Archives of Phytopathology and Plant Protection

ISSN: 0323-5408 (Print) 1477-2906 (Online) Journal homepage: http://www.tandfonline.com/loi/gapp20

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To cite this article: Tebkew Damte & Chris O. Ojiewo (2017) Incidence and within field dispersion pattern of pod borer, Helicoverpa armigera (Lepidoptera: Noctuidae) in chickpea in Ethiopia, Archives of Phytopathology and Plant Protection, 50:17-18, 868-884, DOI: 10.1080/03235408.2017.1401758

To link to this article: https://doi.org/10.1080/03235408.2017.1401758

ARCHIVES OF PHYTOPATHOLOGY AND PLANT PROTECTION, 2017
VOL. 50, NOS. 17–18, 868–884
https://doi.org/10.1080/03235408.2017.1401758

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Incidence and within field dispersion pattern of pod borer, *Helicoverpa armigera* (Lepidoptera: Noctuidae) in chickpea in Ethiopia

Tebkew Damte[a] and Chris O. Ojiewo[b]

[a]Debre Zeit Agricultural Research Center, Ethiopian Institute of Agricultural Research, Debre Zeit, Ethiopia; [b]International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) – Genetic Gains Program, Nairobi, Kenya

ABSTRACT
Podborer is a major pest of chickpea in Ethiopia. Field surveys were conducted in 2013/2014 and 2014/2015 in central and northwestern Ethiopia to assess the prevalence and within field distribution of the pest. Although podborer was prevalent throughout the surveyed areas, there was a significant difference in larval density (0.10–3.75 larvae per m^2) among zones and districts within zones. This variation was attributed to cropping history, cropping patterns, chickpea-crop adjacency, and weather (rainfall and temperature) conditions before and during the season as well as control measures applied. The optimum sample size required for precision ranged from 98, when podborer density was 10/m^2, to 1045, when podborer density was ≤1/m^2. Within field distribution of the larvae fitted a negative binomial distribution indicating that the larvae had a clumped/aggregated dispersion pattern. These results will enable chickpea stakeholders to develop and apply appropriate integrated crop management techniques for the control of podborer.

ARTICLE HISTORY
Received 21 June 2016
Accepted 3 June 2017

KEYWORDS
Incidence; chickpea; Ethiopia; *Helicoverpa armigera*; podborer

1. Introduction

Helicoverpa armigera Hubn is a major pest of chickpea – the world's third most important pulse crop – in almost all countries where the crop is grown, causing substantial damage to the crop especially at the pod formation stage (Deka et al. 1987; Lal 1996; Tripathy et al. 1999; Tebkew 2004). It begins to infest chickpea a week after crop emergence (Sequeira et al. 2001). Chickpea can be re-infested by pest populations that developed on it before the initiation of flower buds (Reed et al. 1987). The average pod damage on chickpea in Ethiopia has been reported to vary significantly depending on seasons and locations under on-farm conditions

CONTACT Chris O. Ojiewo c.ojiewo@cgiar.org, cojiewo@yahoo.com

and ranges from 1 to 72% (Kemal and Tibebu 1994; Shegaw 1995; Amare and Berhan 1998; Tebkew 2004).

H. armigera control with insecticide on chickpea is not common in Ethiopia; rather the majority of the farmers follow a "do nothing" strategy. Ethiopian agriculture is fast transforming from subsistence to commercial farming system and use of pesticides is expected to increase rapidly as scales of production increase. The indiscriminate use of pesticides to tackle losses caused by *H. armigera* can increase cost of production, affect human health, biodiversity and the environment. Besides, several chemical control methods have been evaluated but the pest keeps developing resistance to synthetic chemicals (Lande and Sarode 1995). Therefore, judicious use of pesticides following established guidelines and in a manner that minimises risks to human health, beneficial and non-target organisms, and the environment is recommended.

H. armigera is polyphagous, feeding ferociously and almost indiscriminately on some 181 cultivated and non-cultivated plant species across 45 families (Tsedeke et al. 1982; Lande and Sarode 1995; Waktole 1996). The use of resistant varieties is one component of integrated pest management (IPM) but high yielding chickpea cultivars with resistance to *H. armigera* have not been so far developed, released and commercialised through conventional breeding. Several screening trials have been conducted (Ogenga-Latigo et al. 1994; Bhagwat et al. 1995; Whightman et al. 1995; Hafeez and Kotwal 1996; Patnaik and Mohapatra 1997; Rashid et al. 2003; Hossain 2009; Sarwar et al. 2009) but so far germplasm sources with high levels of resistance to *H. armigera* have not been identified for commercial production. Laboratory and field screening studies have shown that *H. armigera* follows a hierarchy in food choice when a preferred host is unavailable (Jallow and Matsumura 2001). Currently, ICRISAT is working on a transgenic approach to transfer *Bacillus thurigensis* (Bt) genes for durable *H. armigera* resistance in chickpea as has been accomplished in cotton that is currently well adopted (Lu et al. 2012).

An Integrated Pest Management (IPM), combines different techniques such as biological control (Lulie and Raja 2012; Santhanam and Egigu 2014), habitat manipulation (Geletu et al. 1996; Stoll 2000), botanical pesticides (Dhaliwal and Arora 2001), judicious use of synthetic pesticides (Munro 1987; Kemal and Tibebu 1994), and use of less susceptible varieties. Different cultural practices including host plant resistance and insecticides have been evaluated in Ethiopia to determine their efficacy in suppressing *H. armigera* population and promising results have been documented (Seid and Tebkew 2004). These need to be packaged into IPM strategies and introduced to chickpea growers for control of *H. armigera*.

Analysis of seasonal population dynamics and within field distribution patterns is critical for designing efficient and cost-effective integrated pest management strategies (Madadi et al. 2011). Mapping the pest density, geographical as well as within field distribution of podborer, knowledge of the farming systems, insect–host plant interaction and socio-economic constraints are prerequisites for a successful IPM programme. Conducting periodical field survey on the target crop and the associated insect pest is an important step towards generating and consolidating this information. In this study we assessed the current status (prevalence and distribution) and within field distribution of *H. armigera* in chickpea in Ethiopia.

