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Sampling *Mononychellus tanajoa* (Acari: Tetranychidae) on cassava in Africa

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Abstract

Density-specific sampling plans were developed under African conditions for the exotic spider mite, *Mononychellus tanajoa* (Bondar), a serious pest of cassava, *Manihot esculenta*. The within-plant distribution of *Mononychellus tanajoa* was found to favour new foliage, regardless of time of planting or plant age. Consequently, the first developed leaf near the top of the foliage was selected as the sampling unit and related to whole plant populations of *M. tanajoa*. The relationship between the mite population's variance and mean as measured by Taylor's Power Law proved to be stable over a range of planting dates, seasons and locations. Two binomial sampling plans, one based on Taylor's dispersion parameters and another based on direct field observations, were developed and compared. Binomial sampling, appropriate only for densities below 30 mites per leaf, was replaced by an enumerative procedure based on a 'quick count' protocol at higher mite densities.

Introduction

Procedures for quickly and accurately estimating mite densities are needed to facilitate studies on the population dynamics and pest status of the cassava green mite, *Mononychellus tanajoa* (Bondar), in Africa (Yaninek *et al.*, 1989c). This pest was accidentally introduced from the Neotropical Region in the early 1970s (Nyiira, 1972), and has since become a serious pest of cassava, *Manihot esculenta*, causing estimated yield losses of 13–80% annually (Yaninek & Herren, 1988; Yaninek *et al.*, 1990).

The use of sampling plans for monitoring population trends and assessing damage is well developed for tetranychid mites in temperate agricultural systems (Jones & Parrella, 1984; Margolies *et al.* 1984; Wilson *et al.*, 1983; Zahner & Baumgaertner, 1984; Zalom *et al.*, 1984). Similar procedures remain largely undeveloped for tropical agricultural systems, especially in Africa.

Braun *et al.* (1989b) recently examined the within-plant distribution of *Mononychellus tanajoa* as affected by cassava clones and predation in Colombia, and proposed a binomial sampling plan based on their findings. The ecological and agronomic conditions present during this study differ considerably from those normally associated with cassava in Africa. Braun *et al.* (1989b) planted just prior to the dry season and sampled seven times during the first nine months of cassava growth and development. Likewise in the Neotropical Region, a complex of phytophages often occur together on the same plant (Bellotti & van Schoonhoven, 1978) along with locally-adapted natural enemies (Bellotti *et al.*, 1985b) which may confound the effect of individual species in the system.

African farmers plant most of their cassava at the beginning of the wet season, rely on rainfed irrigation, and may leave their crop in the ground for up to two years before harvest (Silvestre & Arraudeau 1983). Since the successful biological control of the exotic cassava mealybug, *Phenacoccus manihoti* Matile-Ferrero (Hemiptera: Pseudococcidae), in most areas where it occurs (Neuenschwander & Herren, 1988), and except for sporadic

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outbreaks of the grasshopper *Zonocerus variegatus* Linnaeus (Orthoptera: Acrididae), *M. tanajoa* is often the only significant phytophage found on cassava in Africa. This mite occurs without the co-evolved natural enemies providing good biological control in its area of origin (Braun *et al.*, 1989a; Yaninek *et al.*, 1987). In addition, cassava in Africa has not traditionally been selected because of its response to this pest, whereas most traditional cultivars found in the pests' area of origin confer some degree of host plant resistance (Bellotti *et al.*, 1985a).

In this paper, procedures for sampling *M. tanajoa* are developed given a range of ecological conditions normally associated with cassava growth in Africa.

Materials and methods

Ten naturally infested cassava fields planted in 1983 and 1984 at two locations in Nigeria were regularly sampled for *M. tanajoa* densities. In 1983, experimental fields were planted during May, June and November at the International Institute of Tropical Agriculture (IITA) near Ibadan, and during May, August and November at the Texagri Farm near Abeokuta located 150 km southwest of Ibadan. In 1984, experimental fields were planted during April, May, July and October at IITA.

