Sampling Plans for *Mononychellus progresivus* and *Oligonychus gossypii* (Acari: Tetranychidae) on Cassava in Africa

OLIVIER BONATO,[1] JOHANN BAUMGÄRTNER,[2] AND JEAN GUTIERREZ[1]

J. Econ. Entomol. 88(5): 1296–1300 (1995)

ABSTRACT Sampling plans were developed for 2 phytophagous mites, *Mononychellus progresivus* Doreste and *Oligonychus gossypii* (Zacher), on cassava in Africa. Analysis of intraplant distribution showed a preference of *M. progresivus* for the apical and middle parts of the plant, and of *O. gossypii* for the middle and lower plant parts. Thus, the 1st fully developed leaf in the middle part was chosen as the common sampling unit for both species. On this unit, both species displayed aggregated distributions. The proposed binomial and enumerative sampling plans permit reliable estimates of both *M. progresivus* and *O. gossypii* densities. Forty fully developed leaves provided satisfactory estimates of the densities of both mite species.

KEY WORDS *Mononychellus progresivus, Oligonychus gossypii,* sampling

TWO TETRANYCHID MITES are predominant on cassava, *Manihot esculenta* Crantz, in Africa: the cassava green mite *Mononychellus progresivus* Doreste (=*tanajoa* [Bondar]) (Gutierrez 1987) and the cotton red mite *Oligonychus gossypii* (Zacher) (Matthysse 1978, Yaninek and Onzo 1988, Bonato 1993, Gutierrez and Bonato 1994). *M. progresivus* is of neotropical origin and was introduced accidentally into Africa in the early 1970s (Nyiira 1972, Lyon 1973). It has since spread rapidly throughout the cassava belt and is currently considered one of the primary constraints for cassava production during the dry season, causing yield losses of 13–80% (Yaninek and Herren 1988, Yaninek et al. 1990). The population dynamics of *M. progresivus* are well known in Nigeria (Yaninek et al. 1989a, b) and Kenya (Skovgard et al. 1993), and several sampling plans have been proposed by various authors (Braun et al. 1989; Nachman et al. 1990, 1993; Yaninek et al. 1991).

Oligonychus gossypii is a polyphagous pan-African species found in cassava plantations mainly during the dry season (Matthysse 1978, Yaninek and Onzo 1988, Bonato 1993). Although it is almost completely absent from cassava plants during the rest of the year, *O. gossypii* may also have an effect on cassava growth, because pest densities can be as high as those of *M. progresivus* (Bonato et al. 1994).

Adequate knowledge of pest dynamics is a prerequisite for the design of a pest management program. Simple, fast, and accurate sampling procedures are required for density estimation and effective management. A sampling plan to accurately estimate the density of both *M. progresivus* and *O. gossypii* has not been reported previously. The 2 objectives of this study were to investigate whether the 1st fully developed leaf (Yaninek 1985) could be used as a common sampling unit for both *M. progresivus* and *O. gossypii,* and to design sampling plans using the fully developed leaves as a sample unit.

Materials and Methods

Experimental Fields. Fields were selected and studied during 1 rainy and 1 dry season (from November 1990 to November 1991) in 3 different locations in southern Congo (Mantsoumba, Brazzaville, Kombé). Both fields were planted in November 1989. The Mantsoumba plot is on an industrial plantation 250 km from Brazzaville in the Bouenza region. The 1,700-m^2 plot was planted with '1M20' cassava at a density of 1 plant per square meter. The experimental site at Kombé, 17 km from Brazzaville, was an on-farm field with an area of ≈800 m^2 planted with equal proportions of 2 cassava cultivars, 'M'Pembé' and 'Moudouma', at a density of 3–5 plants per square meter. The 400-m^2 plot chosen in Brazzaville was planted at Institut Français de Recherche pour le Développement en Coopération (ORSTOM) at a density of 1 plant per square meter using 'F 200'.

Intraplant Distribution: Selecting a Sample Unit. Generally, a sampling method is chosen to estimate the absolute density of an organism with a given degree of accuracy (Karandinos 1976, Ruesink 1980). For economic reasons, counting

[1] Laboratoire d'Acarologie ORSTOM, Avenue Val de Montferrand—B.P. 5045, 34032 Montpellier Cedex 1, France.
[2] Agricultural Bureau of the Grisons, Grabenstrasse 1, 7000 Chur, Switzerland.

