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Sequential sampling for evaluation of caterpillars, small and large in soybean

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Among the main limitations of grain yield in soybean are the insect pests, especially the defoliating caterpillars. It is necessary to reveal and quantify these insects for proper decision-making according to pre-established control levels. So, for the implementation of appropriate management of these soybean insect pests, there is a necessity to establish a sampling plan that will allow an effective, reliable and less time consuming estimation of the population density of pests. This work aims to establish a sequential sampling plan for small and large caterpillars in soybean in accordance with the sequential test of probability rates. Data was collected for two growing seasons (2010/2011 and 2012/2013). The number of small caterpillars (<1.5 cm) and large (>1.5 cm) of the species *Anticarsia gemmatalis* (Hübner, 1818), *Chrysodeixis includens* (Walker, 1857) and *Spodoptera eridania* (Cramer, 1872) was estimated using the vertical cloth-to-beat in a grid of 154 sample points marked with a 20 × 20 m spacing in an area of 6.16 ha of soybean. The distribution of small and large caterpillars in soybean is aggregated. According to the sequential sampling plan, the number of maximum samples, for the decision making of the control or not of caterpillars in soybean is 30 samples units.

Key words: Pest management, sampling plan, vertical cloth-to-beat, spatial distribution.

INTRODUCTION

The productivity of soybean can be affected by several factors, among these the defoliating caterpillars (*Anticarsia gemmatalis, Chrysodeixis includens* and *Spodoptera eridania*) become important constraints. These insect pests feed both limbo and leaf veins and can cause defoliation up to 100%, leading to losses in grain yield (Hoffmann-Campo et al., 2012).

It is extremely important to quantify population of this insect pest, so that decisions are taken properly, based on pre-established levels of control. In soybean, the recommended level of control is 20 large caterpillars (≥1.5 cm) per square meter (Reunião da Pesquisa da Soja na Região Sul, 2014). Therefore, it is necessary to know fast and efficient sampling methods, so that the

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control is executed at the exact moment when the population level reaches the level of control (Fernandes et al., 2002). Choosing the best method is dependent on factors such as the phenological stage of the crop, the target pest in question, the accuracy and precision required for sampling, ease of use, time and cost of performing it (Wade et al., 2006).

The vertical cloth-to-beat method was the most efficient in comparison with cloth-of-beat methods and large cloth-to-beat in several studies (Guedes et al., 2006; Kuss et al., 2007; Stürmer et al., 2012). These samples can be optimized using the sequential sampling plan, which presents itself to be more reliable and faster because it is based on a variable number of samples depending on the size of the sampled population (Kogan and Herzog, 1980).

For the correct development of sequential sampling plans, three basic requirements are required; (1) a probability function is obtained that describes the distribution of insect counts; (2) the level of economic damage (NDE) or threshold in the form of two critical densities, so that the level of damage occurs as soon as the population density exceeds a previously established upper limit and does not occur when the population remains below the limit defined bottom; (3) we select maximum levels of probability of making errors in the decision on population densities, that is, probabilities of α and β to predict a non-prejudicial population as being prejudicial (α = type I error), and the probability of diagnosing a density prejudicial as being non-prejudicial (β = type II error) (Ruesink and Kogan, 1975). Sequential sampling plans are constructed based on Wald's sequential probability ratio test (1945). In order to establish the use of this method of evaluation, it is necessary to know the spatial distribution of insect pests in the culture (Giles et al., 2000).

Therefore, this study aims to implement a sequential sampling plan for the evaluation of small and large caterpillars in soybean.

MATERIALS AND METHODS

The experiments were conducted in an area of 6.16 ha in the Federal University of Santa Maria in Santa Maria, Rio Grande do Sul State which lies at an latitude 29° 42'24 "S; longitude 53°48'42 "W; and altitude, 95 m, in two growing seasons (2010/2011 and 2012/2013). In the first year, the soybean cultivar BMX Potencia RR, of indeterminate growth habit and semi-early maturity group, it was sown on October 29, 2010, in rows spaced 0.5 m, with 25 m plant density. In the second crop, the soybean cultivar used was Nidera A 6411 RG, a determined growth habit and semi-early maturity group, sown on December 10, 2012, in rows spaced 0.43 m, with a plant density of 16 plants per square meter. In both years, fertilization, control of weeds and diseases were conducted according to the technical recommendations for the crop (Reunião da Pesquisa da Soja na Região Sul, 2014). In the year 2010/2011, methomyl was applied (107 g active ingredient ha^{-1}) to control caterpillars on February 3, 2011, on the basis that defoliation had reached the level of control (Reunião da Pesquisa da Soja na Região Sul, 2014). In the year 2012/2013, the pest control was not necessary because the control levels were not achieved. In both crop years, it was marked on the area a grid of 154 sampling points spaced 20 × 20 m. In each of these, 154 points were counted, the number of small (<1.5 cm) and large (>1.5 cm) caterpillars of the species *A. gemmatalis* (Hübner, 1818), *C. includens* (Walker, 1857) and *S. eridania* (Cramer, 1872).