2. Materials and methods

Incidence and within field distribution of *H. armigera* in chickpea crop was assessed in 57 fields in 2013/2014 and 113 fields in the 2014/2015 cropping season in the central and northwestern parts of Ethiopia. Field surveys were conducted in the third to fourth week of December 2013/2014 and from the last week of November to second week of December in 2014/2015. In 2013/2014 cropping season, zones covered by the survey in Oromia Regional State (central Ethiopia) were West Shewa, Southwest Shewa, and North Shewa, whereas in the Amhara Regional State (northwestern Ethiopia) only East Gojjam zone was surveyed. In the 2014/2015 season, other than those zones surveyed in the 2013/2014 season, the Gurage zone in Southern Nation, Nationality, and Peoples (SNNP) regional state was included. Chickpea fields were randomly selected at the interval of 5 to 10 km along roadsides. Since the area of chickpea grown by a household is about 0.1 ha or less, five 1 m × 1 m quadrat samples were taken at two to three metres intervals in cross diagonal line and the crop within the quadrat was inspected for presence of *H. armigera* and other insect pests. In each quadrat the total number of *H. armigera* larvae was visually counted *in situ* and recorded. Moreover, note on natural enemies of *H. armigera* was taken on whole field base. Because most chickpea crop is grown on Vertisols and this soil occupies particular area, the sampled fields within a zone were grouped into one district(s) when the distance between two successive sample fields along a road was ≥20 km. Ancillary data such as planting time, previous crop and *H. armigera* management methods were recorded.

2.1. Statistical analysis

A two factor nested design was used to determine if there were differences among zone or districts within zones in *H. armigera larvae* density. To do this, locations were grouped into one district when the distance between two successive sample chickpea fields along a road was ≥20 km. Sample fields (locations) were nested under each district and the quadrats in a sample field were considered as replicate. Thus, there were five replicates. The data contained many zero values and before analysis larval count data were transformed to log $(x + 1)$, where x = original count data.

To assess the effect of crop stage on *H. armigera* incidence, the chickpea fields within each districts were grouped as vegetative, flowering, poding and full poding stages; for each crop stage mean density of *H. armigera* estimated and finally paired *t*-test conducted.

2.1.1. Landscape diversity

To determine the landscape diversity the crop species grown on fields adjacent to the sample chickpea field were recorded and their frequency was determined over the entire surveyed zones.

2.1.2. Determining within field distribution of H. armigera

To characterise the pattern of dispersion of *H. armigera* within a field, each sample quadrat was assumed to be independent and using these data frequency distribution of *H. armigera* was determined. The larval frequency distribution in both seasons was skewed to the right, which suggests that *H. armigera* larval within field distribution was clump (aggregated) type (Figure 1). Therefore, the data were tested for whether they fit the negative binomial distribution or not. To estimate k of the negative binomial, the maximum likelihood equation was used (Elkinton 1993; Davis 1994). The data used to determine the frequency distribution of *H. armigera* were also used to estimate the overall mean ($\bar{x}$) and its variance(s^2). The mean and the variance in turn were used to estimate the starting k value as:

$$k = \frac{\bar{x}^2}{s^2 - \bar{x}}. \tag{1}$$

Then the accurate value of k was calculated using the starting value of k in the equation:

$$N \ln\left(1 + \frac{\bar{x}}{k}\right) = \sum_{x=0}^{n} \frac{A_{(x)}}{k + x}, \tag{2}$$

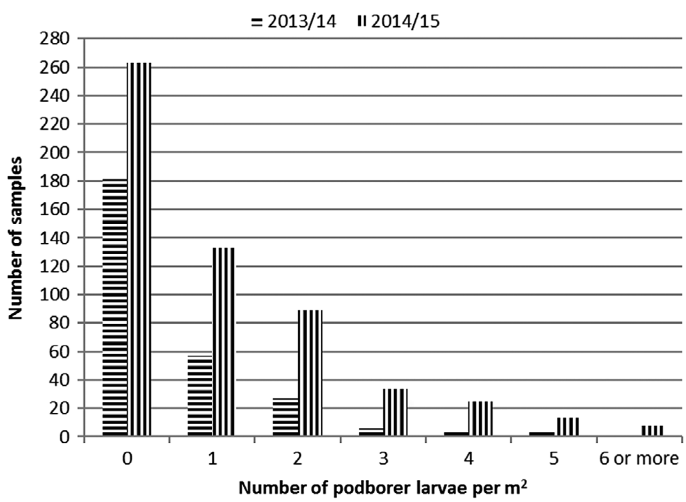

Figure 1. Frequency distribution of podborer, *Helicoverpa armigera* (Hub) larvae in chickpea.

where $A_{(x)}$ = number of samples with more than x individuals, N = total number of samples, n = maximum number of individuals (the highest frequency category), and k as defined above. The starting k value was modified successively until both sides of the equation were equal. After calculating the accurate k value it was used to estimate the probability that a sample contains n number of larvae i.e. $P(X = n)$ as:

$$P(X = n) = \left(\frac{k + n - 1}{n}\right)\left(\frac{\bar{x}}{\bar{x} + k}\right) * P(X = n - 1). \tag{3}$$

While the $P(X = 0)$ was estimated as:

$$P(X = 0) = \left(1 + \frac{\bar{x}}{k}\right)^{-k}. \tag{4}$$

The calculated probability values were multiplied with the total number of sample units (N) to determine the expected frequencies of individuals in the respective larval category. The chi-square test with n = 3 df was used to test the fitness of data onto negative binomial distribution (Figure 1).

2.2. Optimal sample size

The optimum number of sample units is the smallest number of sample units that would satisfy the objectives of the sampling programme and achieve the desired precision of estimates. Thus, the optimum number of sample units for sampling *H. armigera* larvae in chickpea was determined using the formula described by Young and Young (1998), which is:

$$n_{\text{opt}} = \left(\frac{z_{\alpha/2}}{D}\right)^2\left(\frac{1}{\mu} + \frac{1}{k}\right) \tag{5}$$

where n_{opt} = optimal sample size, k = estimated k value of the negative binomial of the respective years, μ = population mean, $\alpha = 0.05$, $Z_{\alpha/2}$ = the $(1 - \alpha/2)$ quantile of the standard normal distribution and D = desired precision at $\alpha = 0.05$ (10 and 20% were considered)

3. Results and discussion

3.1. Landscape diversity

In each season a total of 15 crop species were grown interspersed throughout the surveyed zones. On average, there were four crop species adjacent to individual chickpea fields. The most frequently encountered cereal crop was tef (*Eragrostis tef*), adjacent to 42.2 and 36.0% of the surveyed chickpea fields in the 2013/2014 and 2014/2015, respectively. Wheat (*Triticum aestivum, T. durum*) was second in occurrence (8–9%), while maize (*Zea mays*), sorghum (*Sorghum bicolor*), and barley (*Horedenum vulgare*) were less frequent.

