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Spatial distribution and sampling size for monitoring of African maize stem borer, *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae) on maize (*Zea mays* L.) in Southern Ethiopia

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The African maize stem borer (*Busseola fusca*) is one of the important biotic constraints for maize production in sub-Saharan African. This study determined the spatial distribution and sampling sizes for African maize stem borer in Southern Ethiopia. Twenty four maize farms were visited in 12 localities at three growth stage of maize. Data were collected on the number of infested and not-infested plants, and the number of larvae and pupae. There were variations in the levels of infestations and population density of *B. fusca* in the study areas and years. Percent infestation at mid-whorl stage of maize ranged from 13.6 to 25.9% and 19.5 to 41.4% in 2015 and 2016, respectively. Infestation increased through time and at harvesting stage reached ranges of 36.8 to 68.8% in 2015 and 65.5 to 80.7% in 2016. The optimal sample size for four fixed precision levels of 0.10, 0.15, 0.20 and 0.25 were estimated with Iwao's regression coefficients. The distribution pattern of B. fusca varied between maize growth stages, locations and years. At mid-whorl stage of maize, *B. fusca* infested plants were aggregated but in both at silking and harvesting stage uniformly distributed. At mid-whorl as well as silking stage of maize B. fusca larvae were aggregated. But, larvae at harvesting stage and pupae in both silking and harvesting stages of maize were randomly distributed. For 10% infestation, which is considered as action threshold level for stem borers management on maize, 22 sampling units (660 plants) at the precision of 20% are required.

Key words: *Busseola fusca*, maize, spatial distribution, sample size, precision level.

INTRODUCTION

Maize (*Zea mays* L.) is one of the main food and feed crops in Ethiopia and worldwide (FAO, 2018). In Africa, maize is among the most important field crop providing food, feed and fuel (Smale et al., 2011). Ethiopia is the

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fourth largest maize producing country in Africa, and first in the East African region (FAO, 2018). Maize is mainly grown in Oromia, Amhara, Southern Nations, Nationalities, and Peoples' Region (SNNPR), and Tigray (CSA, 2017/2018). In SNNPR, the average productivity of maize is 3.8 t/ha (CSA, 2017/18) which is slightly less than the national average yield of 3.9 t/ha (CSA, 2017/2018) but much lower than the world average of 5.8 t/ha (USDA, 2018). The low productivity of maize could be attributed to many abiotic and biotic factors (Getu et al*.,* 2001; Desalegn et al., 2012; Tilahun et al., 2012).

Among the biotic factors, insect pests, particularly stem borers are responsible for the low yield of maize crop (Getu et al., 2001; Wale et al*.,* 2006). Yield losses in Ethiopia due to stem borers vary with agroecology, but generally range from 15 to 100% depending on infestation by the pest species, crop and crop growth stage attacked (Wale et al., 2006). In East Africa, the noctuid *Busseola fusca* (Fuller) and the crambid *Chilo partellus* (Swinhoe) are the most important insect pests associated with maize (Mwalusepo et al., 2015). The two lepidopterous stem borers are economic pests of maize in Ethiopia (Wale and Ayalew, 1993; Wale al et., 2006). Gebre-Amlak (1985) reported that *C. partellus* was a predominant species at low elevation (less than 1700 m) and *B. fusca* was dominant at elevations between 1160-2600 m.a.s.l. and cooler areas of Ethiopia.

Spatial distribution is one of the characteristic properties of insect populations; in most cases, it allows us to define them, and is a typical trait in insect populations and is an important characteristic of ecological communities (Debouzie and Thioulouse, 1986). Understanding the distribution and phenology of insects in a different environment is important to plan management practices (Searle et al., 2013). No field sampling can be efficient without understanding the underlying spatial distribution (Taylor, 1984). Spatial distribution allows for the estimation of densities and in turn forms the basis for deciding on pest management programs (Khaing et al., 2002). The appropriate sampling pattern depends on the spatial distribution of the insect or disease (Lin et al., 1979). Insect populations may follow a random, uniform or aggregate distribution, but the degree of aggregation often varies among the population and species (Root and Cappuccino, 1992). The spatial distribution of stem borers varies among and within-host plants possibly due to their suitability for oviposition and larval development (Addo - Bediako and Thanguane, 2012).