Agronomic practices typical of the region were followed. Cassava cuttings were planted during the wet season on ridges at a density of 1 per m^2. Although the size of these fields ranged from 40 to 20,000 m^2, most were in excess of 1000 m^2. The IITA variety TMS 30572 was planted in all fields. All plots were weeded at least once during the first three months of plant growth and were irrigated by rainfall.

Selecting a sampling unit

Counting mite samples is time and labour intensive, hence whole plant samples which are feasible for young cassava become impractical as the plant increases in size. *M. tanajoa* in Africa occurs exclusively on the foliage (Yaninek *et al.*, 1989c), hence an appropriate leaf unit for sampling these populations was sought.

The foliage on a typical cassava plant may be divided into 1) terminal shoots, 2) developing leaves which emerge at the growing tips of each branch, i.e., newly developed leaves just below the terminal shoots, and 3) mature leaves, i.e., older leaves found at or near the bottom of the canopy. *M. tanajoa* individuals spend most of their lives confined to the same leaf; usually in the upper strata of the canopy (Nyiira, 1972). Nymphs and adult females often migrate if the host plant deteriorates, but the number of mites that move within a plant is small (Yaninek, 1988).

The first developed leaf (FDL) found near the top of the plant was chosen as the index sampling unit because it is easily distinguished from the surrounding immature foliage by its mature green colour and by its petiole which intersects the main stem at an angle of less than 90° (Yaninek, 1985).

Mites eggs and active stages (nymphs and adults) may be found on all leaves within a plant, hence all mites found on alternate leaves along a single branching path (any unique series of inter-connected branches between the main stem at the bottom of the plant and a terminal shoot at the top of the same plant) were counted from top to bottom on five plants to assess their within-plant distribution. These results were used to evaluate the suitability of the FDL as a sampling unit, and for developing relationships for estimating whole plant mite populations. This was carried out for cassava planted during April, July and October 1984 at IITA at the beginning (November, 1984), middle (January, 1985) and end (April, 1985) of the dry season. An average density was computed for each leaf position along the branching path (i.e., level) on every sampling date in each planting treatment.

Between stages (eggs and active life stages) and between levels comparisons were made for each location and planting time in a fully crossed factorial analysis of variance nested within sampling date for each planting time. All means ($\bar{x}$) used in this analysis were transformed using $\log(\bar{x} + 1)$.

Sampling first developed leaves (FDL)

M. tanajoa densities on the FDL were estimated using two methods. In the first method, counts of all life stages found on the FDL of three branches from each of 25 plants were made in the laboratory. Samples were taken biweekly in three fields in Abeokuta during 1984. The field planted in April at IITA was similarly sampled during the wet season (April to November, 1984; May and June, 1985), but sampled weekly during the dry season (December to April, 1984–85). The collected leaves were placed in a coolbox and transported to the laboratory where the mites were counted as either eggs or active stages (larvae, nymphs and adults). All counts were pooled per plant and averaged on a per leaf basis. These data were used to develop both binomial and enumerative sampling plans for active stages.

In the second method, mite numbers from the 10 IITA plots described above were estimated in the field using the 'quick count' procedure described by Yaninek (1985). This method was developed because of the need to obtain a mean mite density in the field using a direct and rapid method. It proved easy to categorize the *M. tanajoa* active stages observed per leaf in one of the following four density classes: (1) 0, (2) $0 \leq 25$, (3) $25 \leq 200$, or (4) > 200. The mean number of mites per leaf was then calculated according to equation 1 with direct applicability in the field:

$$\text{mites per leaf} = (10N_1 + 110N_2 + 350N_3)/N^* \qquad (1)$$

where N_i for i = 1, 2, 3 are the number of leaves infested in each of three mite density classes, the coefficients 10 and 110 are the median values expected in two density classes rounded to the nearest ten, and 350 is the empirical mean of 300 field samples with > 200 mites per leaf, N^* is the sum of the leaves sampled, and the ratio $(N^*-N_0)/N,^*$ where N_0 is the number of leaves uninfested, is the proportion of leaves infested. This procedure compares favourably with actual counts obtained as described above (Yaninek, 1985). These estimates were made biweekly on twenty to thirty plants per plot during the 1984 and 1985 wet seasons and weekly during the 1984–85 dry season.