Grasspea (*Lathyrus sativus*) was the most frequent legume adjacent to chickpea at 25.6 and 20.6% adjacency to chickpea fields in 2013/2014 and in 2014/2015, respectively. Chickpea–chickpea adjacency was less frequent at 14.4% in the 2013/2014 and 12.3% in the 2014/2015 season. Other legume crops grown were lentil, faba bean, field pea, and fenugreek. Vegetable crops such as tomato, pepper, onion and potato were also components of the landscape. Noug (*Guizotia abyssinica*) and cotton were prevalent in East Gojjam zone.

The type of diversity introduced by interspersed chickpea fields could help enhance parasite and predator attraction to the agro-ecosystem, especially if the crops in between provide appropriate alternate hosts for the pests or if they provide suitable ground cover for predators (Altieri and Letourneau 1982; Brown and Marten 1986; Andow 1988; Stoll 2000). *H. armigera* is an important pest of most of the crops including tomato, pepper, field pea, faba bean, lentil, cotton, fenugreek and noug (Tsedeke et al. 1982). For example, some of the crops after which chickpea was planted in the double cropping practice of Welkite area are alternate hosts of the pest (Tsedeke et al. 1982; Waktole 1996), providing opportunity for the pest to build up faster and sooner on the chickpea crop

In the 2013/2014 season only 15.3% ($n = 13$), 21.4% ($n = 14$) and 3.7% ($n = 27$) chickpea fields in Southwest Shewa, West Shewa and East Gojjam zone, respectively, were sown to improved chickpea varieties. In the 2014/2015, the proportion of chickpea fields sown to improved chickpea varieties were only 23.3% ($n = 30$), in Southwest Shewa, 18.8% ($n = 16$) in West Shewa, 9.0% ($n = 11$) in Gurage zone and 11.8% ($n = 51$) in East Gojjam zone. In both seasons the remaining fields were sown to local landraces.

3.2. *Incidence of* H. armigera

In 2013/2014 season, there was significant difference among district ($F = 2.314$, $\alpha = 0.05$, $df_1 = 6$, $df_2 = 48$) and highly significant difference among locations within districts ($F = 2.784$, $\alpha = 0.01$, $df_1 = 48$, $df_2 = 225$) in the number of *H. armigera* larvae per m^2. However, in terms of variance component, district and locations within district accounted for only 27 and 24% of the total variability, respectively. The highest larval density was recorded in Abeya Gorge, which was followed by Debre Work – Mota districts, both in East Gojam zone (Table 1). On the other hand, chickpea fields in Dejen-Awabel districts had the lowest larval density. The remaining zones and districts had intermediate level of *H. armigera* infestation.

Similarly, in 2014/2015 season, there was highly significant difference among districts and locations within districts ($F = 10.919$, $\alpha = 0.01$, $df_1 = 12$, $df_2 = 100$ and $F = 3.084$, $\alpha = 0.01$, $df_1 = 100$, $df_2 = 452$, respectively) in the number of *H. armigera* larvae per m^2. In terms of variance component, district accounted for 33.6% of the total variance, while locations within district accounted for about 19.6%. As

Table 1. Incidence of *Helicoverpa armigera* in different chickpea growing districts of Ethiopia.

		Year 2013/2014		Year 2014/2015	
Zone	District	Number of sample quadrats	Average density of larvae per m^2	Number of sample quadrats	Average density of larvae per m^2
Southwest Shewa	Sebeta-Woliso	65	0.65 ± 0.20	95	0.46 ± 0.08
	Buie-Alemgena	–	–	55	1.82 ± 0.18
West Shewa	Holeta-Ambo	65	0.54 ± 0.12	80	0.71 ± 0.11
East Gojam	Dejen-Debre Work	50	0.52 ± 0.11	55	0.56 ± 0.13
	Debre Work-Mota	40	0.95 ± 0.19	45	1.73 ± 0.25
	Dejen-Awabel	30	0.10 ± 0.05	40	0.10 ± 0.05
	Abeya Gorge	15	1.80 ± 0.48	35	3.49 ± 1.14
North Shewa	Debre Tsige-Fitche	15	0.47 ± 0.21	25	0.12 ± 0.07
Gurage	Welkite	–	–	20	1.20 ± 0.33
	Buie-Butajira	–	–	35	1.49 ± 0.22
West Gojam	Asterio-Adet	–	–	35	1.37 ± 0.20
	Bahir Dar Zuria	–	–	25	1.44 ± 0.20
	Jiga-Debre Markos	–	–	20	1.75 ± 0.40

was the case in 2013/2014 season, chickpeas in Abeya Gorge and Dejen-Awabel districts had the highest and lowest larval density, respectively (Table 1).

3.3. Southwest Shewa zone

In Sebeta-Woliso district only few (15.3%) of the surveyed chickpea fields in 2013/2014 season were at vegetative stage but in the succeeding season, nearly half of (47.4%) the surveyed fields were at vegetative stage, sown mostly in October. About 23.1% ($n = 13$) in the 2013/2014 and 26.3% ($n = 19$) in the 2014/2015 season were free of *H. armigera* infestation, while the remaining fields were infested by different levels of *H. armigera* larvae (Table 2). The average density of *H. armigera* larvae was greater in chickpea fields that were at reproductive stages than those at vegetative stage.

The relatively low laval density observed at Sebeta-Woliso niche of Southwest Shewa could be associated with the planting time at this district. Trials on planting date, using kabuli varieties on vertisols at Debre Zeit, Akaki, and Chefe Donsa in Ethiopia showed that there were significant and consistent differences in the level of infestation among planting dates. The earliest planting date (1st week of August) gave the highest grain yield of chickpea at all locations, most likely because of better soil moisture (Million 1994). It would be expected that very early and very late planted chickpea would be more infested with the pest because there would be fewer "alternative food" in the field. With October planting and plants at vegetative stages, it is not surprising that the laval density was relatively low.