At the end, the total number of small caterpillars and the total number of large caterpillars were recorded through the vertical cloth-of-beat sampling (Figure 1), 14 phenological stages of soybean (V7, V9, V11, R1 R2, R3, R4, R5.1, R5.3, R5.5, R6, R7.1, R7.3 and R8.2) on the 2010/2011 season, and 8 stages for the year 2012/2013 (R2, R4, R5.1, R5.2, R5.5, R6, R7.1 and R7.3) using the scale proposed by Ritchie et al. (1982). The sampling method and the manner of collection are described subsequently.

Vertical cloth-to-beat, consisting of a wooden stick at the top end and a polychloride polyvinyl tube (100 mm), cut in half lengthwise, the lower end, connected by a white cloth with 1 m of length and height-adjustable to the height of soybean plants. The polychloride polyvinyl tube served as a gutter to collect insect pests. To collect the insects, the cloth was placed vertically between the lines of the crop and only one row of plants were shaken against the surface of the cloth. This procedure was conducted by 2 m of soybean line in order to sample the area of 1 m^2.

Each of the 2,156 collections of 1 m^2 formed by the combination of 154 points × 14 phenological stages in the year 2010/2011 and 1,232 collections formed by the combination of 154 points × 8 phenological stages in the year 2012/2013 accounted for the number of caterpillars (small, large and total). Statistical analysis was performed with the help of MINITAB 17 software and Office Excel application.

To verify the degree of aggregation of small and large caterpillars, dispersion indexes described subsequently were used.

Dispersion indexes

Reason variance/average, called dispersion index, is the most common of the indexes used. It is given by the variance/mean relation ($I = s^2/m$). According to Rabinovich (1980), it is a measure of the deviation of an arrangement of the conditions of randomness. Values equal to the unit indicate dispersion at random, values lower than the unity indicate regular or uniform distribution, and significantly higher values that the unit indicate aggregate spatial distribution. The limitations of this index are the influence of sample size on the amount of sampled individuals, affecting the aggregations (Krebs, 1999).

K exponent of negative binomial distribution

The estimated values of K are obtained by two methods, the first method of the moments:

$$k = \frac{m^2}{s^2 - m}$$

and by the method of maximum verossimilitude:

$$N \ln\left(1 + \frac{\hat{m}}{\hat{k}}\right) = \sum_{i=1}^{nc} \left(\frac{A(x_i)}{\hat{k} + x_i}\right)$$

where N = number of sampling units, A(x) = sum of the frequencies of the values higher than x and xi = number of subjects sampled by point. Negative values indicate uniform distribution, low and positive values (k<2), highly aggregated arrangement, values ranging from

