Title: SPATIAL DISTRIBUTION OF *SAHLBERGELLA SINGULARIS* HAGL. (HEMIPTERA: MIRIDAE) POPULATIONS AND ASSOCIATED DAMAGE IN UNSHADED YOUNG COCOA-BASED AGROFORESTRY SYSTEMS IN CAMEROON

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Abstract
The aim of this study was to analyze the spatial distribution of *S. singularis* populations and associated damage in young not yet shaded cocoa-based agroforestry systems. The study was carried out in six 4 years-old cocoa plantations located in the Centre region of Cameroon. Three different specialized models were used for analysis: the Taylor's power law, the binomial negative distribution and semi-variograms. The populations of *S. singularis* were strongly aggregated in the studied plantations. Recent damage, namely feeding lesions on flushes and pods, was also relatively aggregated yet less clearly than mirid populations. In contrast, older damage, namely cankers on trunks and branches, was more regularly distributed, although some zones of the cacao plantations were more damaged than others. These results provide information about the history of mirid infestations in these young and unshaded plantations, and suggest that, if mirid populations are usually aggregated, infestation areas vary over space and time, leading to relatively uniform cumulated damage. However, the presence of higher infestations in some areas of the cocoa plantations could indicate that there are zones that offer better ecological conditions (in the form of habitat and/or food) to mirids. Our study contributes to the understanding of the spatial distribution of *S. singularis* populations and its damage in young cocoa plantations, and these should be taken into consideration for integrated pest management (IPM) strategies against *S. singularis*, especially in unshaded cocoa plantations.

Introduction
The brown cocoa mirid, *Sahlbergella singularis* Haglund is the most harmful insect pest of the cocoa tree in Cameroon (Babin *et al.*, 2010; Bisseleua *et al.*, 2011). Mirids feed by inserting their mouthparts into the plant tissues, injecting a toxic saliva which causes necroses of part of the plant tissue. Cocoa yield losses due to mirids have been estimated at 30-70% in West Africa (Entwistle, 1972; Anikwe *et al.*, 2009).

In Cameroon, cocoa mirids are primarily controlled through insecticide spraying which has numerous negative externalities. Although research has been oriented for many years towards the development of more sustainable control strategies, no practical alternative to chemical control is available to farmers today, the more so since there is still a substantial lack of knowledge on mirid ecology. Mirid population dynamics has been studied in traditional shaded cocoa agroforestry systems (Babin *et al.*, 2010; Bisseleua *et al.*, 2011). In these systems, mirids are aggregated in those areas where cocoa trees are exposed to direct sunlight through shade canopy breaks (Babin *et al.*, 2010). Data on mirid population dynamics and/or dispersion in unshaded cocoa plantations is scarce. Authors usually agree with the fact that unshaded plantations show higher levels of damage and contain more uniform mirid distribution patterns than shaded plantations (Williams, 1953; Entwistle, 1972). Yet, the spatial distribution of mirid populations and associated damage in unshaded has actually received very little attention. Since 2006, innovative cocoa systems are developed with farmers in the Centre region of Cameroon. In these systems, the crop is diversified by intercropping fruit trees on a regular basis. Since the cocoa and fruit trees are planted at the same time, cocoa trees have been growing and actually still are under unshaded conditions, since the fruit trees are not high enough to provide shade. In this study, our objective was to study the spatial distribution of mirids and associated damage in unshaded, homogenous cocoa plantations.

Material and methods
The study was conducted in 6 unshaded 4 year-old cocoa plantations, planted after a minimum fallow period of 20 years, in the Centre region of Cameroon.

From July to September in 2009 and 2010 individuals of *S. singularis* were counted on each tree of the selected plots. Counting was done early in the morning since mirids usually escape direct sunlight by sheltering in bark crevices (Babin *et al.*, 2010).

Mirid damage was assessed by visual scoring of the degree of recent (desiccated leaves and shoots) and old (cankers) damage. The scoring scale was the same for the 2 types of damage and ranged from 0, for no damage to 3, for more than half of the tree having damage. Final scores given for each tree was the average score of 3 experimented observers. Damage data was collected from February to mid-March 2010, i.e. during the dry season when cocoa trees do not bear fruits.