Management method cannot be implemented effectively without accurate estimates of insect population and its effects on yield (Nabil, 2010). To estimate insect density, sampling time, sampling unit and sampling size are crucial (Southwood and Henderson, 2000). The number of samples size and units could be varied with insects being sampled, their distribution patterns (Southwood and Henderson, 2000); purpose of sampling, infestation pattern, severity and economic considerations (Frisbie and Whorter, 1986). Too few sample sizes will reduce the value of the estimate (Vlug and Paul, 1986) and too many will increase the cost of the program (Blackshaw and Hicks, 2013). Therefore, the present study was designed to determine the spatial distribution patterns and the sampling size for monitoring of *B. fusca* on maize.

MATERIALS AND METHODS

Study areas

The study was conducted in Wolaita, Sidama and Gurage zone (Table 1) which are found in southern Ethiopia during 2015 and 2016 main cropping seasons (May- October). The number of districts, localities, sampling farms, sampling plots and plants in each zone are described in Table 2. Districts and localities were selected based on road accessibility and intensity of maize production.

Sampling procedures

In this study, twenty four maize farms in 12 localities having similar inputs and management practices were covered. The farms did not receive any insecticide treatment and grew the popular maize varieties BH540 and Shone. In each maize farm five sampling spots with a size of $9m^2$ each were measured in 'X' pattern at mid-whorl, silking and harvesting stages of maize. In each spot, the total number of plants (30 plants on the average) and those infested by stem borers (characterized by dead heart, scarified leaves, and larval entry and exit holes in stems, the presence of frass) were recorded and percent of infestation (%) calculated using the formula $IP\% = \frac{IP*100}{TP}$ Where, IP = infested plants, TP = total plants. When infestations were observed, ten plants were randomly selected from each spot and dissected to record the number of larvae and pupae. The same fields were used for samplings at different stages of maize.

Spatial distribution pattern determination

The spatial distribution pattern of *B. fusca* was determined by using four indices, namely Taylor's power law, Iwao's mean crowding regression, Lloyd's mean crowding, and index of dispersion. Percent of infested plants and numbers of insects per spot were used.

Taylor's power law (1984)

Log (S^2) = a +blog ($\bar{X}$), where S^2 is the variance, $\bar{X}$ is sample mean, a is intercept and b is the slope. When b=1, b < 1 and b> 1 the distribution is random, uniform and aggregated, respectively.

Iwao's regression (1968)

Iwao's regression method was used to quantify the relationship between mean crowding index (X*) and mean density (*m*) using by solving the following equation: $X^* = \alpha + \beta \bar{X}$. Where α indicates the tendency to crowding (positive) or repulsion (negative) and β =1, β

Table 1. Description of the study areas in Southern Ethiopia.

Zone	Altitude (m.a.s.l.)	Annual Average temperature (^{0}c)		Annual Average rainfall (mm)		Distance from Addis Ababa (km)
		Minimum	Maximum	Minimum	Maximum	
Gurage	1001- 3600	13.0	30.0	600	1600	158
Sidama	501-3000	10.0	25.0	801	1600	275
Wolaita	1200 - 2950	15.1	25.1	1200	1300	340

Source: SNNPRS Resource Potential and Investment Opportunities (2008).

Table 2. Study areas, number of sampling farms per locality, plots per farm and plants per plot.

Study area			No of sampling farms/locality	No of sampling plots/farm	No of sampling plants / plot
Zone	Districts	Localities			
Gurage	Mareko	Dida Halibo	2	5	10
		Dida Midore	2	5	10
	Meskane	Dida	2	5	10
		Ochageneme	2	5	10
Hawassa	Wondo Genet	Aruma	2	5	10
		Youwo	2	5	10
	Hawassa Zuria	Jara Kerara	2	5	10
		Jara Demuwa	2	5	10
Wolaita	Damot Gale	Shasha Galea	2	5	10
		Buge	2	5	10
	Boloso Sore	Wermuma	2	5	10
		Dola	2	5	10

< 1 and β > 1 the distribution is random, uniform and aggregated, respectively.

Index of dispersion ($S^2/\overline{X}$ and Z)

$S^2/\overline{X}$ variance (S^2) to mean ($\overline{X}$) ratio was calculated and values 1 random, < 1 uniform and > aggregated distribution. The index of dispersion (ID); ID = (n-1) $S^2/\overline{X}$, where n denotes the number of samples. The index was tested by Z value as follows:- $Z = \sqrt{2I_D} - \sqrt{(2v-1)}$, where v = n -1 if 1.96 >= Z > - 1.96 and the distribution is random but if Z < - 1.96 or Z > 1.96, it would be uniform and aggregated, respectively (Patil and Stiteler, 1978).