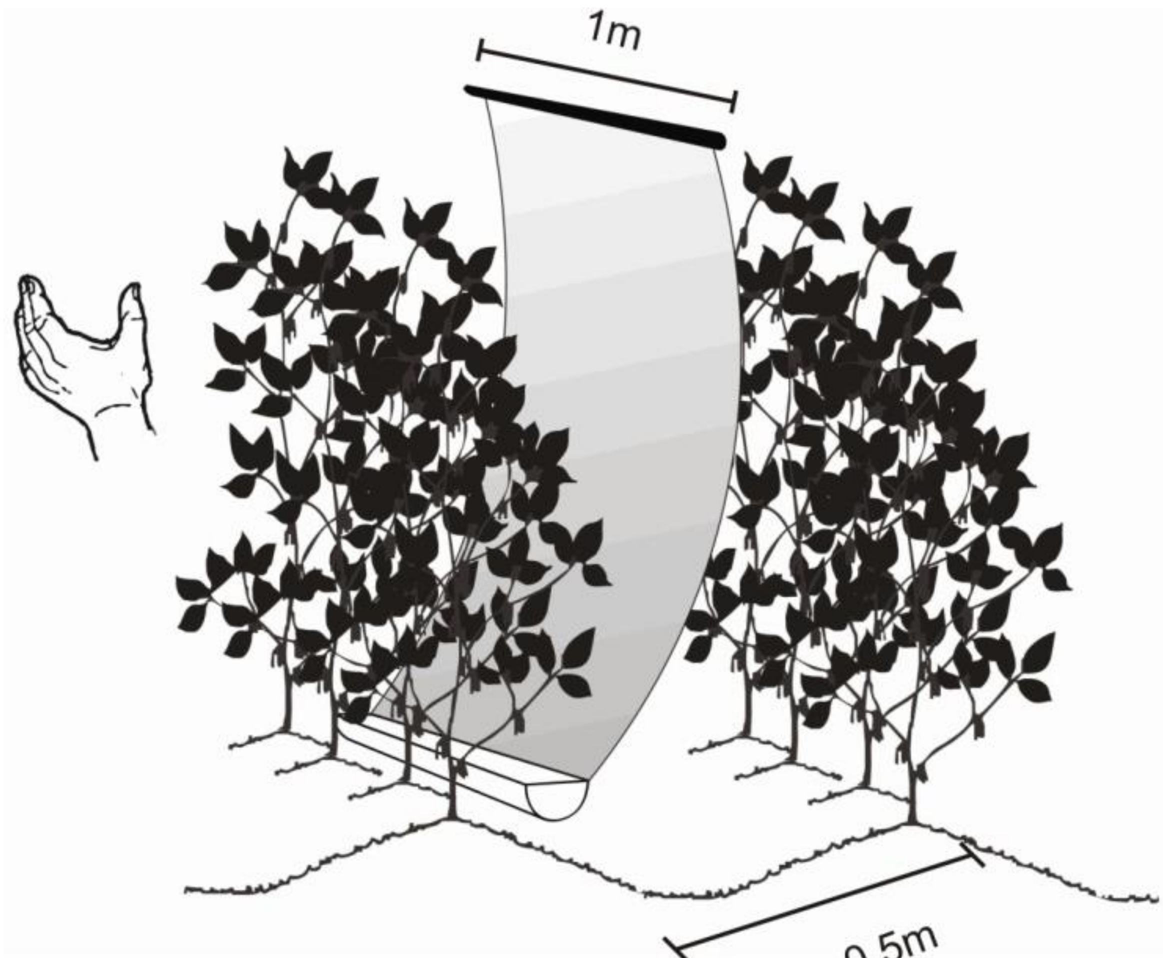

Figure 1. Representation of the vertical cloth-to-beat used in sampling caterpillars, small and large, in soybean (Stürmer et al., 2012).

two to eight indicate moderate aggregation and values greater than eight randomized distribution (Elliott, 1979).

Probabilistic models for the study of spatial distribution of pests

Poisson distribution is also known as random distribution, with variance equal to the average (m = s2). The formulas for calculating the series are given by:

$$P(0) = e^{-\hat{m}}$$

and

$$P(x) = \frac{\hat{m}}{x}.P(x-1)$$

where x = 1,2,3 ...; e = base of the natural logarithm (e = 2.718282 ...); P (x) = probability of finding × individuals in a sampling unit; and m = sample mean.

Negative binomial distribution shows greater variance than the average (s^2>m), namely, aggregate distribution and has two parameters, the mean (m) and the exponent k (k> 0). The odds are calculated by the formulas:

$$P(0) = (1-\frac{\hat{m}}{\hat{k}})^{-\hat{k}}$$

$$P(x) = \frac{\hat{k}+x-1}{x}.(\frac{\hat{m}}{\hat{m}+\hat{k}}).P(x-1)$$

for x = 1, 2, 3, ..., where P (x) = probability of finding a sampling unit containing × individuals, sample mean, estimate of the negative binomial exponent k, obtained by the method of moments.

Sequential sampling is the next step which was the establishment of a sequential sampling plan for small and large caterpillars in soybean. The plan is based on the sequential test of likelihood ratio (TSRP) proposed by Wald (1945). The plan aims to test with the lowest expected number of samples, the hypotheses H0 and H1. H0 indicates that the population is below the safety level, while the H1 hypothesis is that the population is above the level of control. Thus, H0 rejection, or the acceptance of H1, may indicate the need for application of insect control methods, and accepting H0 indicates the non-application (Barbosa, 1992). For preparation of the sequential sampling plan of caterpillars, the level of control of 20 caterpillars/m² was adopted and a safety level of 10 caterpillars/m². Using the errors of type I and type II, the values α = β = 0.10.

The required decision lines for the rest were built. The top line brings the number of individuals needed to achieve the proposed level of control, the lower decision line indicates the total number of organisms stating that the population is below the safety level and does not require the adoption of any measure of control.

For the operating characteristic curve and expected medium size for the sample, the evaluation of the test TSRP does not need determination of the Operating Curve CO(p) and the Curve of the Expected Size of Sampling units Ep(n). The Operating Characteristic Curve CO(p) is a graphical representation of the operational characteristic function, providing the probability that sampling is finished, not recommending the control to a certain degree of crop infestation. This indicates the probability of adopting a right or wrong decision on a certain level of infestation. The Curve of the Expected Size of Sampling Units Ep(n) represents the average number of observations/samplings required for decision making. According to Young and Young (1998), the functions for the determination of both curves at any type of distribution is described as:

$$CO(p) = \frac{\dfrac{(1-\beta)^h - 1}{\alpha}}{\dfrac{(1-\beta)}{\alpha} - \dfrac{(\beta)^h}{1-\alpha}}$$

$$E_p(n) = \frac{CO(p)(h_0 - h_1) + h_1}{p - S}$$

where p = average number of individuals; h = auxiliary dependent variable of p; α = type I error; β = type II error; H0 = hypothesis H0; H1 = hypothesis H1.

RESULTS AND DISCUSSION

The dispersion index of the reason of the variance/mean (I) showed values greater than the unity for small caterpillars in the 2010/2011 season, the 11 initial assessments, that is, in all stages with a mean different from zero, indicating aggregate distribution (Table 1). As for the estimation of K by the moments method (K mom) in five of the phenological stages (V7, V9, R5.1, R5.3 and R6), values were low and positive, called highly aggregated dispersion. In other evaluations, were found individuals (V11, R1, R2, R3, R4 and R5.1), the values found ranged between 2 and 8, which indicates aggregate distribution. In the three remaining assessments (R7.1, R7.3 and R8.2) individuals were found in the area. The number of small and large caterpillars was not collected in the area, in the 2010/2011 season, for the last three stages evaluated, mainly due to insecticide application and the competition for food.

Only in V7 values were negative showing uniform distribution. In other stages, the index ratio variance/mean values were higher than one. To estimate K by the method of moments in the stages V9, V11, R2 and R5.5 values obtained are found between 0 and 2, in the other five stages, values denoted moderately aggregate distribution (2 <k <8).