Statistical analyses

We used three different models to study the spatial distribution of *S. singularis* populations: i) Taylor's power law (TPL), ii) negative binomial distribution (NBD) and iii) semivariograms (SVs). The distribution of recent and old damage was studied only using SVs.

Taylor power law stipulates that the variance (S^2) of a population density is proportional to a fractional power of the arithmetic mean density (m): $S^2 = am^b$. To estimate a and b, values of $log(S^2)$ for the different plots were regressed against those of $log(m)$ using the following formula: $log(S^2)=log(a) + blog(m)$, where the constant a is essentially a sampling factor related to sample unit size (Southwood, 1978), and the slope b is an index of aggregation that indicates a uniform (b<1), random (b=1), or aggregated (b>1) distribution (Taylor, 1961; Bisseleua *et al.*, 2011).

Negative binomial distribution: For each plot, the distribution of mirid densities was compared to a NBD, which is commonly used to describe insect distributions. To check the fit of the distribution of mirid densities to a NBD, observed density values were compared to expected values. Here, k is a parameter of aggregation calculated as ($k=m^2/ S^2-m^2$). When $k \rightarrow 0$, populations are aggregated, whereas when $k \rightarrow \infty$ populations are randomly distributed or follow a Poisson distribution.

Semivariograms: Cartesian coordinates X and Y were given in meters for each cocoa tree by projecting plot maps onto an orthonormal grid. For each plot, mirid spatial distribution or damage distributions were characterized by fitting SV theoretical models to observed semivariograms using GS^+ software (version 9; Robertson, 2008). Distribution maps were obtained by kriging

Results

Mirid populations' distribution

Taylor power paw: The TPL regression revealed that: $log(S^2) = 1.49 + 1.58log(m)$ in year 1 and $log(S^2) = 1.30 + 1.50log(m)$ in year 2. The determination coefficients were R^2= 0.756 in year 1 and R^2=0.988 in year 2. The Taylor's aggregation index was relatively constant for both years with b=1.58 in 2009 and b=1.50 in 2010. These positive values of index (b>1), show that mirid populations were aggregated in the studied plots.

The Negative Binomial distribution (NBD): The results show that the variance was higher than the mean for mirid densities for all the studied plots (Table 3). This result indicates that the number of *S. singularis* varied considerably between cocoa trees. The index of dispersion k was low, with a mean 0.02 ± 0.01. These results also confirm that mirid populations were aggregated in the selected plots. However, the results of tests to fit the NBD law gave probability values for only 4 out of 12 tests. This result suggests that our data did not fit well to the NBD.

Semivariograms (SV): Analysis of SV showed a spatial dependence of mirid densities in the selected plots during both years. The general mean range (A) of the spatial dependence for both years was 5.14 ± 1.08 m, with minimum and maximum values of 3.54 and 7.32 m respectively. The range of spatial dependence slightly differed between the two years. In 2009, the mean range was slightly lower (4.56 ± 1.08 m) compared to 2010 (5.73 ± 0.81 m). Kriging maps show that mirid populations were aggregated.

Damage distribution

Mirids damage were more evenly distributed than mirid populations (Figure 1). Recent damage, however was more aggregated compared with old damage (Figure 1). Analysis of the SVs showed a spatial dependence for mirid damage on cocoa trees. The value of the range differed between the types of damage and plots. The general mean range of the spatial dependence (A) was 20.16 ± 17.64 m, with a minimum value of 5.67 m and a maximum of 50.91 m for cankers and 18.75 ± 19.08 m, with a minimum value of 5.54 m and a maximum of 53.18 m for dry leafs.

Discussion

These results show that mirid populations are aggregated in unshaded cocoa plots, just like in traditional shaded ones (Babin *et al.*, 2010; Bisseleua *et al.*, 2011). Since light is probably not a deciding factor here, the aggregation is likely linked to other factors which remain to be determined.

The index of aggregation b obtained from TPL in the present study (b = 1.58 in 2009 and b = 1.50 in 2010) is similar to the one of a recent study (b = 1.50) conducted in traditional shaded cocoa agrosystems (Bisseleua *et al.*, 2011). These results strengthen the belief that the value b is more or less constant and characteristic for a particular species whichever the experimental conditions (Taylor, 1961). Then, aggregation is rather linked to intrinsic (biological) factors like reproductive behavior. In contrast, our values for the parameter of aggregation *k* are different from those obtained by Babin *et al.* (2010) in traditional shaded cocoa agrosystems. The difference of *k* values observed between the two studies may be linked to the difference of the (1) experimental conditions and (2) sampling methodology. We performed visual counts of mirids on trees, whereas Babin *et al.* (2010) used a knock down sampling method. The variability of *k* value between the plots and years could also be explained by high variability in population size. That's the prevalent explanation, which has already been showed in Cilas *et al*., 1996, Babin *et al*., 2010. For mirids, densities are strongly linked to sampling methodology.

