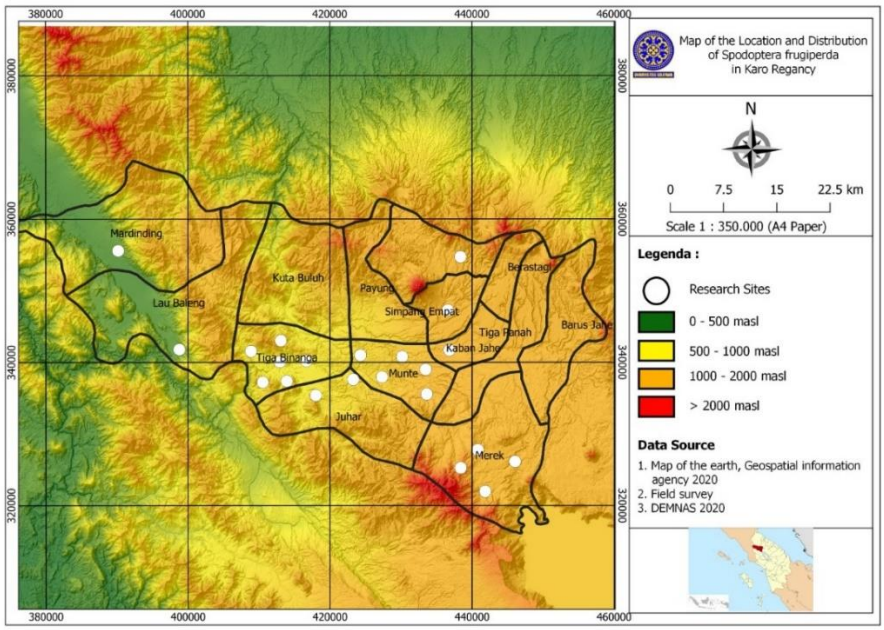

Figure 3. Distribution map of *S. frugiperda* in Karo Regency, North Sumatra.

As a result, temperature and growth rate are closely related to biological mechanisms, pest species distribution, and abundance in the field. Insect development, which occurs at a certain temperature, is associated to the rate of development [25], the duration of the life cycle [26], and the survival rate [27]. When the environment temperature rises to a level that is close to the optimum temperature for insects, their metabolism increases [27,28]. Several Southeast Asian nations, such as Indonesia, which has a tropical environment with approximately 12 hours of daylight each day, have an average temperature in the middle of the dry season reaching 36°C and rainfall of less than 50 mm/10 days, allowing FAW to spread. Favorable climatic conditions, irrigation systems, and the effect of host plants dispersed widely in the field all influence the spread of FAW in a tropical climate country such as Indonesia [29].

3.2. Population density of S. frugiperda larvae on maize crops in Karo Regency

The results of field observations showed that the emergence of FAW larvae on corn crops occurred when the plants were 2 weeks after planting (wap). The highest number of FAW populations was found in corn plants aged 2-4 (wap), namely 14.20 individual/sample unit at an altitude of 500-1,000 m.a.s.l. The decline in the FAW population began to occur when the corn plant reached the age of 11 (wap), which was 0.60 individuals/sample unit (Figure 4). The population density of FAW larvae was found to be dominant at an altitude of 500-1,000 m.a.s.l, higher than in the lowlands (< 500 m.a.s.l) and highlands (> 1,000 m.a.s.l). It is strongly suspected that this event was caused by limited host plants grown in the lowlands. (<500 m.a.s.l) and high (>1,000 m.a.s.l).

Altitude differences and the availability of host plants have a major impact and attract FAW to the region. Further to that, temperature and humidity are environmental limitations in terms of insect growth, development, and dispersion. Based on the current findings, an average ambient temperature of 26-30°C at an altitude of 500-1,000 m.a.s.l is the ideal temperature range for insect development. When the temperature increases, insect moths develop and completed their life cycle rapidly [24,30]. Baloch et al. [29] and Feldmann et al. [31] explained that the reproductive ability of insects and larval populations was inhibited and decreased when the external temperature was too high or low.