Similar results were observed by Stecca (2011), when the spatiotemporal distribution of defoliating caterpillars of soybean was analyzed, concluding that they present gregarious behavior, due to its population growth. Fernandes et al. (2003) found in the cotton crop, for *Spodoptera frugiperda*, also aggregate distribution, that is, adjusting for the negative binomial distribution. These results confirm those found by Moura (2012), where the spatial distribution and the sequential sampling plan of *C. includens* in different soybean seeding systems was evaluated.

Thus, it is understood that the distribution of large and small caterpillars in the 2010/2011 season adjusts to the distributions that describe this arrangement, as the negative binomial distribution. These results go against Maruyama et al. (2002), which show that, generally, the distribution of insects in the field is given in aggregate form.

For the index of variance/mean ratio for the number of small caterpillars in the 2012/13 crop, the values were higher than one in all of the soybean stages which denotes aggregate population distribution.

For the analysis of the k index of the moments, in three phenological stages of the culture (R6, R7.1 and R7.3) K values are between 0 and 2, which denotes a highly aggregated distribution. In the other stages the values showed a moderately aggregate distribution.

For the number of large caterpillars in the season 2012/2013, the I = S²/m index presented values indicating the aggregate distribution in the first 6 phenological stages (R2, R4, R5.1, R5.2, R5.5 and R6). In the others (R7.1 and R7.3) the values were smaller than 1 (uniform distribution). For the estimation of K by the moments method, the results were similar. In stages R7.1 and R7.3, negative values were found. In R4, R5.1 and R6 values were between 0 and 2 (highly aggregated); R2 and R5.2, the indices showed a moderately aggregate distribution. In R5.5, the value presented was greater than 8, denoting a random distribution.

Adjustment tests for small caterpillars in the 2010/2011 season showed that in three phenological stages there was a fit to the negative binomial distribution, and in none was a fit to the Poisson distribution. Demonstrating that the population of small caterpillars tend to have an aggregate distribution. As for large caterpillars of the 14 sampled phenological stages, in six, there was a fit to the negative binomial distribution showing no significant values. Adjusting just one to the Poisson distribution, demonstrating also that the distribution of large caterpillars this season, occurs as aggregate (Table 2).

For 2012/2013 harvest, relative to the number of small caterpillars in the area, no adjustment in any of the

Table 1. Mean, variance and dispersion indices for the number of small and large caterpillars.

		Season 2010/2011							
		Small caterpillars				Large caterpillars			
Indexes		m	S²	I = S²/m	K mom	m	S²	I = S²/m	K mom
Sampling Season	V7	0.2532	0.3472	1.3710	0.6825	0.0519	0.0496	0.9542	-1.1354
	V9	0.8312	1.4354	1.7269	1.1434	0.1883	0.2061	1.0947	1.9894
	V11	2.5584	5.8299	2.2787	2.0008	1.0909	2.1224	1.9455	1.1537
	R1	5.1104	12.1381	2.3752	3.7162	1.0844	1.6595	1.5303	2.0449
	R2	9.0455	35.3639	3.9096	3.1089	3.2922	10.2082	3.1007	1.5672
	R3	26.5130	158.7221	5.9866	5.3169	10.0130	51.7776	5.1710	2.4006
	R4	24.3312	123.8177	5.0889	5.9506	25.5260	131.3490	5.1457	6.1572
	R5.1	4.5195	10.8787	2.4071	3.2120	4.5390	10.7207	2.3619	3.3327
	R5.3	2.1364	8.8506	4.1428	0.6798	1.7273	2.9055	1.6821	2.5321
	R5.5	1.4351	3.3193	2.3130	1.0930	0.5909	0.9492	1.6063	0.9746
	R6	0.5130	1.2841	2.5033	0.3412	0.1039	0.1068	1.0278	3.7403
	R7.1	0	0	-	-	0	0	-	-
	R7.3	0	0	-	-	0	0	-	-
	R8.2	0	0	-	-	0	0	-	-
		Season 2012/2013							
Sampling Season	R2	2.3117	3.9414	1.7050	3.2790	3.5195	8.0290	2.2813	2.7468
	R4	5.9156	10.7314	1.8141	7.2665	1.4156	3.1334	2.2135	1.1666
	R5.1	6.5519	26.7587	4.0841	2.1244	3.0909	13.4688	4.3576	0.9206
	R5.2	4.1883	9.9316	2.3713	3.0543	1.3442	1.7958	1.3360	4.0003
	R5.5	1.6688	2.8765	1.7237	2.3060	0.5325	0.5643	1.0598	8.9071
	R6	0.5584	1.1240	2.0128	0.5514	0.1234	0.1873	1.5181	0.2382
	R7.1	1.0779	2.4383	2.2621	0.8541	0.0325	0.0316	0.9739	-1.2419
	R7.3	0.4675	0.7081	1.5145	0.9087	0.0714	0.0668	0.9346	-1.0929

m - sampling mean; S² - variance; I – variance/mean ration K mom - k estimation by the method of moments.

Table 2. Chi-square test results (χ^2) for adjusting the Poisson and negative binomial distributions, for the number of large and small.