0022-0493/95/1296–1300$02.00/0

mites on an entire cassava plant is not feasible, and a sampling unit smaller than the plant is needed. Yaninek et al. (1991) proposed a method to estimate *M. progresivus* densities based on examination of the 1st fully developed leaf (Yaninek 1985). Alternatively, the number of *M. progresivus* on a single plant is estimated by using stratified sampling procedures (Nachman et al. 1990). Yaninek et al. (1991) found that the optimum number of strata was 3 and divided the foliage of a standard cassava plant into the following strata: terminal shoots, developing leaves that emerge at the growing tips of each branch (that is, newly developed leaves just below the terminal shoots), and mature leaves.

In our study, a single shoot per plant was selected, and the following 3 strata were used to estimate mite densities: 1 young leaf (the 3rd from the tip), the 1st fully developed leaf, and a mature leaf (the 4th from the base).

In each field, 30 plants were chosen at each sampling date by dividing the field lengthways into 30 strips. One plant was chosen at random from each strip, and 1 leaf from each shoot from the 3 strata was selected randomly. The leaves were then labeled, placed in plastic bags, and put into a cold box. In the laboratory, mobile stages (immature and adult mites) of each species were counted on each leaf under a binocular microscope. Only the distribution of mobile stages was considered. Sampling was conducted monthly at Mantsoumba, semimonthly at Kombé, and weekly at Brazzaville.

Within-plant distribution of *M. progresivus* and *O. gossypii* was studied using analysis of variance (L.E.A.S. 1989). Variations in density on each of the 3 leaves for each mite species and each sampling date were compared after transforming each count into $\log(x + 1)$ (Zar 1984). If the F test revealed significant differences, means were compared using the Scheffé method (L.E.A.S. 1989). The level of significance was set at $P \leq 0.05$.

Interplant Distribution. Taylor power law (1961) was used to analyze the distribution of the 2 mite species on the fully developed leaves. According to Southwood (1978), the coefficients a and b can be estimated with:

$$\log s^2 = \log a + b \log m \qquad (1)$$

where s^2 = sample variance, m = sample mean.

Designing a Common Sampling Plan. *Relation Between the Number of Mites per Leaf and the Proportion of Fully Developed Leaves Infested.* The binomial (presence–absence) sampling model proposed by Nachman (1984) relates the proportion of infested fully developed leaves to mean number of mites per leaf:

$$p = 1 - \exp(-\alpha' m^{\beta'}) \qquad (2)$$

p = proportion of infested fully developed leaves, m = sample mean, α' and β' = population parameters obtained by $\log_e$ transformation of equation 2.

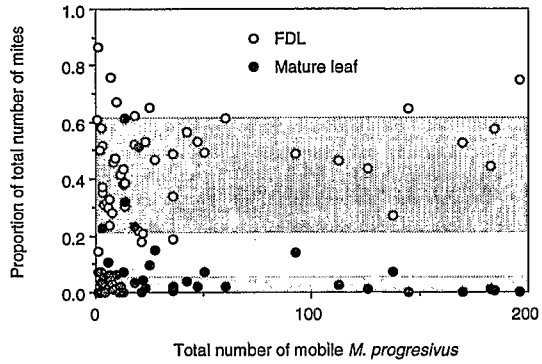

Fig. 1. Proportion of population of *Mononychellus progresivus* on the 1st fully developed leaf (FDL) and mature leaf in relation to the total mite number (young leaf + 1st FDL + mature leaf) for each sampling operation (shaded areas contain 75% of the values).

Binomial and Enumerative Sampling Plan. This procedure calculates the number of presence–absence samples to be taken to estimate the mean densities with a given reliability. The optimal sample size (that is, the number of leaves required to estimate this proportion with a given degree of reliability) that is expressed here by normal probabilistic statements (confidence interval equal to a proportion D_o of p) was determined according to Karandinos (1976):

$$n = \left(\frac{t}{D_o}\right)^2 \frac{1 - p}{p} \qquad (3)$$

where n = number of fully developed leaves to be collected, D_O = level of precision, t = Student t, p = proportion of fully developed leaves infested.