Lloyd's means crowding (1967)

$X^* = \overline{X} + S^2/\overline{X} - 1$, where S^2 is variance and $\overline{X}$ is the sample mean. To remove the effect of changing in density, the ratio of mean crowding to the mean was used and $X^*/\overline{X}$ =1 random, <1 uniform and >1 aggregated

Sample size determination

At mid-whorl stage of maize, the number of required sampling units per field were determined using proportion of infested plants and Kuno (1969) formula $n = (a+1/\overline{X} + \beta - 1)/D^2$, Where n = number of sampling units; $\overline{X}$ means of infestation; a and β are coefficients obtained from Iwao's regression, D = precision level. The allowable precision levels (10, 15, 20 and 25 %) in ecological research (Southwood and Henderson 2000) were used.

Data analysis

B. fusca distribution indices were generated by using SPSS 21.0 software. Mean of *B. fusca* infestation, larvae and pupae in each zone, maize growth stage and year ware analysis using SPSS software. The count and percent data were transformed using square root and arcsine, respectively.

RESULTS

Levels of infestations and population density of *B. fusca* larvae and pupae

There were variations in the levels of infestations and population density of larvae and pupae in the different study locations and years (Table 3). Percent infestation by *B. fusca* at mid-whorl stage of maize ranged from 13.7

to 25.9% and 19.4 to 41.4% in 2015 and 2016, respectively. The level of infestation increased through time and at harvesting stage reached to ranges of 36.8 to 68.8% in 2015 and 65.5 to 80.7% in 2016. The numbers of larvae were higher at mid-whorl stage (4.14 to 5.8 / plant in 2015 and 4.05 to 7.7 /plant in 2016) than the subsequent stages of maize. Pupae were recovered starting the silking stage of maize and there were 0.5 to 1.14 and 0.7 to 1.55 pupae per plant in 2015 and 2016, respectively.

Distribution of infested maize plants with *B. fusca*

In both years, at mid-whorl stage the index of dispersion and Lloyd's mean crowing ($S^2/\bar{X}$ and $X^*/\bar{X}$) *for* percent number of infested plants were greater than one and the coefficients of Taylor's power law (b) and Iwao's patchiness regression (β) were significantly greater than one (Table 4). Index of dispersion ($S^2/\bar{X}$) ranged from 0.99 to 1.81; Lloyd's mean crowing ($X^*/\bar{X}$) from 1.18 to 1.72; coefficients of Taylor's power law (b) from 1.10 to 1.91 and Iwao's regression (β) from 1.40 to 2.40; whereas at silking as well as maturity stage of maize, all the distribution indices were less than one. The study showed that at the mid-whorl stage of maize, the distribution pattern of *B. fusca* infestation was aggregated and uniform at both silking and harvesting stages of maize.

Distribution of *B. fusca* larvae at mid-whorl stage of maize

During the study periods, *B. fusca* was the only stem borer species recorded in the three zones of the study areas. In both years, at the mid-whorl stage of maize, the index of dispersion (S^2/) for *B. fusca* larvae was greater than one (1.46 to 2.64); Z value was greater than 1.96 and Lloyd's mean crowding ($X^*/\bar{X}$) ranged from 1.10 to 1.51 (Table 5). The coefficients of Taylor's power law (b) and Iwao's (β) were significantly greater than one and ranged from 1.82 to 3.88 and 1.14 to 1.7, respectively. All the dispersion values indicated that at the mid-whorl stage of maize *B. fusca* larvae had an aggregated distribution.

Distribution of *B. fusca* larvae and pupae at silking stage of maize

Similar to mid-whorl stage, at silking stage of maize, *B. fusca* larvae distribution indices ($S^2/\bar{X}$ and $X^*/\bar{X}$) were greater than one; Z values greater than 1.96; Taylor power and Iwao coefficients were significantly greater than one (Table 5). In both years, the index of dispersion ($S^2/\bar{X}$) ranged from 1.24 to 2.30; (Z) from 1.87 to 3.20; Lloyd's mean crowing ($X^*/\bar{X}$) ranged 1.08 to 1.52 and the Taylor power coefficients (b) ranged from 1.21 to 3.54. The slopes of the regression lines for Iwao's mean crowding regression were also numerically greater than one, ranged from 1.2 to 1.4. The dispersion values indicated that *B. fusca* larvae were aggregated at silking stage of maize. Index of dispersion ($S^2/\bar{X}$) of pupae ranged from 0.84 to 1.26; with (Z) values from 0.90 to 1.31; Lloyd's mean crowing ($X^*/\bar{X}$) ranged from 0.82 to 1.30 and coefficients of Taylor's power law (b) ranged from 0.94 to 1.34 (Table 6). The slopes of the regression of Iwao's were near to one and ranged from 0.89 to 1.24. All the indices indicated that at silking stage of maize *B. fusca* pupae had a random distribution.