The SV analyses also showed that mirid populations were aggregated in unshaded cocoa plantations. Spherical semivariogram models characterize plantations with small groups of infested adjacent cocoa trees (less than twenty trees in general) whereas exponential ones characterize the plantations with larger groups of adjacent infested cocoa trees (twenty to thirty trees in general). Similar results have been found by Babin *et al.* (2010) in shaded cocoa. These results indicate that whichever the experimental conditions, mirids were usually aggregated in less than 20 groups of adjacent cocoa trees within the plots.

Our results show that cumulative mirid damage, i.e. cankers on branches and trunks, is more widely spread in selected plots than more recent damage, i.e. dry leaves. Moreover, recent damage is less clearly aggregated than mirid populations themselves. These results lead us to hypothesize that mirids feed on a large number of cocoa within the plots before selecting certain trees to lay their eggs on. However, this hypothesis remains to be tested.

This study contributes to improve knowledge on the mirid ecology, especially the spatial distribution of mirid populations' and associated damage in the young unshaded cocoa plantations. Mirid populations are aggregated in the plots whereas their damage were regularly distributed notably the old ones. However, the factors that govern this distribution, for example, feeding and reproduction ecology of *S. singularis*, cocoa genotype, etc…, remains to be clarified; but the results obtained provide information about the history of mirid infestations in these young and unshaded plantations, and these should be hopefully in the end help for integrated pest management (IPM) strategies against *S. singularis*.

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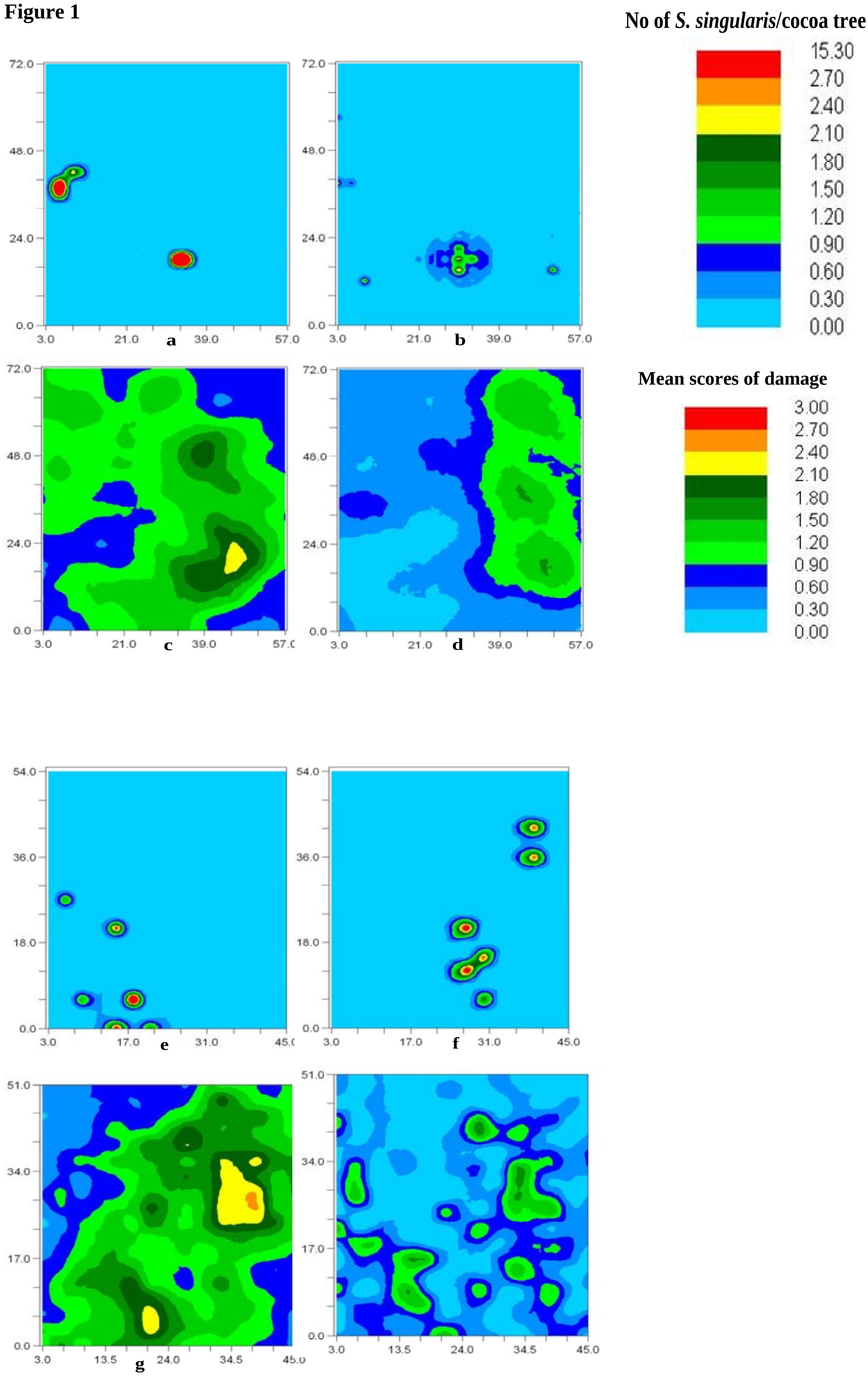
Figure 1