In the enumerative sampling plan, p of equation 2 was substituted in equation 3 to yield:

$$n = \left(\frac{t}{D_o}\right)^2 \frac{1 - [1 - \exp(-\alpha' m^{\beta'})]}{1 - \exp(-\alpha' m^{\beta'})} \qquad (4)$$

Note that the level of precision, D_o, is still related to the proportion of infested leaves. Equation 4 does not take into consideration the error in the transformation of p in equation 3.

Results and Discussion

Intraplant Distribution of *M. progresivus* and *O. gossypii*. Figs. 1 and 2 show the proportion of mites inhabiting the fully developed leaves and mature leaf for *M. progresivus* and the fully developed leaves and young leaf for *O. gossypii*, respectively, plotted against the total mite number (young leaf, fully developed leaf, and mature leaf) for each sampling operation.

The proportion of *M. progresivus* observed on mature leaves was always low (10% of total mite numbers), even during population outbreaks. In 6 of 45 samplings, the densities of mobile stages differed significantly between the young leaf and the

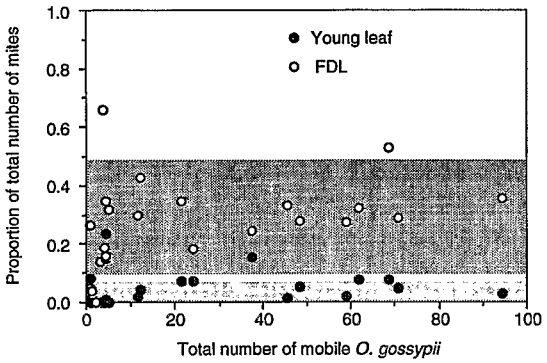

Fig. 2. Proportion of population of *Oligonychus gossypii* on the 1st fully developed leaf (FDL) and young leaf in relation to the total mite number (young leaf + 1st FDL + mature leaf) for each sampling operation (shaded areas contain 75% of the values).

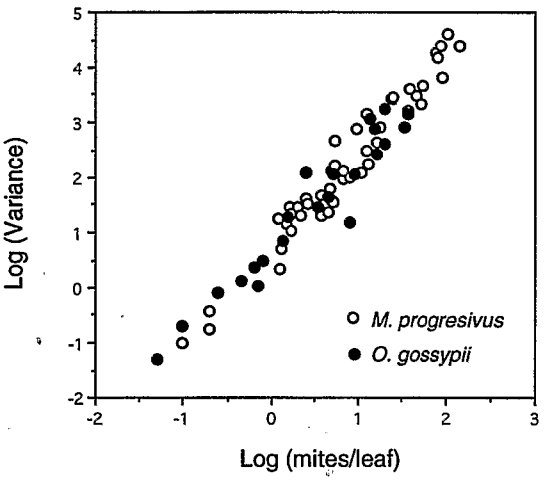

Fig. 3. Log variance versus log mite per leaf relationship for observed *Mononychellus progresivus* and *Oligonychus gossypii* described by the Taylor (1961) power law as: $s^2 = 4.93m^{1.76}$ for *M. progresivus* and $s^2 = 5.37m^{1.57}$ for *O. gossypii*. Data correspond to samples from 3 fields for *M. progresivus* and 2 fields for *O. gossypii*, representing a range of sampling periods, seasons, and locations.

fully developed leaf. Mobile stage densities were significantly different 31 times between the fully developed leaf and the mature leaf and 37 times between the young leaf and the mature leaf. The highest relative densities of mobile stages of *M. progresivus* were always recorded on the young leaf and on the 1st fully developed leaf (that is, in the 2 upper strata of the cassava plants). On some dates the densities on the 3 leaves were the same. This result can be explained by either season or low-density effects. During the dry season plants have few leaves and growth is slow; thus it is difficult to distinguish between young, fully developed leaves, and mature leaves. When mite populations are low (<1 individual per leaf), analysis typically does not reveal significant differences because low-density means are also usually associated with high variability. *M. progresivus* was distributed evenly between the apical and middle sections of the plant. This is in agreement with the results obtained by Braun et al. (1989) in Colombia and by Yaninek et al. (1991) in Nigeria.