Distribution of *B. fusca* larvae and pupae at harvesting stage of maize

Unlike mid-whorl and silking stages, at harvesting stage of maize *B. fusca* larvae distribution indices ($S^2/\bar{X}$ and $X^*/\bar{X}$) were near to one; Z values less than 1.96; Coefficients Taylor power (b) and Iwao values (β) were not significantly different from one (Table 5 and 6). The larvae index of dispersion ($S^2/\bar{X}$) ranged from 0.97 to 1.26; Z values from 1.08 to 1.43; Lloyd's mean crowding ($X^*/\bar{X}$) from 0.99 to 1.38 and Taylor power coefficients (b) ranged from 1.0 to 1.36 (Table 5). Similarly, the slopes of the regression lines of Iwao's regression (β) were not significantly greater than one and ranged from 1.01 to 1.20. The index of dispersion ($S^2/\bar{X}$) for pupae ranged from 0.93 to 1.21 with (Z) values from 0.90 to1.53; Lloyd's mean crowding ($X^*/\bar{X}$) ranged from 0.86 to 1.15 and the coefficients of Taylor's power law (b) ranged from 0.68 to 1.32; Iwao's coefficients (β) from 0.82 to 1.09 (Table 6). These results indicate that in both years, the distribution of *B. fusca* larvae and pupae at harvesting stage of maize was random.

Sampling size based on percent infestation of maize at mid-whorl stage

Sample size estimates were similar for the two years. The required sample units to estimate 5 to 30% mean infestation of maize by *B. fusca* ranged from,101 - 73, 45 - 32, 25-18 and 16 to 12 in 2015 and 104-76, 42-30, 26-19 and 17 to 12 in2016, for 10, 15, 20 and 25% precision, respectively (Figure 1). For 10% infestation, which is considered as action threshold level for stem bores management on maize, 85, 38, 22 and 14 sampling units were required for 10, 15, 20 and 25% precision, respectively.

DISCUSSION

Infestation of maize with *B. fusca* was aggregated at

Table 3. Levels of infestations and population density of *B. fusca* larvae and pupae in 2015 and 2016.

Location (Zone)	Stage of maize	2015			2016		
		Larvae/ plant	Pupae/ plant	Infestation (%)	Larvae/ plant	Pupae/ plant	Infestation (%)
Gurage	Mid-whorl	5.8±0.24		25.9±4.7	7.7±0.14		41.4±1.2
	Silking	3.0±0.18	1.2±0.08	42.3±4.8	2.7±0.15	1.6±0.09	67.3±4.8
	Harvesting	1.2±0.08	0.6±0.06	68.8+5.2	1.3±0.11	0.7±0.08	80.7±5.4
Sidama	Mid-whorl	4.2±0.21		13.6±2.7	4.1±0.21		19.5±2.1
	Silking	2.5±0.17	1.1±0.06	21.3±2.1	2.3±0.14	1.4±0.12	33.0±3.9
	Harvesting	0.9±0.07	0.6±0.5	36.8±1.5	0.9±0.09	0.8±0.07	65.5±6.5
Wolaita	Mid-whorl	4.7±0.18		21.5±2.5	6.0±0.17		32.0±1.6
	Silking	3.0±0.19	1.3±0.07	45.0±1.2	2.3±0.08	1.6±0.14	60.8±2.3
	Harvesting	1.3±0.08	0.9±0.07	60.8±1.7	1.5±0.12	0.8±0.08	72.7±3.4

Table 4. Distribution of *B. fusca* infestation in maize field derived from two distribution indices and two regressions at three stages of maize crop.