No of *S. singularis*/cocoa tree
15.30
2.70
2.40
2.10
1.80
1.50
1.20
0.90
0.60
0.30
0.00
Mean scores of damage
3.00
2.70
2.40
2.10
1.80
1.50
1.20
0.90
0.60
0.30
0.00
72.0
48.0
24.0
0.0
3.0
21.0
39.0
57.0
54.0
36.0
18.0
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c
d
e
f
g

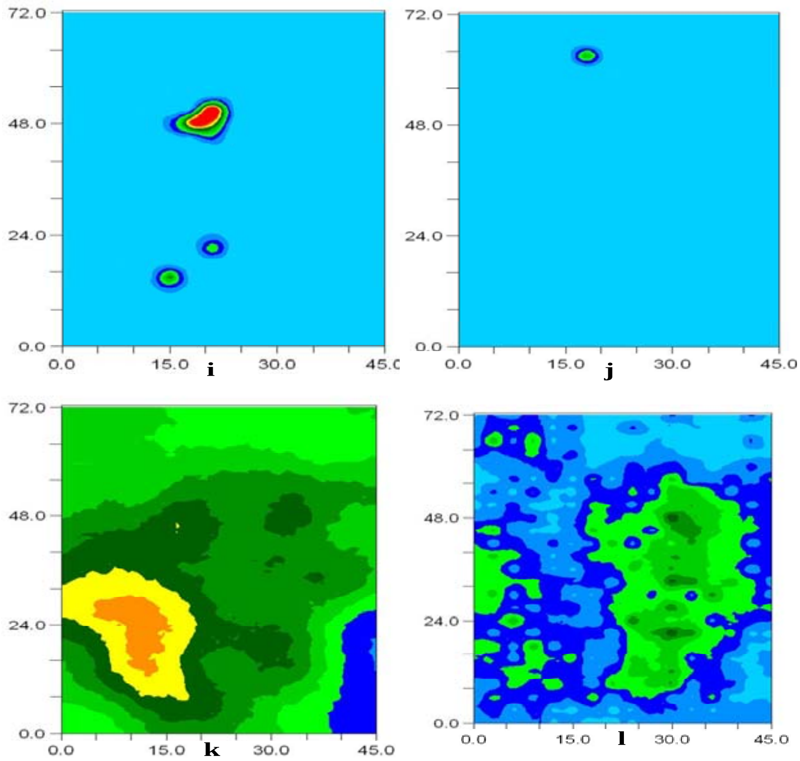

Figure 1: Example of the maps showing the spatial distribution the of *S. singularis* in 2009 (a,e,i) and in 2010 (b,f,j) and damage (c,g,k) for cankers and (e,h,l) for dry leaves in the three selective plots.