Chickpea fields at Awash Bune (both on kabuli and desi chickpea types) and Seyoma were sprayed with insecticides against *H. armigera* but the density was still an average of 0.4–1.6/m^2.

Table 2. The effect of crop stage on *Helicoverpa armigera* larval density in different chickpea growing areas of Ethiopia.

		Crop stage (2013)*				Crop stage (2014)*			
Zone	District	Vegetative	Flowering	Poding	Full poding	Vegetative	Flowering	Poding	Full poding
Southwest Shewa	Sebeta Wolliso	$0.50^{b}\pm0.26$ (10)	$0.45^{c}\pm0.18$(20)	$0.0^{d}\pm0.0$ (5)	$0.93^{a}\pm0.27$ (30)	$0.29^{c}\pm0.09$ (45)	$0.51^{b}\pm0.13$ (35)	$0.50^{b}\pm0.22$ (10)	$1.60^{a}\pm0.68$ (5)
	Buie-Alemgena		–	–	–	–	$2.40^{a}\pm0.92$ (5)	$1.89^{b}\pm0.26$ (35)	$1.47^{c}\pm0.25$ (15)
North Shewa	Debre Tsi-ge-Fitche		–	–	0.47 ± 0.21 (15)	–	$0.10^{b}\pm$ 0.10 (10)	$0.13^{a}\pm0.09$ (15)	–
West Shewa	Ambo-Holeta		$0.08^{c}\pm0.06$ (25)	$0.85^{a}\pm0.24$ (20)	$0.80^{b}\pm$ 0.28(20)	$0.68^{b}\pm0.18$ (40)	$0.60^{c}\pm0.14$ (35)	$1.80^{a}\pm0.37$ (5)	–
East Gojam	Dejen-Debre Work		$0.33^{b}\pm0.16$ (15)	$0.60^{a}\pm0.23$ (20)	$0.60^{a}\pm0.19$ (15)	–	0.56 ± 0.13 (55)	–	
	Debre Work Mota	$0.00^{c}\pm0.00$ (5)	$0.0^{c}\pm$ 0.00 (10)	$0.93^{b}\pm0.15$ (15)	$2.4^{a}\pm$ 0.47(10)	$0.0^{c}\pm0.0$ (5)	$1.84^{b}\pm0.23$ (25)	–	$2.13^{a}\pm0.60$ (15)
	Abeya Gorge	–		$1.40^{b}\pm0.97$ (5)	$2.00^{a}\pm0.55$ (10)	–	$3.75^{a}\pm0.52$ (20)	–	$3.13^{b}\pm0.46$ (15)
	DejenAwabel	–	$0.10^{a}\pm0.06$ (20)	$0.10^{a}\pm0.01$ (10)		$0.04^{b}\pm0.04$ (25)	$0.20^{a}\pm0.10$ (15)	–	
Gurage	Welkite	–	–	–	–	1.20 ± 0.33 (20)	–	–	–
	Buie-Butajira	–	–	–	–	$1.21^{c}\pm0.41$ (10)	$1.57^{b}\pm0.25$ (15)	$1.80^{a}\pm0.55$ (10)	
West Gojam	Asterio-Adet	–	–	–	–	$1.15^{b}\pm0.22$ (20)	$1.67^{a}\pm0.36$ (15)	–	–
	Bahir Dar Zuria	–	–	–	–	1.44 ± 0.20 (25)	–	–	–
	Jiga Debre Markos	–	–	–	–	1.75 ± 0.40 (20)	–	–	–

*Means followed by different letters within a row in a year are statistically different from each other at $p < 0.05$; the number in parenthesis indicates the number of quadrats.

In the Alemgena-Buie district all the chickpea fields were at reproductive stage and the density of *H. armigera* was greater at flowering stage than at poding and full poding stages (Table 2). Farmers in this district sow chickpea between the third and fourth week of August. In this district, except in the Haro area where there was no infestation, the pest was prevalent in all other fields and there were an average of ≥1 larvae per m^2. The infestation was severe in Lemen and Kersalema areas and there were 2–5 larvae per m^2. Moreover, in many locations such as Teree, Mazoria-golba and Awash Melka areas the percentage of damaged pods per plant was 30–40% but the number of larvae found was ≤2/m^2.

The high prevalence of *H. armigera* observed in Alemgena-Buie niche was no surprise as planting here was done early and the crop was at full podding stage. Damage by *H. armigera* begins on young shoots, leaves and pods soon after hatching. The population peaks generally corresponds to the full bloom and pod formation stage of chickpea (Patel and Koshiya 1999).

3.4. West Shewa zone

In the 2013/2014 season all the surveyed fields were at reproductive stage, whereas in the 2014/2015 season half of the crop was at vegetative stage and the other half at reproductive stage (Table 2). In 2014/2015, the rainy season was unusually long, lasting from June to October, necessitating late planting to avoid wilt/root rot and ascochyta blight. Larval infestation was not detected on 21.4 and 18.9% of the surveyed fields in 2013/2014 and 2014/2015 season, respectively. Moreover, in the majority of the chickpea fields the larval density was <1 per m^2. In both seasons, the highest larval density was recorded in chickpea fields that were at poding stage. *H. armigera* population is affected by prevailing weather conditions such as strong winds, heavy rains, or extreme temperature. In particular, heavy rainfall and winds reduce the population at the egg and larval stages (Karmawati and Kardinan 1995; Fowler and Lakin 2001). This could have been the case from *H. armigera* host plants available prior to chickpea planting, reducing the population during chickpea growing period to near zero.

A few chickpea fields (21.4%) in the 2013/2014 season were sprayed with insecticide but the crop was still infested. Although the exact reason why the spraying was not effective is not known, pesticide resistance, poor time of application, poor coverage, poor calibration, pesticide expiry, increased oviposition for increased laval population and pod damage are the likely reason for such outcome. The situation is indicative of the need for rendering advisory service and training farmers on safe use of insecticides on chickpea and application of IPM packages.

In both West and South West Shewa, the spatial continuum of chickpea fields was very fragmented; as a result chickpea fields were interspersed with *H. armigera* host and non-host crop fields. Although the contribution of this diverse landscape to the reduction of infestation has not been studied, we can postulate that it created mechanical barriers and restricted the dispersal of the pest by increasing the host searching time of egg-laying moths or served as diversionary host to the adult moths (Shelton and Badenes-Perez 2006). Besides, landscape diversity could provide habitat for natural enemies (Brown and Marten 1986; Stoll 2000).