Zone	Maize growth stage	Year	Indices of dispersion	Lloyd's crowding	Taylor's power			Iwao's regression		
			$S^2/\bar{X}$	$X^*/\bar{X}$	a	b	P-value	a	β	P-value
Gurage	Mid-whorl	2015	1.67	1.59	-0.71	1.40	0.04	0.71	2.40	0.01
Sidama			1.48	1.72	-0.20	1.20	0.06	-0.60	2.40	0.03
Wolaita			1.91	1.18	-1.12	1.91	0.03	0.51	1.90	0.02
Gurage		2016	0.99	1.31	-0.40	1.70	0.03	0.24	1.90	0.02
Sidama			1.04	1.57	-0.62	1.50	0.02	0.60	1.40	0.05
Wolaita			1.81	1.35	-0.50	1.80	0.00	0.50	2.30	0.00
Gurage	Silking	2015	0.81	0.75	0.19	1.04	0.21	-0.51	0.92	0.13
Sidama			0.70	0.88	0.77	0.72	0.15	0.23	0.75	0.22
Wolaita			0.82	1.12	0.35	0.59	0.11	0.31	0.83	0.10
Gurage		2016	0.93	0.92	-0.03	0.94	0.06	-0.32	0.84	0.08
Sidama			0.87	0.97	0.08	0.87	0.07	-0.11	0.97	0.21
Wolaita			0.76	0.83	0.07	0.66	0.09	-0.21	0.86	0.09
Gurage	Harvesting	2015	0.99	0.55	0.03	0.78	0.12	0.03	0.85	0.19
Sidama			0.79	0.68	0.23	1.12	0.09	-0.13	0.69	0.21
Wolaita			0.74	0.54	0.16	0.83	0.07	-0.15	0.74	0.13
Gurage		2016	0.88	0.57	-0.02	0.65	0.73	-0.10	0.91	0.62
Sidama			0.83	0.74	-0.13	0.76	0.06	-0.14	0.93	0.51
Wolaita			0.66	0.67	-0.33	0.75	0.17	-0.21	0.60	0.42

P -values test whether or not b and β values for Taylor's power law and Iwao's are significantly different from 1; "a" stands for the intercept ; "b and β" stands slope values for Taylor's power law and Iwao's regression, respectively.

mid-whorl stage but uniform at silking and maturity stage of maize. *B. fusca* larvae were aggregated at both mid-whorl and silking stage of maize. The aggregated distribution pattern of distribution pattern during season could be caused by changes in population density or movement of larvae. *Busseola fusca* females oviposit a highly variable number (from 100 up to 800) of round and flattened eggs in batches (Kruger et al., 2012); larvae migrate to neighboring plants throughout the larval stages (Van Rensburg et al., 1987; Calatayud et al., 2014). Sun and Du (1991) reported that rice stem borer (*Chilo suppressalis*) larvae have an aggregated distribution pattern the active seasons but the dispersal rate of larvae in changes with developmental stages. The

Table 5. Spatial distribution of *B. fusca* larvae derived from two distribution indices and two regressions at three growth stage of maize crop in 2015 and 2016.

Zone	Maize growth stage	Year	Indices of dispersion		Lloyd's crowding	Taylor's power law			Iwao's regression			
			$S^2/\bar{X}$	Z	$X^*/\bar{X}$	a	b	p-value	R^2	a	β	P-value
Gurage	Mid-whorl	2015	1.87	2.67	1.27	-2.41	3.88	0.01	0.86	1.40	1.7	0.01
Sidama			1.46	2.23	1.10	-1.83	2.16	0.07	0.63	1.03	1.20	0.04
Wolaita			1.77	2.40	1.23	-3.03	3.46	0.04	0.72	1.40	1.40	0.00
Gurage		2016	2.64	2.82	1.25	-0.88	2.37	0.01	0.79	2.30	1.45	0.03
Sidama			2.02	2.57	1.51	-0.43	1.62	0.08	0.92	1.00	1.16	0.01
Wolaita			2.20	3.05	1.33	-0.50	2.17	0.03	0.92	1.20	1.14	0.00
Gurage	Silking	2015	2.30	3.20	1.52	-2.12	3.54	0.00	0.91	0.20	1.30	0.00
Sidama			1.24	1.87	1.21	-0.87	1.97	0.03	0.48	0.95	1.13	0.06
Wolaita			1.93	2.65	1.38	-2.28	2.37	0.02	0.76	0.52	1.26	0.01
Gurage		2016	1.34	2.21	1.35	0.25	2.31	0.06	0.76	0.28	1.20	0.04
Sidama			1.30	1.98	1.08	0.37	1.21	0.03	0.94	0.38	1.17	0.07
Wolaita			1.74	2.35	1.53	-1.20	1.50	0.04	0.91	1.14	1.12	0.02
Gurage	Harvesting	2015	1.09	1.19	1.21	0.21	1.18	0.56	0.87	-0.59	1.01	0.12
Sidama			0.97	1.08	0.99	0.14	1.00	0.49	0.50	-0.03	1.08	0.26
Wolaita			1.07	1.05	1.08	-0.56	1.29	0.12	0.76	-0.12	1.02	0.08
Gurage		2016	1.18	1.43	1.38	-0.01	1.36	0.08	0.65	-0.12	1.10	0.06
Sidama			1.26	1.21	1.33	0.85	1.05	0.12	0.73	-0.28	1.03	0.19
Wolaita			1.19	1.39	1.21	-0.56	1.14	0.07	0.86	-0.22	1.04	0.05