Analysis of dispersion

Dispersion of *M. tanajoa* was evaluated by analysing the variance to mean relationship of the field density counts. Taylor (1961) showed that this relationship for a wide range of species may be described by the function:

$$s^2 = a\bar{x}^b \quad (2)$$

where s^2 = sample variance, $\bar{x}$ = sample mean, and a, b are fitted coefficients. According to Taylor (1961), the parameter b is a measure of dispersion of the sample mean, whereby $b > 1$, $b = 1$ and $b < 1$ indicate aggregated, random and regular distributions, respectively. The parameters a and b were estimated by regressing log s^2 against the log $\bar{x}$ (Southwood, 1978).

Developing a sampling plan

Wilson & Room (1982) incorporated Taylor's Power Law into Karandinos' (1976) model for estimating the number of samples (n) needed to achieve a specified level of reliability (D_0) as follows:

$$n = (t/D_0)^2 a\bar{x}^{b-2} \quad (3)$$

where t is the standard normal deviate (1.96 for $n > 30$) and D_0 is defined as a fixed proportion of the mean ($\bar{x}$) to one half the confidence interval at 95% probability. The other parameters are as defined in equation 2.

Spider mites such as *M. tanajoa* are often too numerous or too difficult to count efficiently when large numbers of samples are involved. Simplified procedures such as binomial sampling save considerable time and effort. Wilson & Room (1983) proposed a presence-absence sampling procedure that predicts average densities ($\bar{x}$) from the proportion of sampling units (p) infested based on a negative binomial model modified to include Taylor's a and b parameters:

$$p = 1 - e^{-\bar{x}(\ln(a\bar{x}^{b-1}-1))} \quad (4)$$

where the parameters are as defined in equation 2. This approach indirectly establishes the relationship between the proportion of sampling units infested and the mite population density via the dispersion parameters.

Another presence-absence procedure was proposed by Nachman (1984):

$$p = 1 - e^{-\alpha\bar{x}^{\beta}} \quad (5)$$

In this model the population parameters α and β are estimated by linearizing equation 5 with a natural log transformation. The sample constants *a'* and *b'* are then derived from the proportion of leaves uninfested ($p_0 = 1 - p$) and the sample mean ($\bar{x}$) as shown by Nachman (1984). This approach establishes the relationship between the proportion of sampling units infested and the mite population density directly from field observations.

In the case of *M. tanajoa*, the proportion of leaves infested saturates to unity at relatively low densities. For this reason, an enumerative sampling plan based on sequential sampling methods and Taylor's a and b parameters (Green, 1970), was developed for higher mite densities. For this procedure, sampling is continued until the cumulative total mites encountered (T_n) found on n leaf samples satisfies equation 6 for level of precision D_0:

$$\ln(T_n) = \ln(D_0^2/a)/(b-2) + ((b-1)/(b-2))\ln(n) \quad (6)$$

Here the average mite density per leaf ($\bar{x}$) is estimated indirectly by dividing the cumulative total number of mites encountered (T_n) by the number of leaves sampled (n). As this method requires prompt estimates of cumulative mites densities (T_n) in the field and direct counts are not practical, 'quick counts' as outlined above are utilized.

Results

Within-plant distribution

The within-plant distribution data confirm that *M. tanajoa* in Africa is most abundant on young leaves regardless of plant age (fig. 1). Mite densities were significantly greater on young compared to old leaves, and