All data on *O. gossypii* were obtained from the Kombé and Mantsoumba plots; none were observed in the plot at ORSTOM in Brazzaville. Densities observed on young leaves were low even during outbreak periods, composing only 10% of the total mite population observed on the 3 leaves in each sampling operation. Statistical analyses showed that in the 21 sampling operations, densities of mobile stages of *O. gossypii* were significantly different between the young leaf and the mature leaf, the young leaf and the fully developed leaf, and between the fully developed leaf and the mature leaf. Densities of the fully developed leaf and the mature leaf were generally not significantly different. *O. gossypii* was therefore preferentially distributed in the middle and lower part of the plant.

Distributions of *M. progresivus* and *O. gossypii* showed that the 1st fully developed leaves can be used as a common sampling unit. The relative densities observed on the fully developed leaves were characteristic of the populations on the plant, showing that the fully developed leaves can be used to derive density estimates for the whole plant (Yaninek et al. 1991, Bonato 1993).

Interplant Distribution. Fig. 3 shows the relationship between the variance and the number of mobile stages observed on the fully developed leaves on different shoots on each sampling date in the 3 plots for *M. progresivus* and in the Mantsoumba and Kombé plots for *O. gossypii*. Parameters a and b of the Taylor power law (1961) are (±SEM) $a = 4.93$ ($\log_{10}a = 0.69 \pm 0.06$), $b = 1.76 \pm 0.06$ ($r^2 = 0.95$, $F = 978.7$, df = 62, $P < 0.0001$) for *M. progresivus*, and $a = 5.37$ ($\log_{10}a = 0.73 \pm 0.07$), $b = 1.57 \pm 0.08$ ($r^2 = 0.95$, $F = 414.8$, $P < 0.0001$) for *O. gossypii*. The 2 slopes were significantly different ($t = 2.45$, df = 62) (Zar 1984). Both slopes were also significantly >1, indicating that *M. progresivus* and *O. gossypii* display aggregated distributions.

Designing a Common Sampling Plan. *Relation Between the Number of Mites per Leaf and the Proportion of Fully Developed Leaves Infested.* The coefficients of Nachman's (1984) model (Fig. 4) were determined after linearization of equation 2 (±SEM) for *M. progresivus*: $\alpha' = 0.36$ ($\log_e\alpha' = -1.03 \pm 0.11$) and $\beta' = 0.48 \pm 0.07$ ($r^2 = 0.72$, $F = 75.1$, df = 35, $P < 0.0001$); and for *O. gossypii*: $\alpha' = 0.27$ ($\log_e\alpha' = -1.30 \pm 0.09$) and $\beta' = 0.57 \pm 0.04$ ($r^2 = 0.93$, $F = 203.5$, df = 30, $P < 0.0001$). The 2 slopes were significantly different ($t = 3.88$, df = 43). For either mite species, when the mobile stage count per fully developed leaf for that spe-

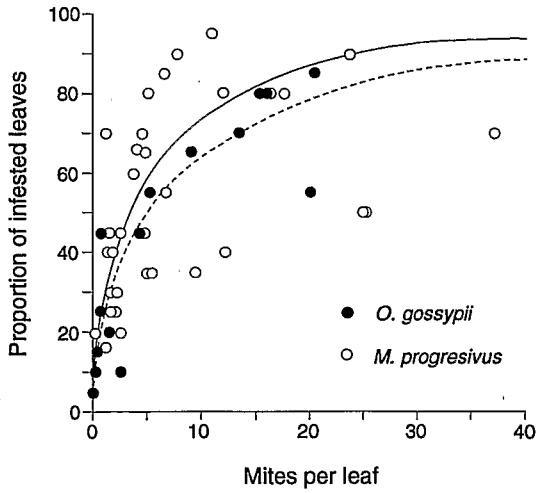

Fig. 4. Proportion of leaves infested with 1 or more mites per leaf versus mobile stages of *Mononychellus progresivus* and *Oligonychus gossypii* per leaf. Observed values (symbols) and predicted densities based on the Nachman (1984) model (*M. progresivus*, solid line; *O. gossypii*, dashed line).