P - values test whether or not b and β values for Taylor's power law and Iwao's are significantly different from 1; "a" stands for the intercept ; "b and β" stands slope values for Taylor's power law and Iwao's regression, respectively.

Table 6. Spatial distribution of *B. fusca* pupae derived from two distribution indices and two regression at two growth stages of maize crop in 2015 and 2016.

Zone	Maize growth stage	Year	Indices of dispersion		Lloyd's crowding	Taylor's power			Iwao's regression			
			$S^2/\bar{X}$	Z	$X^*/\bar{X}$	a	b	p-value	R^2	a	β	P-value
Gurage	Silking	2015	1.15	1.31	1.15	-0.09	1.21	0.05	0.86	0.33	0.89	0.08
Sidama			0.84	1.15	0.82	0.22	0.94	0.12	0.63	-0.21	1.24	0.04
Wolaita			1.08	1.21	1.09	-0.44	1.34	0.20	0.71	0.50	1.16	0.07
Gurage		2016	1.00	1.09	1.30	0.62	1.34	0.14	0.67	0.53	1.02	0.15
Sidama			0.94	0.90	1.00	0.83	1.00	0.06	0.70	0.83	0.94	0.15
Wolaita			1.26	1.01	1.09	-0.21	1.03	0.11	0.88	-0.43	1.06	0.06
Gurage	Harvesting	2015	1.21	1.53	1.04	0.04	1.42	0.33	0.61	-0.06	1.09	0.63
Sidama			0.93	1.14	0.86	0.42	0.68	0.43	0.56	0.61	0.82	0.50

Table 1. Contd.

Wolaita		1.02	1.22	1.07	-0. 05	1.09	0.13	0.74	0.20	1.07	011
Gurage	2016	1.03	1.06	0.93	-0.16	1.36	0.05	0.89	0.16	0.99	0.42
Sidama		0.95	0.90	0.89	0.06	0.85	0.12	0.77	-0.38	0.84	0.15
Wolaita		1.12	1.15	1.15	0.21	1.14	0.09	0.82	-0.21	1.03	0.12

P - values test whether or not b and β values for Taylor's power law and Iwao's are significantly different from 1; "a" stands for the intercept ; "b and β" stands slope values for Taylor's power law and Iwao's regression, respectively.