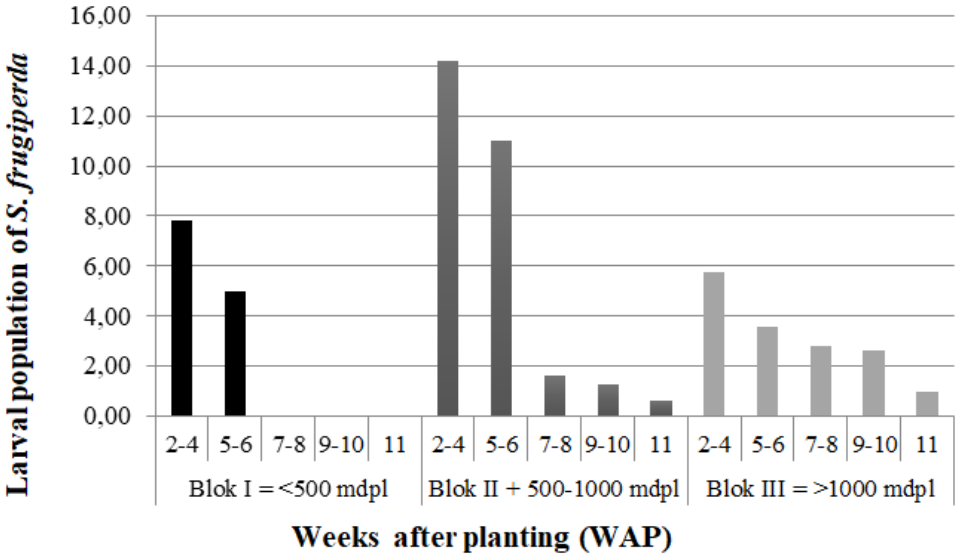

Figure 4. Population of *S. frugiperda* larvaea per unit sample on maize crop in Karo Regency, North Sumatra.

The availability of feed ingredients in the form of type and amount is also the cause of the high number of insect populations in an agroecosystem habitat. The findings of Supartha et al. [15] showed that the peak population of *S. frugiperda* larvae was found on host plants aged 4 and 5 (wap), due to Lepidoptera insects prefer young plants compared to old ones. The reduced number of FAW larvae in plants aged 11 (wap) was caused by the lower nutritional content of the leaves compared to young plants. Lepidoptera larvae require appropriate proportions of protein, fat, vitamins, carbs, water, and minerals for optimum growth and development. In addition to the nutritional content of plants, the low number of larvae in 11-year-old corn plants (wap) was also caused by the physical condition of plant tissues that had begun to harden, therefore *S. frugiperda* larvae had obstacles to consume parts of these plants. Maize leaves that have grown old have thickened cell walls, makes them less compelling to larvae. In contrast when the leaves of plants are still young, the leaf tissue is still soft so that it is easier for larvae to consume them [30].

3.3. Percentage and level of FAW attack on maize crops in Karo Rregency

3.3.1. Percentage of infected plants. The results of field observations showed that the percentage of FAW attacks on maize plantations in Karo Regency had a lower tendency to occur at an altitude of < 500 and > 1,000 m.a.s.l, when compared to the percentage of attacks at an altitude of 500-1,000 m.a.s.l, especially when the plants were 2-4 (wap), namely by 82% (Figure 5). The lowest percentage of attack was found at an altitude of >1,000 masl with a plant age of 7-8 (wap), which was 26%. The high level of crop damage has a close relationship with the higher pest population density in the agro-ecosystem area [32]. The age of the stadia and the susceptibility level of the host plant also have a role in the high percentage of armyworm attacks [33]. Furthermore, corn plants aged 11 (wap) at an altitude of 500-1,000 and > 1,000 m.a.s.l had the same percentage of 27% in the heavy category. We assumed that this was because the larval instars found in the field included 5th and 6th instars. The results of previous studies explained that 4-6 instar larvae were capable of causing severe damage to maize crops [15]. At the age of maize that have reached 7-11 (wap), the FAW attack rate was still high but with a declining larval population. This is considered to be due to a high degree of insect invasion between the ages of 2-4 (wap) and 5-6 (wap), causing the lesions on the maize plants to continue to appear. FAW larvae, on the other hand, are assumed to have entered the pupa and adult phases, such that while the proportion of infestations on maize plants is high, there are fewer populations.