3.5. North Shewa zone

Most of the chickpea growing fields here were inaccessible. Therefore, only few fields were surveyed. In both seasons the crop was at reproductive stage. Although most fields were infested by *H. armigera,* the larval density was $<1/m^2$ (Table 2). Like all other zones, there was significant landscape diversity with chickpea fields interspersed between a wide array of host and non-host plants. The type of diversity introduced by interspersed chickpea fields could help enhance parasite and predator attraction to the agro-ecosystem, especially if the crops in between provide appropriate alternate hosts for the pests or if they provide suitable ground cover for predators (Altieri and Letourneau 1982; Andow 1988).

3.6. Gurage zone

In Welkite district all the sample chickpea fields were double cropped either after harvesting maize or haricot bean. All fields were at vegetative stage, but they were infested by the *H. armigera* (Table 2). The average density of larvae per m^2 was lowest in Wolkite area, whereas the highest larval density ($1–5/m^2$) was recorded in Hole area. Most of these crops after which chickpea was planted are alternate hosts of the pest (Tsedeke et al. 1982; Waktole 1996), providing opportunity for the pest to build up faster and sooner on the chickpea crop.

In Butajira-Buie district, chickpea was at reproductive stage and all of the surveyed fields were infested by *H. armigera*. However, chickpea fields that were at poding stages had greater larval density than those fields that were at flowering stage (Table 2). The crop stand in most fields was very poor. In Negesa area *H. armigera* infestation was severe ($\leq 5/m^2$). The higher larval density in Butajira-Buie and Buie-Alemgena districts was probably due to availability of *H. armigera* hosts such as cotton, tomato and other vegetables which are grown under irrigation throughout the year in the Rift Valley. The adult *H. armigera* moths are known to migrate short and long distance from such host plants (Pimbert and Srivastava 1991; Bouvier and Boudinhon 2005).

3.7. East Gojjam zone

In Dejen-Debre Work niche (Bichena plain) chickpea was at reproductive stage in both seasons. Two chickpea fields were free of *H. armigera* infestation. The average density of *H. armigera* larvae was $<1/m^2$ (Table 2). In the first season, the *H. armigera* density was greater at poding stage than at full poding or flowering stage. In Debre Work-Mota district chickpea crop was at reproductive stage except in Dimet-Gedel area, where the crop was sown after the river water had receded. The frequencies of chickpea fields which were not infested by the *H. armigera* were greater in the 2013/2014 than in the 2014/2015 season. Moreover, the density of H. armigera was greater at full poding stage than at flowering stage.

In the 2014/2015 season two-thirds of the surveyed chickpea fields had ≥1 *H. armigera* larvae per m^2. In the Beza-Bizuhan area the number of *H. armigera* larvae per m^2 ranged 1–8 and about 40% of the pod was damaged. Farmers in this area indicated that they do not know any type of control measure against *H. armigera* . The low *H. armigera* density in Dejen-Debre Work niche might be attributed to the unavailability of suitable host. Besides, there were 1.2–31.2 and 2.6–26.4 dead plants per m^2 due to wilt/root rot disease in 2013/2014 and 2014/2015 season, respectively. Wilted and/or dead plants are unattractive to ovipositing *H. armigera* moths and are nutritionally less suitable to the larvae (Nyambo 1988). Like most parts of North Shewa, the cropping patterns in East Gojjam included wide crop diversities mixing host and non-host plants of *H. armigera.* It is plausible to recommend that judicious selection of species/varieties for intercrop could add to IPM packages by reducing the population or feeding damage to chickpea by serving as a more suitable host for the pest or its natural enemies. Care should be taken to avoid exacerbating the pest problem by providing more shelter and food plants to the pest and building up its populations against the target crop at later stages.

In Abeya Gorge niche chickpea was at reproductive stage and the *H. armigera* was prevalent in all the surveyed fields. Compared to all other districts, in both years, Abeya Gorge district had the highest *H. armigera* larval density and up to 85% of the pods were damaged. In Kontir (2) area there were 2–11 *H. armigera* larvae per m^2. The high density of *H. armigera* here was probably due to the cropping sequences that the farmers had developed over the years. Farmers sow *H. armigera* host plants such as cotton, haricot bean, pepper, maize and sunflower at the beginning of the rainy season and the *H. armigera* that bred on these crops will infest chickpea crops sown later in the season. Therefore, reducing the *H. armigera* larval population on early season crops will help to reduce the level of infestation in chickpea. The other possible reason for high density of *H. armigera* in this area is the higher temperature (20–35 °C) that provided optimum conditions for the pest life cycle. The optimum temperature for development from 1st instar larva to adult, and the optimal survival temperatures for pupae and for larvae have been reported to be 33.9, 27 and 24 °C, respectively (Twine 1978).

In the Dejen-Awabel district all chickpea fields in the first season and 37.5% of the chickpea fields in the second season were at reproductive stage. The remaining 63.5% were at vegetative stage and flowering stages. Only few chickpea fields were infested, with <1 larva per m^2. Other than chickpea, grasspea (*Lathyrus sativus*) is the only cultivated host grow in this district. In the Asteriyo-Adet, the crop was at vegetative and flowering stage and there were more H. armigera larvae in chickpeas that were at flowering stage than those at vegetative stage. In Bahir

Dar-Zuria and Jiga-Debre Markos districts most chickpea fields were double crops after tef, barley, or haricot bean and they were at vegetative stage. All chickpea fields were infested with ≥1 larvae per m^2. This is expected as the preceding crops are alternate hosts of the pest.