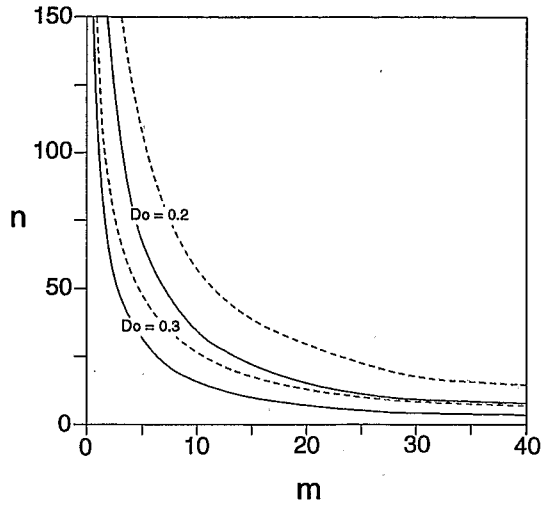

Fig. 5. Number of samples required to estimate mobile stages of *Mononychellus progresivus* (solid line) and *Oligonychus gossypii* (dashed line) per leaf using an enumerative sampling procedure for a given level of precision (D_0).

cies is >40, Nachman's (1984) binomial model shows that the proportion of infested leaves is >90%.

Binomial and Enumerative Sampling Plan. Wilson and Room (1983) showed that the binomial sampling plan could be modified to account for the economic threshold. According to Byrne et al. (1983), the economic threshold for *M. progresivus* is 8 mobile stages per leaf (Ezulike and Egwuatu 1990). An enumerative sampling plan is required for density estimation of the relative densities of both mite species. Fig. 5 shows the optimum sample size (that is, the number of fully developed leaves to be taken to estimate *M. progresivus* and *O. gossypii* populations assuring average precision levels D_0 of 0.2 and 0.3). The values vary according to the species, but the results show that a collection of 40–70 fully developed leaves is sufficient for satisfactory estimates of mite densities on fully developed leaves. For example, if the mean density is at least 8 mobile stages per fully developed leaves, then 30–40 fully developed leaves provide good estimate of the densities (D_0 = 0.3) of both *M. progresivus* and *O. gossypii*.

Sampling procedures permit population density estimates, which are an important aspect of pest management programs. The use of the fully developed leaf as the common sampling unit for *M. progresivus* and *O. gossypii* was satisfactory. For monitoring purposes and for population studies, the use of a binomial sampling procedure (that is, a presence–absence sampling plan) and an enumerative sampling plan on the fully developed leaves gave reliable results. The selection of 30–40 fully developed leaves from shoots selected at random on each of 30–40 plants, chosen at random in a field, is sufficient for a satisfactory density estimate for both mite species.

References Cited

Bonato, O. 1993. Dynamique des populations de l'acarien vert du manioc *Mononychellus progresivus* et de l'acarien rouge *Oligonychus gossypii* au Congo. Modélisation du sous-système acariens phytophages-manioc. Ph.D. dissertation, University of Montpellier II, France.

Bonato, O., J. Baumgärtner, and J. Gutierrez. 1994. Impact of *Mononychellus progresivus* and *Oligonychus gossypii* on cassava growth and yield in Central Africa (Acari: Tetranychidae). J. Hortic. Sci. 69: 1089–1094.

Braun, A. R., J. M. Guerrero, A. C. Bellotti, and L. T. Wilson. 1989. Within plant distribution of *Mononychellus tanajoa* (Bondar) (Acari: Tetranychidae) on cassava: effect of clone and predation on aggregation. Bull. Entomol. Res. 79: 235–249.

Byrne, D. H., A. C. Bellotti, and J. M. Guerrero. 1983. The cassava mites. Trop. Pest Manage. 29: 378–394.

Ezulike, T. O., and R. I. Egwuatu. 1990. Determination of damage threshold of green spider mite *Mononychellus tanajoa* (Bondar) on cassava. Insect Sci. Appl. 11: 43–45.

Gutierrez, J. 1987. The cassava green mite in Africa: one or two species? (Acari: Tetranychidae). Exp. Appl. Acarol. 3: 163–168.

Gutierrez, J., and O. Bonato. 1994. Les acariens tetranychidae attaquant le manioc au Congo et quelques uns de leurs prédateurs. J. Afr. Zool. 108: 191–200.

Karandinos, M. G. 1976. Optimum sample size and comments on some published formulae. Bull. Entomol. Soc. Am. 22: 417–421.

[L.E.A.S.] Logiciels d'Enseignement et d'Analyses Statistiques. 1989. Chaire de Mathématiques. Un-

ité de Biometrie de l'Ecole Nationale Superieure Agronomique de Montpellier, France.