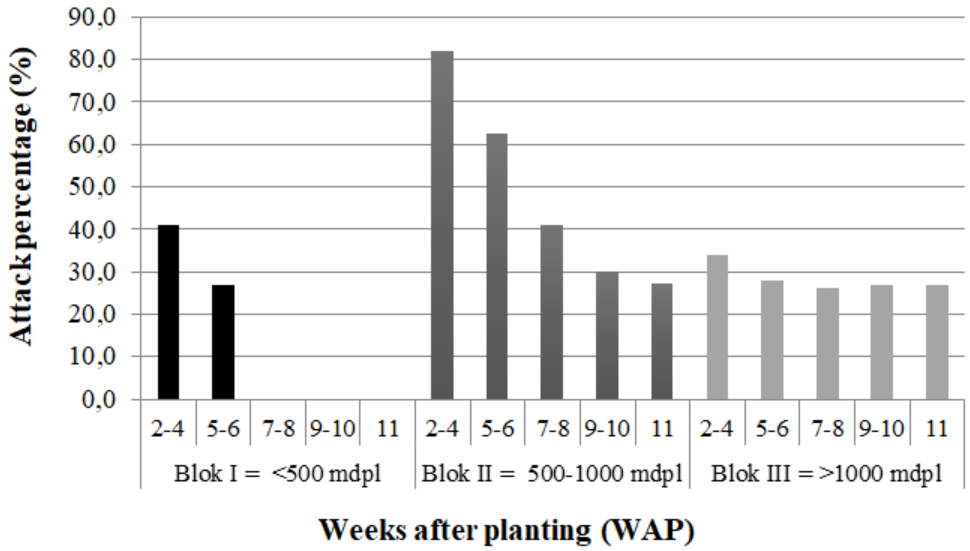

Figure 5. Percentage of maize crops attacked by *S. frugiperda* in Karo Regency.

3.3.2. Attack rate on corn crops. The attack rate of *S. frugiperda* at each height and age stadia of maize plants had different values. The results showed that the highest percentage of infected leaves was found in maize crops aged 2-5 (wap), while the lowest was found at age 7-11 (wap) (Figure 6). At an altitude of <500 m.a.s.l, the percentage of leaves affected on corn crops aged 2-4 (wap) was 24.3%, including the medium category, and on corn crops aged > 4 (wap) was 22.2%, including the mild category. At an altitude of 500-1,000 m.a.s.l, the highest percentage of affected leaves was found in corn plants aged 2-4 (wap), which was 70.6% with a very heavy attack category.

In corn crops aged 5-6 (wap), the percentage of leaves affected was up to 51% with a moderate attack category. These results indicated that FAW larvae have high destructive power and have the potential to reduce maize productivity in the field. The lowest percentage of affected leaves was at the age of 11 (wap), which was 3.4% with a mild attack category. Furthermore, at an altitude of > 1,000 m.a.s.l, the highest percentage of affected leaves was on corn crops aged 2-4 (wap), which was 23.7% with a moderate attack category and the lowest percentage of leaves attacked was on 11-aged corn crops (wap), which was 5.2% with the lowest attack category. The high level of attack on maize crops aged 2-4 (wap) is in line with the results of the study by Supartha et al. [15] because at that age, the leaves of corn plants contain high nutrients and relatively low crude fiber content, so that they are favored by *S. frugiperda* larvae. Helmiyeti et al. [34] stated that the content of crude fiber affects the growth of insects. This is because the process of eating and digestion of insects will be disturbed if the crude fiber content of the feed is high. In addition, the burrs on the leaves when they are young can recover if they are supported by good fertilization and tillage by farmers [33, 35].

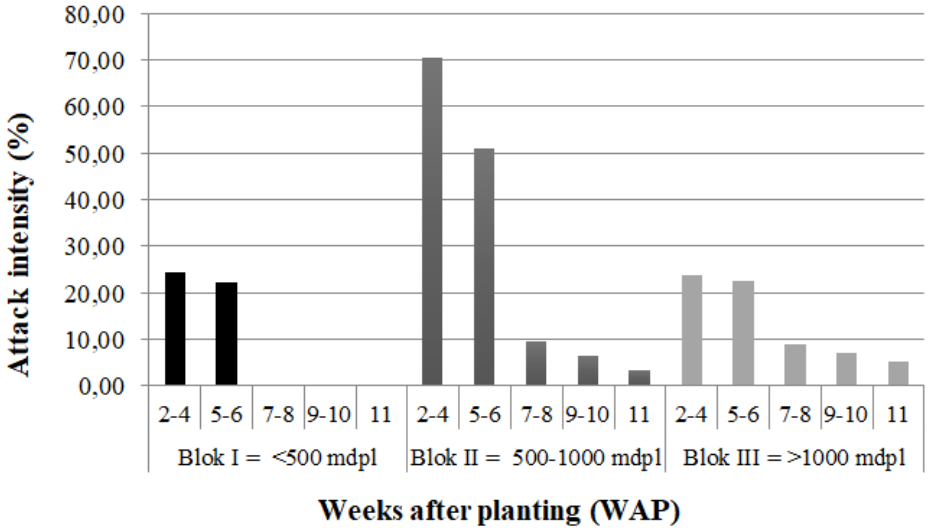

Figure 6. The attack rate of *S. frugiperda* on maize crops in Karo Regency.

4. Conclusions

Overall, here we first inform the case of the widespread and even distribution of the Fall Armyworm (FAW), *S. frugiperda* in corn crops in Karo Regency, North Sumatra. FAW caused a significant percentage and level of damage on corn crops in the field at an altitude of 500-1,000 m.a.s.l, with the worst attack intensity occurring in Tigabinanga District. It was also found that the FAW colonization period occurred three times in one season of maize planting in the field. Our findings can help to enhance understanding of maize distribution and give critical information for creating management measures for managing this pest in North Sumatra.

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