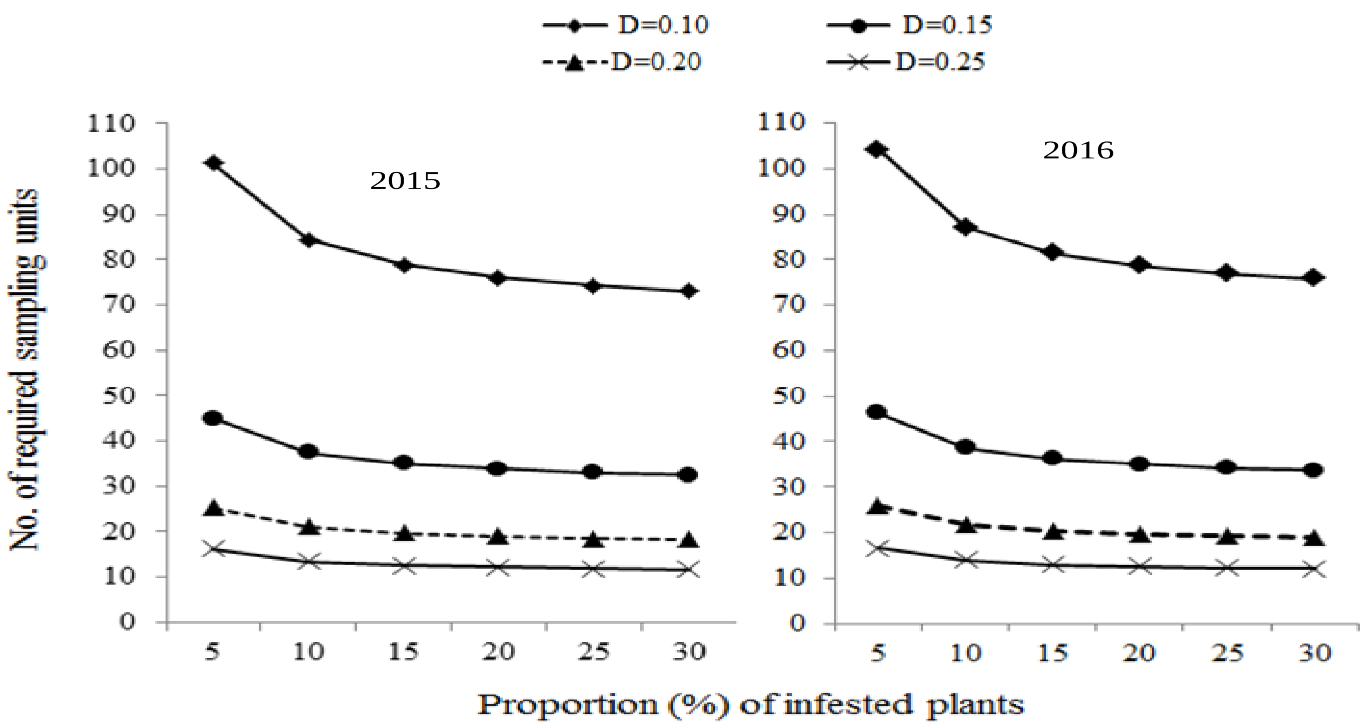

Figure 1. Relationship between number of required sampling units and proportion of infested maize plants by maize stem borer in 2015 and 2016 for four levels of precision (D = 0.10, D = 0.15, D = 0.20, D = 0.25 and D = 0.30) based on Kuno's (1969) method.

numbers of the required sampling units are dependent upon the insects being sampled, their distribution patterns, and other factors (Pedigo and Van Schaik, 1984). The required sampling size typically increased with higher precisions and for lower levels of infestations. An action threshold for *B. fusca* 10% infested plants has been recommended (Ong'amo et al., 2016; Van Rensburg et al., 1988). For 10% infestation 14 to

85 sampling units were required for precision ranges of 10 to 25%. A 25% level of precision is acceptable for scouting programs (Southwood, 1978). Taking a higher precision of 20%, for the 10% infestation 22 sampling units (660 plants) are required. In this study the required sample units were estimated with Kuno (1969)'s method which is based on Iwao's patchiness regression. Many studies used Taylor's power to estimate sample sizes. The Taylor's method reduces the necessary sample size when compared with Iwao's method (Darbemamieh et al., 2011; Ifoulis and Savopoulou-Soultani, 2006). Hence, the sample size recommended in this study could be considers as optimum.

Techniques of scouting which are easy to follow, save time and effort, and avoid needless insecticide applications are required. Although various studies have established the relationship between density of larvae of stem borers and yield loss in maize, count of larvae which employs destructive sampling is time consuming and not feasible to scout and decide on the management of stem borers. Van Rensburg and Pringle (1989) developed a sequential sampling method for egg surveys (based on the negative binomial distribution) and the method saved on time and effort required for sampling while allowing for more timely application of insecticides. We used presence and absence of infestation on maize by the stem borer which is easy to execute in the field.

This study concludes that, stem borer, B. *fusca* is a major constraint for the production of maize in southern Ethiopia. *B. fusca* has not one type of distribution pattern for all of its life stages. Infestation of maize with *B. fusca* is aggregated at mid-whorl stage but uniform at silking and maturity stage of maize. *B. fusca* larvae had an aggregated pattern at both mid-whorl and silking stage of maize and random at harvesting stage. At silking and harvesting stage of maize the distribution pattern of *B. fusca* pupa is random. The required sampling size typically increased with higher precisions and for lower levels of infestations. For 10% infestation, which is considered as action threshold level for stem borers management on maize, 22 sampling units (660 plants) at the precision of 20% are required.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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