Stage	Sampling stage	2010/2011 Season			
		Poisson		Negative Binomial	
		χ^2	GL	χ^2	GL
Small caterpillars	V7	-	-	22.04677*	3
	V9	17.2964*	2	162.9631*	6
	V11	79.1846*	6	34.7255*	11
	R1	93.6846*	9	26.8771*	15
	R2	266.56*	12	73.6158*	24
	R3	790.880*	11	54.4815^{ns}	47
	R4	561.175*	11	58.0907^{ns}	43
	R5.1	87.1134*	8	16.9580^{ns}	15
	R5.3	177.672*	5	5376.7214*	12
	R5.5	59.7105*	4	65.2473*	9
	R6	34.2815*	2	596.5029*	7
	R7.1	-	-	-	-
	R7.3	-	-	-	-
	R8.2	-	-	-	-
Large caterpillars	V7	-	-	0.2707^{ns}	1

Table 2. Contd.

V9	0.07^{ns}	1	3.7976^{ns}	3
V11	51.93*	3	30.1082*	7
R1	11.7258*	3	8.9343^{ns}	5
R2	93.2229*	7	394.155*	15
R3	246.943*	7	199.8869*	28
R4	492.742*	11	67.0357*	44
R5.1	81.777*	8	25.3457^{ns}	16
R5.3	21.0309*	4	12.2190^{ns}	8
R5.5	15.3693*	2	41.9777*	5
R6	0.07738*	1	0.06472^{ns}	2
R7.1	-	-	-	-
R7.3	-	-	-	-
R8.2	-	-	-	-

χ = Chi-Square statistics test; GL: Chi-Square degrees of freedom; *Significant at a 5% probability; ^{ns}Non-Significant at a 5% probability.

Table 3. Chi-Square test results (χ^2) for adjusting the Poisson and negative binomial distributions, the number of large and small caterpillars.

Stage	Sampling Stage	2012/2013 Season			
		Poisson		Binomial Negativa	
		χ^2	GL	χ^2	GL
Small caterpillars	R2	32.1367*	5	22.7616*	9
	R4	64.0598*	10	17.9859^{ns}	15
	R5.1	96.220*	10	1.7×10^{8}*	16
	R5.2	79.5813*	8	85.4421*	13
	R5.5	37.3942*	4	23.2786*	8
	R6	40.5273*	2	134.2888*	6
	R7.1	56.9278*	3	386.7366*	7
	R7.3	6.3761*	1	253.3033*	4
Large caterpillars	R2	139.905*	7	49.9388*	12
	R4	14.8944*	3	7.21842^{ns}	6
	R5.1	307.330*	6	3043.452*	15
	R5.2	9.8291*	3	2.9547^{ns}	6
	R5.5	0.20820^{ns}	2	1.0397^{ns}	4
	R6	-	-	388.4375*	2
	R7.1	-	-	0.0970^{ns}	1
	R7.3	-	-	0.4962^{ns}	1

χ^2 = Chi-Square Statistycal test; GL: Chi-Square degrees of freedom; *Significant at a 5% probability; ^{ns}Non-Significant at a 5% probability.

stages with the Poisson distribution happened, and only in R4 to the negative binomial distribution, demonstrating a population random distribution, which can be explained by the smaller population in the area. For the population of large caterpillars, there was adjustment in five samples for negative binomial distribution and only R5.5 for Poisson distribution (Table 3).

These results demonstrate that for both small and large caterpillars, the population distribution of these pests tends to be aggregated, as described by Moura (2012) in a study of *C. includens* in different soybean planting systems.

With the adhesion test showing that the number of large and small caterpillars in seasons 2010/2011 and 2012/2013 had a more satisfactory adjustment to the negative binomial distribution, fits this model with a K_{common} which is the representative of all evaluations, therefore the values obtained are shown in Table 4.

From the K_{common} index, sequential sampling plans were constituted for large and small caterpillars in season

Table 4. K_{common} indices for small and large caterpillars in the 2010/2011 and 2012/2013 season.

Index	Season 2010/2011		Season 2012/2013	
	Small caterpillars	Large caterpillars	Small caterpillars	Large caterpillar
Kcommon	4.801852452	4.300367607	2.986652923	1.500572399