3.8. *Natural enemies of* H. armigera

Ichneumonid wasps were reported to cause 5–10% mortality of the pest on chickpea in Wollo Zone. Further, Assasin bugs, Tachinids, Ichneumonid wasps (*Charos spp*), spider and egg parasitoids (*Trichograma* species) were reported to prey on the pest on different crops (Seid and Tebkew 2004). Besides, 11 natural enemies of pod borer on bean and cotton have been reported in the Rift Valley (Tsedeke 1995). In this study, general predators such as dragonflies, wasps and different bird species were noted preying on *H. armigera*. The level of parasitoid attack on *H. armigera* was low and only ichneumon wasps were found in Beza Bizuhan, Jiga and Killt area. In East Africa, parasitoids and predators of *H. armigera* are associated with particular host (Van der Berg and Cock 1993). Research on natural enemies of chickpea pests in general and *H. armigera* in particular has not gone beyond preliminary survey in Ethiopia (Seid and Tebkew 2004). Thus, to identify the natural enemies of *H. armigera* associated with chickpea and determine their contribution to the reduction of *H. armigera* population, monitoring of natural enemies in relation to the phenology of the crop and the insect is recommended.

3.9. *Within field distribution of* H. armigera

The estimated k values of the negative binomial distribution were 0.6801 and 1.0818 in the 2013/2014 and 2014/2015 season, respectively. There was no statistically significant difference ($X^2 = 6.48$ in 2013/2014 and $X^2 = 6.10$ in 2014/2015, X^2 ($\alpha = 0.05$, df = 4) = 9.49) between observed and expected larval density frequencies. Therefore, the within field distribution of *H. armigera* larvae fits the negative binomial distribution indicating that the *H. armigera* had clumped/aggregated type of spatial dispersion in chickpea. However, the clump size was close to one individual larva per clump per m^2 (Figure 1). The density of *H. armigera* larvae was variable from sampling point to sampling point within a field, which was revealed as clumped/ aggregated in the spatial dispersion analysis. Even though spatial distribution patter is believed to be species characteristics (Coster and Johnson 1979), clumped pattern of dispersion might arise from the distribution of the host on which the herbivore feeds and breeds (Elkinton 1993). The larvae were not equal in age and had different colour pattern, which suggests that the adult moths had laid their eggs at different times.

3.10. Optimal sample size

As indicated above the spatial dispersion patter of *H. armigera* was aggregated type and the average number of individual larva per clump was about one (0.845). This mean number was used as minimum mean number of *H. armigera* per m^2 in determining the optimal sample size. The optimal size required to estimate the mean number of *H. armigera* with precision level of 10 and 20% ($D = 0.1$ and $D = 0.2$, respectively) of the mean with 95% confidence ($\alpha = 0.05$) is shown in Figure 2. Generally, the optimal sample size in 2013/2014 season was greater than the 2014/2015 season. Thus, to get mean of 0.8 larvae per m^2, which is the average size of the clump, at a precision level of 10%, the optimal sample size was 1045 in the 2013/2014, while it was only 835 in the 2014/2015 season. Similarly, at precision level of 20% the optimum sample size required to get a mean of 0.8 larvae per m^2 were 261 and 209, in 2013/2014 and 2014/2015 seasons, respectively. The optimal number of samples decreased as the number of larvae per m^2 increased. Thus, if the mean number of pod borers per m^2 were 10, the optimum number of samples at 10% in 2013/2014 season would 603 and only 394 in the 2014/2015 season. It further dwindled to 151 and 98 at 20% precision in the 2013/2014 and 2014/2015 seasons, respectively.

Aside from characterising the spatial dispersion pattern of an insect species, the k value of the negative binomial distribution is used to determine the optimum sample size required for precise population estimates (Ifoulis and

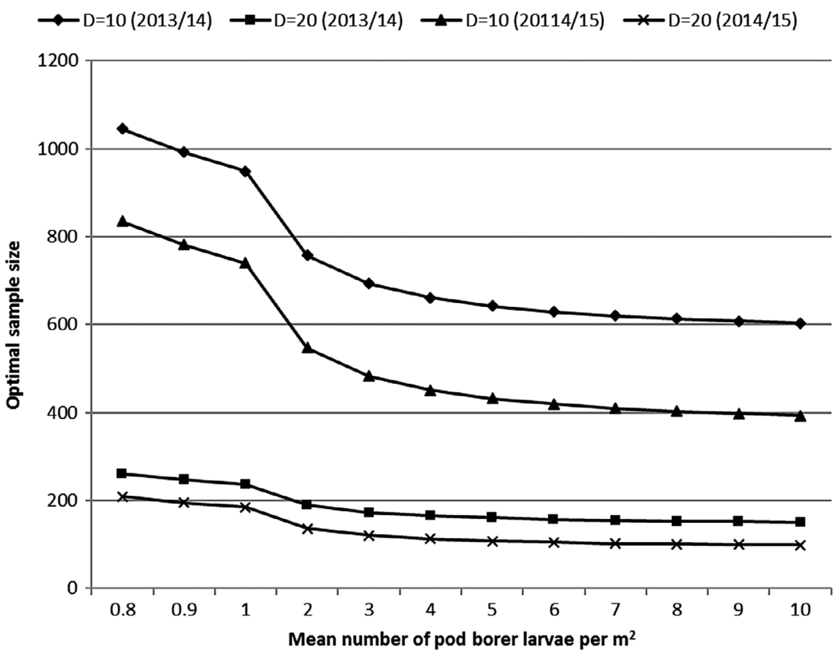

Figure 2. Relationship between mean number of pod borer larvae per m^2 and optimal sample size.

Savopoulou-Soultani 2006). However, in this study, the optimum sample sizes estimated based on the calculated k values were relatively large especially when the larval density was ≤1 per m^2. Moreover, the sample size fluctuated between seasons, precision level required and density of pod borer larvae. Similar type of optimal sample size fluctuation has also been reported for other insect pests such as *Sitonia humeralis* in alfalfa (Arbab and McNeill 2014), *Megacopta cribraria* in soybean (Stubbins et al. 2014). Optimal sample size also varies between generations of a particular species (Ifoulis and Savopoulou-Soultani 2006). Such sample size fluctuation could be attributed to the sample size used to estimate parameters such as *k* of the negative binomial and to the direct and indirect effect of season on the population of insects. Moreover, according to Binns and Nyrop (1992) densities of a particular life stage changes independently of overall population density through phenological maturation of the population.