Lyon, W. F. 1973. A plant-feeding mite *Mononychellus tanajoa* (Bondar) (Acarina: Tetranychidae) new to the African continent threatens cassava (*Manihot esculenta* Crantz) in Uganda, East Africa. Pest Artic. News Summ. 19: 36–37.

Matthysse, J. G. 1978. Preliminary report on mites collected from plants and animals in Nigeria. I. Mites from plants. Niger. J. Entomol. 1: 57–70.

Nachman, G. 1984. Estimates of mean population density and spatial distribution of *Tetranychus urticae* (Acarina: Tetranychidae) and *Phytoseiulus persimilis* (Acarina: Phytoseiidae) based upon the proportion of empty sampling units. J. Appl. Ecol. 21: 903–913.

Nachman, G., O. Carsten Pedersen, M. Münster-Swedensen, and J. Tomkiewicz. 1990. Sampling strategies for assessing the intra-plant density of the cassava green mite (*Mononychellus tanajoa*): a case study. Exp. Appl. Acarol. 9: 31–49.

Nachman, G., H. Skovgard, J. Tomkiewicz, M. Münster-Swedensen, and O. Carsten Pedersen. 1993. Sampling strategies for assessing the overall density of the cassava green mite (*Mononychellus tanajoa*). Exp. Appl. Acarol. 17: 5–28.

Nyiira, Z. M. 1972. Report of investigation of cassava mite *Mononychellus tanajoa* (Bondar). Kawanda Research Station, Kampala, Uganda.

Ruesink, W. G. 1980. Introduction to sampling theory, *In* M. Kogan and D. C. Herzog [eds.], Sampling methods in soybean entomology. Springer, New York. pp. 61–78.

Skovgard, H., J. Tomkiewicz, M. Münster-Swedensen, and G. Nachman. 1993. The dynamics of the cassava green mite *Mononychellus tanajoa* in a seasonally dry area in Kenya. Exp. Appl. Acarol. 17: 41–58.

Southwood, T.R.E. 1978. Ecological methods. Chapman & Hall, London.

Taylor, L. R. 1961. Aggregation, variance and the mean. Nature (Lond.) 189: 732–735.

Wilson, L. T., and P. M. Room. 1983. Clumping patterns of fruit and arthropods in cotton, with implications for binomial sampling. Environ. Entomol. 12: 50–54.

Yaninek, J. S. 1985. Field monitoring of *Mononychellus tanajoa* populations, pp. 136–138. *In* Annual report 1984. International Institute of Tropical Agriculture, Ibadan, Nigéria.

Yaninek, J. S., and H. R. Herren. 1988. Introduction and spread of the cassava green mite, *Mononychellus tanajoa* (Bondar) (Acari: Tetranychidae), an exotic pest in Africa, and the search for appropriate control methods: a review. Bull. Entomol. Res. 78: 1–13.

Yaninek, J. S. and A. Onzo. 1988. Survey of cassava green mite in the People's Republic of Benin, January 1988. Report IITA (International Institute of Tropical Agriculture).

Yaninek, J. S., A. P. Gutierrez, and H. R. Herren. 1989a. Dynamics of *Mononychellus tanajoa* (Acari: Tetranychidae) in Africa: experimental evidence of temperature and host plant effects on population growth rates. Environ. Entomol. 18: 633–640.

1990. Dynamics of *Mononychellus tanajoa* (Acari: Tetranychidae) in Africa: effects on dry matter production and allocation in cassava. Environ. Entomol. 19: 1767–1772.

Yaninek, J. S., H. R. Herren, and A. P. Gutierrez. 1989b. Dynamics of *Mononychellus tanajoa* (Acari: Tetranychidae) in Africa: seasonal factors affecting phenology and abundance. Environ. Entomol. 18: 625–632.

Yaninek, J. S., J. Baumgärtner, and A. P. Gutierrez. 1991. Sampling *Mononychellus tanajoa* (Acari: Tetranychidae) on cassava in Africa. Bull. Entomol. Res. 81: 201–208.

Zar, J. H. 1984. Biostatistical analysis, 2nd ed. Prentice-Hall, Englewood Cliffs, NJ.

Received for publication 30 June 1994; accepted 28 March 1995.