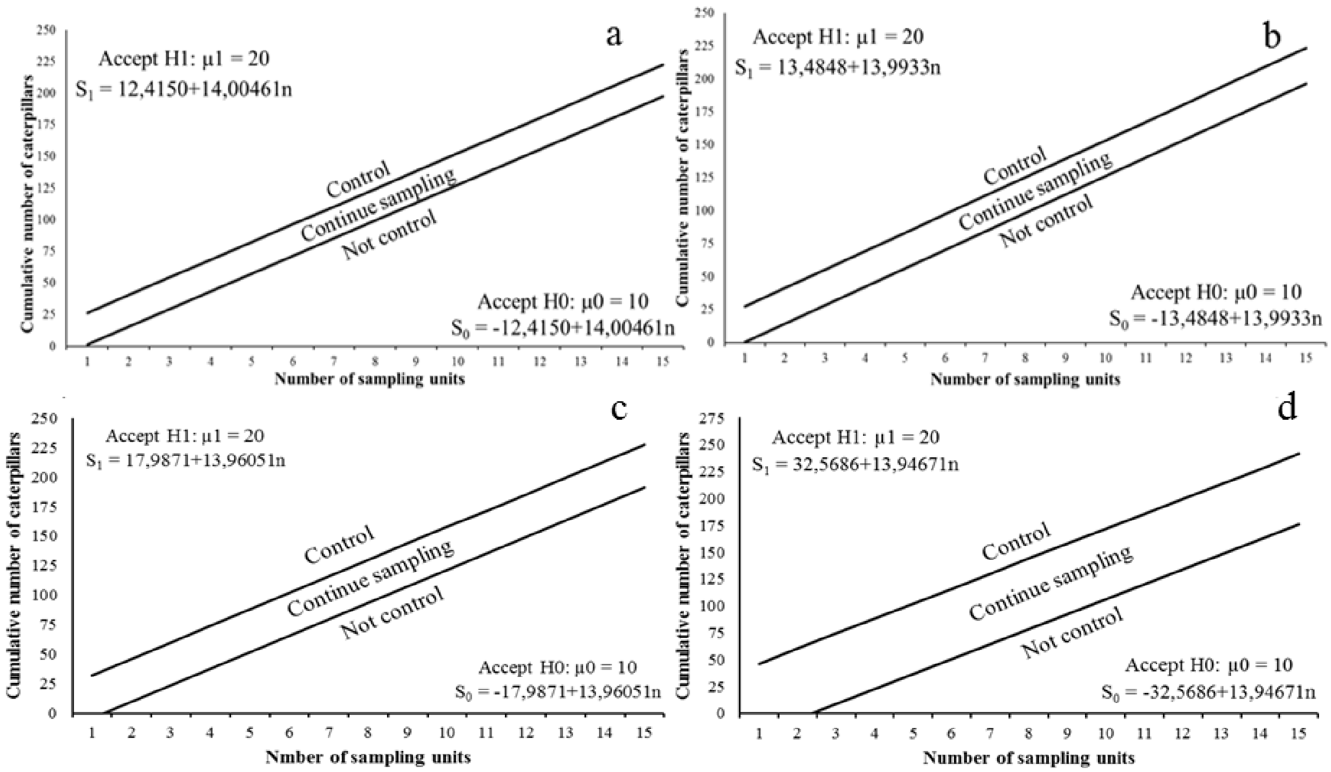

Figure 2. Decision lines of the sequential sampling plan for the number of small caterpillars (a) and large caterpillars (b) collected by vertical cloth-to-beat method at 154 sampling points in 14 growth stages, based on the negative binomial distribution, 2010/2011 harvest. Decision lines of the sequential sampling plan for the number of small caterpillars (c) and large caterpillars (d) collected by vertical cloth-to-beat method at 154 sampling points in 8 phenological stages, based on the negative binomial distribution, 2012/2013 harvest..

2010/2011 and 2012/2013 in graphical form (Figure 2). The top line brings the number of insects required for the control of caterpillars, rejecting H0, the bottom line accepts H0, requiring no control.

From these graphs field sheets are obtained Tables 5, 6, 7, and 8, which facilitate the sequential sampling field work. For each value of n, the value of S, found by S1 and S0 functions was is calculated. The second column of the table represents the lower limit of the graph, that is, the points S0, and the last column represents the points obtained through S1.

The field procedure is performed in the following manner, the area in question is covered, so that random sampling of large and small caterpillars is done, after counting at each sampling point, this number is accumulated, thus being compared with the limits in the field sheet, in a manner that you control or not the insect pests. If the total accumulated value is greater than the upper limit, it accepts H1, sampling stops and control is done. If the number of insects is less than S0 line, H0 is accepted, rejecting H1, sampling stops and the control is not done in the area. When the accumulated value does not exceed any of the decision lines, staying between them, sampling continues until the expected maximum number of caterpillars, both large and small for the decision making. New sampling taking place after one week, when the survey is biweekly, or after 4 days when the survey is weekly (Gallo et al., 2002). It is recommended that the minimum number of 6 samples to start the control or not of the insect pest in question, according to recommendations of Embrapa (2016).

The characteristic operating curve (CO) is the

Table 5. Field sheet for small caterpillars sampling in soybean using the vertical cloth-to-beat 2010/2011 season.

Points	Lower level	Accumulated number of caterpillars	Upper level
1	2	-	26
2	16	-	40
3	30	-	54
4	44	-	68
5	58	-	82
6	72	-	96
7	86	-	110
8	100	-	124
9	114	-	138
10	128	-	152
11	142	-	166
12	156	-	180
13	170	-	194
14	184	-	208
15	198	-	222
16	212	-	236
17	226	-	250
18	240	-	264
19	254	-	279
20	268	-	293

Table 6. Field sheet for sampling of large caterpillars in soybean using the vertical cloth-of-beat 2010/2011 season.

Points	Lower level	Accumulated number of caterpillars	Upper level
1	1	-	27
2	15	-	41
3	28	-	55
4	42	-	69
5	56	-	83
6	70	-	97
7	84	-	111
8	98	-	125
9	112	-	139
10	126	-	153
11	140	-	167
12	154	-	181
13	168	-	195
14	182	-	209
15	196	-	223
16	210	-	237
17	224	-	251
18	238	-	265
19	252	-	279
20	266	-	293

probability of completion of sampling, so that there is no control of the target insects for degree of infestation.