4. Conclusions

There are two major limitations of determining optimal sample size. First, although the determination of optimum sample size using different formulae is theoretically acceptable, the calculated sample size might not fit for small scale chickpea production system, where the size of chickpea field is smaller. For instance, in this study, at precision level of 10%, at $\alpha = 0.05$ and mean larval density of 0.8/m^2, the estimated optimum sample size was 1045 1 m^2 quadrats, which often times equals the size of the entire field. Second, as pointed out by Morris (1960) the procedures used to determine optimum sample size do not consider costs associated with sampling. Therefore, the large optimal samples size, at precision level of 10%, can be used in ecological studies on pod borer, while the relatively small optimal sample size, at precision level of 20%, can be for decision making in integrated pod borer management in chickpea. In this study, a significant difference in *H. armigera* larval density was found among zones and districts within zones. This could be due to differences in cropping history, cropping patterns, chickpea-crop adjacency, and weather (rainfall and temperature) conditions before and during the season as well as pest management measures. These, therefore are important factors for consideration in designing and integrated pest management regime for control of *H. armigera* of chickpea in Ethiopia.

Acknowledgement

The authors acknowledge Dr Negussie Tadesse, Asrat Zewudie, Eresi Megersa, Tayu Shewangizaw, Woncha Bejiga and Assefa Kebede for their help during data collection.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This study was conducted jointly by Debre-Zeit Agricultural Research Center and the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) as part of the Tropical Legumes III project with financial support availed from Bill and Melinda Gates Foundation through ICRISAT..

ORCID

Chris O. Ojiewo http://orcid.org/0000-0002-2885-9381

References

Altieri MA, Letourneau DK. 1982. Vegetation management and biological control in agroecosystems. Crop Prot. 1:405–430.

Amare A, Berhan A. 1998. Research on insect pest and diseases in North Shewa. In: Beyen S, Abera D, editors. Agricultural research and technology transfer attempts and achievements in Northern Ethiopia. Proceedings of the 4th Technology Generation, Transfer and Gap Analysis Workshop in Bahidar Ethiopia. Ethiopia: Ethiopian Institute of Agricultural Research. p.146–147.

Andow DA. 1988. Management of weeds for insect manipulation in agro-ecosystems. In: Altieri MA, Liebman M, editors. Weed management in agro-ecosystems: ecological approaches. Boca Raton (FL): CRC Press; p. 265–300.

Arbab A, McNeill MR. 2014. Spatial distribution and sequential sampling plans for adult *Sitona humeralis* Stephens (Coleoptera: Curculionidae) in alfalfa. J Asia-Pac Entomol. 17:515–519.

Bhagwat VR, Aherkar SK, Satpute US, Thakare HS. 1995. Screening of chickpea (*Cicer arietinum* L.) genotypes for resistance to gram pod borer *Helicoverpa armigera* (Hubner) and its relationship with malic acid in leaf exudates. J Entomol Res. 19:249–253.

Binns MR, Nyrop P. 1992. Sampling insect populations for the purpose of IPM decision making. Annu Rev Entomol. 37:427–453.

Bouvier RB, Boudinhon L. 2005. Insecticide resistance and mechanism of resistance to selected strains of *Helicoverpa armigera* (Lepidoptera: Noctuidae) in the south France. Crop Prot. 24:814–820.

Brown BJ, Marten GG. 1986. The ecology of traditional pest management in the Southeast Asia. In: Marten GG, editor. Traditional agriculture in the Southeast Asia: a human ecology perspective. Boulder (CO): Westview Press; p. 241–272.

Coster JE, Johnson PC. 1979. Characterizing flight aggregation of the Southern pine beetle. Environ Entomol. 8:381–387.

Davis PM. 1994. Statistics for describing populations. In: Pedigo LP, Buntin GD, editors. Handbook of sampling methods for arthropods in agriculture. Boca Raton (FL): CRC Press; p. 33–54.

Deka NK, Prasad D, Chand P. 1987. Succession and incidence of insect pests in chickpea, *Cicer arietinum* L. Giornale Italiano di Entomol. 3:421–428.

Dhaliwal GS, Arora R. 2001. Integrated pest management: concepts and approaches. New Delhi: Kalyani; 427 p.

Elkinton JE. 1993. Insect population ecology: an African perspective. Nairobi: ICIPE Science Press; 99 p.

Fowler G, Lakin K. 2001. Risk assessment: the old bollworm, *Helicoverpa armigera* (Hubner), (Lepidoptera: Noctuidae). Raleigh (NC): USDA-APHIS, Center for Plant Health Science and Technology (Internal Report); p. 1–19.

Geletu B, Million E, Yadeta A. 1996. Improved cultivars and production technology of chickpea in Ethiopia. Research Bulletin No. 2. Debre-Zeit, Ethiopia: Debre-Zeit Agricultural Research Center, Alemaya University of Agriculture. 60 p.

Hafeez A, Kotwal DR. 1996. Screening of chickpea varieties against gram pod borer *Helicoverpa armigera* Hubner. Ann Plant Prot Sci. 4:171–172.

Hossain AM. 2009. Field screening of chickpea genotypes against pod borer. Bangladesh J Agri Res. 34(3):517–521.

Ifoulis AA, Savopoulou-Soultani M. 2006. Use of Geostatistical Analysis to Characterize the Spatial Distribution of Lobesia botrana (Lepidoptera: Tortricidae) Larvae in Northern Greece. Environmental Entomology. 35(2):497–506.

Jallow M, Matsumura M. 2001. Influence of temperature on the rate of development of *Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae). Appl Entomol Zoo. 36:427–430.

Karmawati E, Kardinan A. 1995. Development of cotton pest *Helicoverpa armigera* Hubner on several alternate hosts. Ind Crops Res J. 1:145–151.

Kemal A, Tibebu HW. 1994. Research on insect pests of cool season food legumes. In: Asfaw T, Bejiga G, Saxena MC, Solh MB, editors. Cool Season Food Legumes of Ethiopia Proceeding of 1st National Cool-Season Food Legume Review Conference. A.A. Ethiopia. ICARDA, Aleppo, Syria; p. 367–396.

Lal OP. 1996. An outbreak of pod borer, *H. armigera* Hubner on chickpea in Eastern Uttar Pradesh. Indian J Entomol Res. 20:179–181.

Lande SS, Sarode SV. 1995. Response of *Helicoverpa armigera* (Hübner) to pyrethroids. Pest Res J. 7(1):92–94.

Lu Y, Wu K, Jiang Y, Guo Y, Desneux N. 2012. Widespread adoption of Bt cotton and insecticide decrease promotes biocontrol services. Nature. 487(7407):362–365.