Figure 3 represent the CO(m) for small and large caterpillars in the 2011/2012 and the 2012/2013 season.

Table 7. Field sheet for small caterpillars sampling in soybean using the vertical cloth-of-beat 2012/2013 season.

Points	Lower level	Accumulated number of caterpillars	Upper level
1	ND	-	32
2	10	-	46
3	24	-	60
4	38	-	74
5	52	-	88
6	66	-	102
7	80	-	116
8	94	-	130
9	108	-	144
10	122	-	158
11	136	-	172
12	150	-	186
13	163	-	199
14	177	-	213
15	191	-	227
16	205	-	241
17	219	-	255
18	233	-	269
19	247	-	283
20	261	-	297

ND: Not determined

Table 8. Field sheet for sampling of large caterpillars in soybean using the vertical cloth-of-beat 2012/2013 season.

Points	Lower level	Accumulated number of caterpillars	Upper level
1	ND	-	46
2	ND	-	60
3	9	-	74
4	23	-	88
5	37	-	102
6	51	-	116
7	65	-	130
8	79	-	144
9	93	-	158
10	107	-	172
11	121	-	186
12	134	-	200
13	148	-	213
14	162	-	227
15	176	-	241
16	190	-	255
17	204	-	269
18	218	-	283
19	232	-	297
20	246	-	311

ND: Not determined

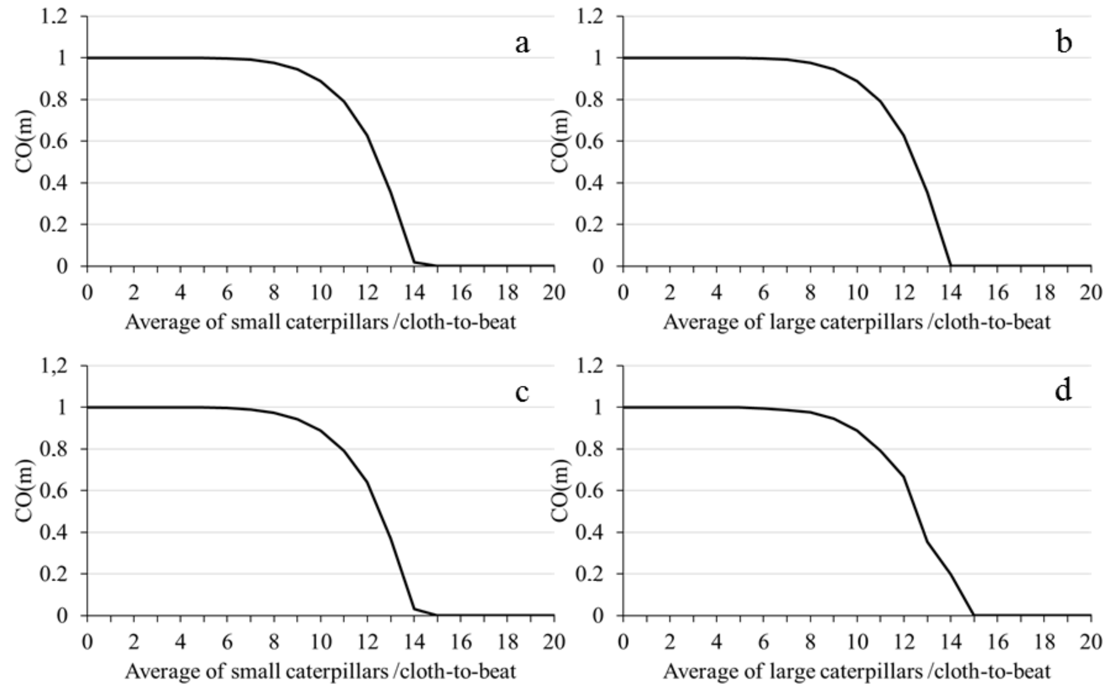

Figure 3. Characteristic operating curve CO(m) of the sequential sampling plan for small caterpillars (a) and large caterpillars (b) collected by vertical cloth-to-beat method at 154 sampling points in 14 growth stages, 2010/2011 harvest. Characteristic operating curve CO(m) of the sequential sampling plan for small caterpillars (c) and large caterpillars (d) collected by vertical cloth-to-beat method at 154 sampling points in 8 phenological stages, 2012/2013 harvest.

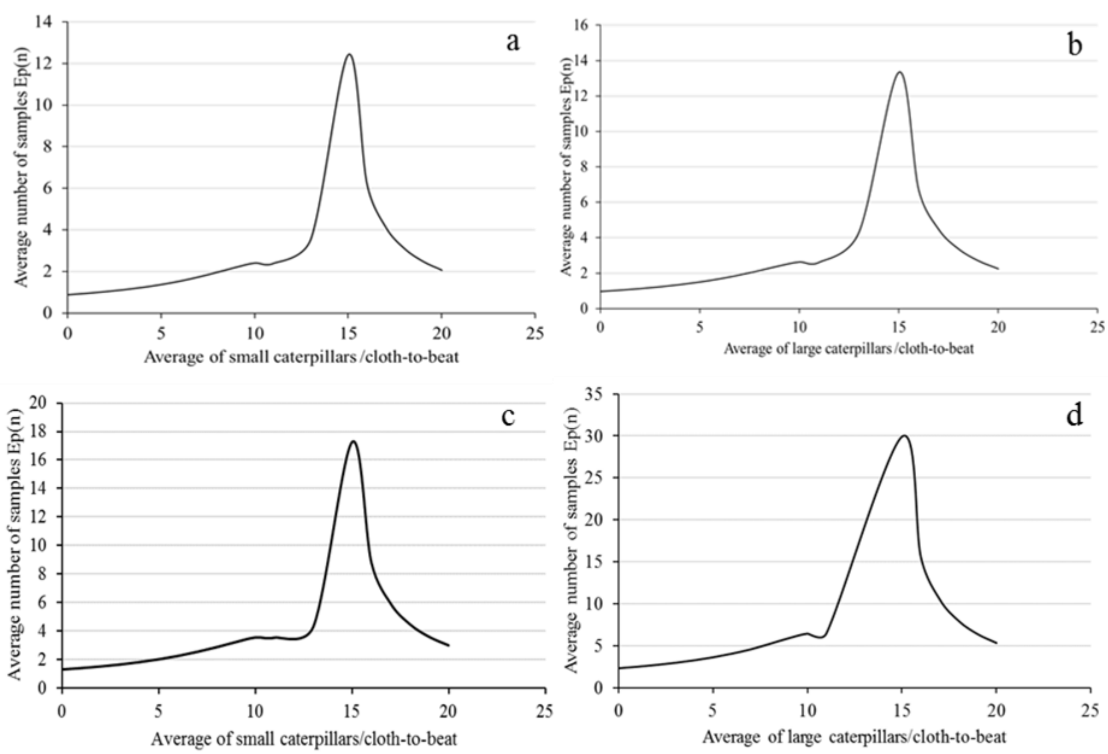

Figure 4. Curve of the expected size of the sample units Ep(n) of the Test of the Sequential of the Likelihood Ratio for the number of small caterpillars (a) and large caterpillars (b) in soybean in the 2010/2011 season. Curve of the expected size of the sample units Ep(n) of the Test of the Sequential of the Likelihood Ratio for the number of small caterpillars (c) and large caterpillars (d) in soybean in the 2012/2013 season.

The results for the Expected Number of Sampling Units Ep (n) for small caterpillars in the 2010/2011 season (Figure 4a) indicate that for an average infestation of 15 caterpillars/vertical cloth-to-beat, the maximum number of samples to be performed is 13. As for large caterpillars in soybean in the 2010/2011 season (Figure 4b), the maximum number of samples is close to 14. Figure 4c indicates that for the number of small caterpillars in the 2012/2013 season, the maximum sampling would be 17, for large caterpillars in the same season (Figure 4d), the maximum number is 30, both with an average infestation of 15 caterpillars/vertical cloth-to-beat.

As the distribution of defoliating caterpillars of soybean is given in an aggregate manner, plans can be used efficiently and effectively for the different caterpillar sizes, as well as for the total population of caterpillars in the area, regardless of species.

It is recommended that the sequential sampling plan is used in order to meet the standards of Integrated Pest Management (IPM) in uniform stands with regard to planting, cultivating, topography, soil type, management, cultural practices, among others.

Conclusion

The distribution of small and large caterpillars in soybean tends to be aggregated, regardless of population density. Four sequential sampling plans for small and large caterpillars were built in two growing seasons, based on the negative binomial distribution. For the evaluation of caterpillars in the soybean crop, a number of samples for decision making, ranging from at least 6 sample units, up to a maximum of 30, should be used for determined and indeterminate growth cultivars.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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APPENDIX

Appendix A - Description of soybean growth stages

I	Vegetative Phase
VC	From emergency to open cotyledons.
V1	First node; open unifoliolate leaves.
V2	Second node; first open trefoil.
V3	Third node, second open trefoil. Vn Nth (last) node with open trefoil, before flowering.

II	Reproductive Phase (observation on the main stem)
R1	Beginning of flowering up to 50% of plants with a flower.
R2	Full flowering. Most racemes with open flowers.
R3	End of flowering. Pods up to 1.5 cm in length.
R4	Most of the pods in the upper third with 2-4 cm, with no noticeable grain.
R5.1	Grains perceptible to touch 10% of graining.
R5.2	Most pods graining 10 to 25%.
R5.3	Most pods between 25 and 50% of graining.
R5.4	Most pods between 50 and 75% of graining.
R5.5	Most pods between 75 and 100% graining.
R6	Pods with graining 100% and green leaves.
R7.1	Beginning to 50% yellowing leaves and pods.
R7.2	Between 51 and 75% yellow leaves and pods.
R7.3	More than 76% of leaves and yellow pod.
R8.1	Home to 50% defoliation.
R8.2	More than 50% of pre-harvest defoliation.
R9	Crop maturation point.

Fonte: Ritchie, S.W. et al. How a soybean plant develops. Ames: Iowa State University of Science And Technology Cooperative Extension Service. Special Report, 53, mar. 1982. (Adaptado por J. T. Yorinori (1996)).