Lulie N, Raja N. 2012. Evaluation of certain botanical preparations against African bollworm, *Helicoverpa armigera* Hubner (Lepidoptera: noctuidae) and non-target organisms in chickpea, *Cicer arietinum* L. J Biofertil Biopest. 3(5):1–6.

Madadi H, Dashti F, Enkegaard A. 2011. Spatial distribution of *Thrips tabaci* and the development of a fixed-precision sampling plan for greenhouse cucumber. J Entomol. 8:280–287.

Million E. 1994. Chickpea and lentil agronomic research. In: Asfaw T, Geletu B, Saxena MC and Solh MB eds. Cool season food legumes of Ethiopia. Proceeding of the First National Cool Season Food Legumes Review Conference,16-20 December 1993. Addis Ababa, Ethiopia. ICARDA/IAR: ICARDA, Aleppo, Syria. p. 230–251.

Morris RF. 1960. Sampling insect populations. Annu Rev Entomol. 5:243–264.

Munro JM. 1987. Cotton. 2nd ed. New York (NY): John Wiley and Sons Inc; p. 1–5.

Nyambo BT. 1988. Significance of host-plant phenology in dynamics and pest incidence of the cotton bollworm, *Heliothis armigera* Huebner (Lepidoptera: Noctuidae), in Western Tanzania. Crop Prot. 7:161–167.

Ogenga-Latigo MW, Obuo JE, Orotin P. 1994. Infestation and pod damage by *Helicoverpa armigera* (Hubner) on Chickpea (*Cicer arietinum* L.) in Uganda. Int J Pest Manag. 40:245–248.

Patel CC, Koshiya DJ. 1999. Seasonal abundance of American bollworm, *Helicoverpa armigera* on different crop hosts at Junagadh (Gujarat). Indian J Entomol. 59:396–401.

Patnaik HP, Mohapatra R. 1997. Performance of chickpea cultivars against *Helicoverpa armigera* (Hubn.) under filed conditions in the central plateau region of Orissa. Legume Res. 18:177–180.

Pimbert MP, Srivastava CP. 1991. The influence of rainfall deficits on the abundance of *Helicoverapa* (=*Heliothis) armigera* in Andhra Pradesh, India. Biol Agri Hort. 8:153–176.

Rashid A, Saeed HA, Akhtar LH, Siddiqi SZ, Arshad M. 2003. Performance of advance chickpea strains against gram pod borer (Helicoverpa armigera Hubner). Asian J Plant Sci. 2:418–419.

Reed W, Cardona C, Sithanantham S, Lateef SS. 1987. Chickpea insect pests and their control. In: Saxena MC, Singh KB, editors. The chickpea. Wallingford: CAB International; p. 283–318.

Santhanam SR, Egigu CM. 2014. Field evaluation of a botanical formulation from the milky mangrove *Excoecaria agallocha* L. against *Helicoverpa armigera* Hübner. In: *Abelmoschus esculentus* (lady's finger) and *Cajanus cajan* (pigeon pea). Asian Pac J Trop Med 7(Suppl 1): S171–S176.

Sarwar M, Ahmad N, Toufiq M. 2009. Host plant resistance relationships in chickpea (*Cicer Arietinum* L.) against gram pod borer (*Helicoverpa Armigera* Hubner). Pak J Bot. 41(6):3047–3052.

Seid A, Tebkew D. 2004. African bollworm: a key pest in pulse production in Ethiopia. In: African bollworm management in Ethiopia: status and needs. Proceedings of the National Workshop. p. 27–36.

Sequeira RV, McDonald JL, Moore AD, Wright GA, Wright LC. 2001. Host plant selection by *Helicoverpa* spp. in chickpea-companion cropping systems. Entomol Exp Appl. 101:1–7.

Shegaw T. 1995. African boll worm and its damage. Bahir Dar Plant Health Clinic, Bahir Dar, Ethiopia. Annual Report.

Shelton AM, Badenes-Perez FR. 2006. Concepts and applications of trap cropping in pest management. Annu Rev Entomol. 51:285–308.

Stoll G. 2000. Natural crop protection in the tropics: letting information come to the life. Marburg, Germany: Margraf Verlage, AGRECOL. p. 37.

Stubbins FL, Seiter NJ, Greene JK, Reay-Jones FPF. 2014. Developing sampling plans for the invasive *Megacopta cribraria* (Hemiptera: Plataspidae) in soybean. J Econ Entomol. 107:2213–2221.

Tebkew D. 2004. Importance of podborer in chickpea in some chickpea growing regions of Ethiopia. Pest Mgt J Eth. 8:105–110.

Tripathy MK, Kumar R, Singh HN. 1999. Host range and population dynamics of *Helicoverpa armigera* Hübn. in eastern Uttar Pradesh. J Appl Zoolog Res. 10:22–24.

Tsedeke A. 1995. Pest management in lowland pulses: progress and prospects. In: Habtu A, editor. Proceedings of the 25th Anniversary of Nazareth Agricultural Research Center, 25 Years of Experience in Lowland Crop Research, September. Nazareth: Nazareth Agricultural Research Center. p. 181–194.

Tsedeke A, Tadesse GM, Kemal A. 1982. Arthropod pests of grain legumes in Ethiopia: their importance and distribution. Addis Ababa: Institute of Agricultural Research (IAR); p. 22–28.

Twine PH. 1978. Effect of temperature on the development of larvae and pupae of corn earworm, Heliothis armigera (Hübner) (Lepidoptera: Noctuidae). Queensl. J. Agric. Anim. Sci. 35:23–28.

Van der Berg H, Cock MJW. 1993. Stage-specific mortality of *Helicoverpa armigera* in three smallholder crops in Kenya. J Appl Ecol. 30:640–653.

Waktole S. 1996. Management of cotton insect pests in Ethiopia: a review. In: Proceedings of Integrating Biological Control and Host Plant Resistance. CTA/IAR/IIBC, Addis Ababa, Ethiopia. p. 224–252.

Whightman JA, Anders MM, Rao VR, Reddy L. 1995. Management of *Helicoverpa armigera* (Lepidoptera: Noctuidae) on chickpea in southern India: threshold and the economics of host plant resistance and insecticide application. Crop Prot. 14:37–46.

Young LJ, Young JH. 1998. Statistical ecology. Norwell (MA): Kluwer Academic Publishers.