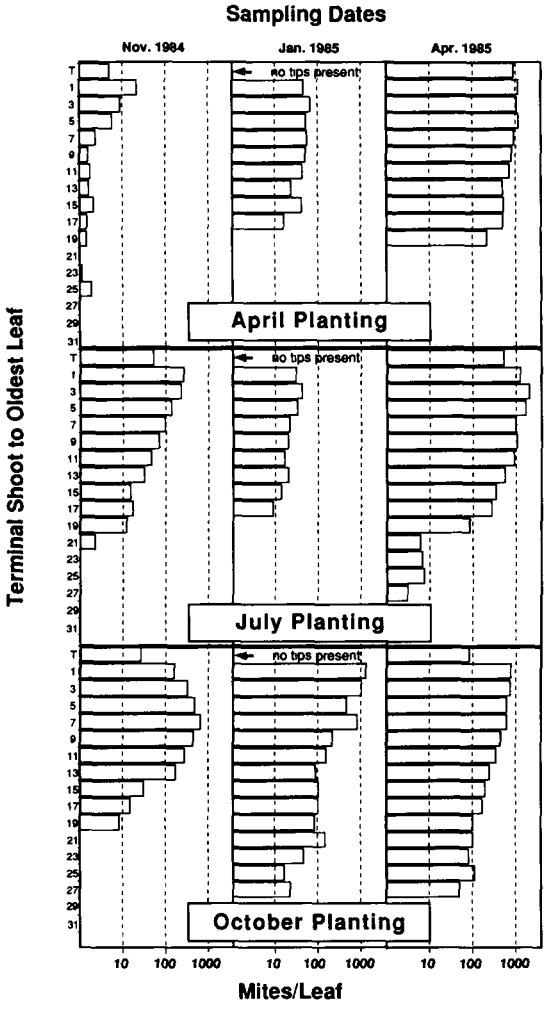

Fig. 1. Within-plant distribution of total mites (eggs + actives) per leaf on cassava planted in April, July and October 1984 sampled at the beginning (November), middle (January), and end (April) of the 1984–85 dry season.

densities steadily declined with leaf age under all conditions (Newman-Keuls *a posteriori* comparison, $q_{\cdot 05,216,p=9}$) (table 1). Peak densities occurred on either the first or third fully developed leaf in all samples, except the November sample from the October planting where a peak density was found on the seventh leaf (fig. 1).

Mite densities on the first developed leaf (FDL) averaged 10 ± 2% of the total population per branching path based on all samples. This proportion was stable regardless of time of planting or plant age, and suggests that the FDL is a reasonable choice as a sampling unit for monitoring *M. tanajoa* on cassava. Whole plant densities can be estimated as the product of 10 times the number of mites on the FDL times the number of branching paths with leaves.

A significantly greater proportion of eggs compared to active stages was found at the end of the wet season (all planting dates; table 1). This trend was reversed at the height of the dry season in January samples from April and July plantings when the suitability of the remaining leaves and *M. tanajoa* reproduction generally declined (Yaninek *et al.*, 1989a). No significant interactions were found between mite stage and leaf position. Thus, most of the explained variation in mite densities was due to planting date, leaf level and mite stage effects.

Dispersion

The parameters of Taylor's (1961) power law (eqn. 2) for the data shown in fig. 2 are; a = 2.604 and b = 1.689 ($r^2 = 0.964$, df = 71, $p < 0.001$), indicating an aggregated distribution. These values are similar to values reported in the literature for other species of spider mites (Margolies *et al.*, 1984; Zahner & Baumgaertner, 1984). Braun *et al.* (1989b) reported b values that were similar, but a values that were considerably higher for *M. tanajoa* in Colombia.

Sampling plan for M. tanajoa

The number of leaf samples needed for a given level of precision across all observed densities may be computed using Wilson & Room's (1982) enumerative sampling rule (eqn. 3) shown in fig. 3. This method requires an accurate estimate of mean density which is often impractical for field populations of spider mites. The 'quick count' method provides one alternative, but binomial methods are usually more efficient when applicable. A plot of the proportion of infested leaves versus observed mites per leaf indicates that binomial sampling is reasonable only for mite densities below 30 per leaf (fig. 4). At higher densities, the proportion of infested leaves saturates, yielding little information. For this reason, the analysis separates into densities above and below 30 mites per leaf.

For field densities below 30 mites per leaf, Wilson & Room's (1983) presence-absence model (eqn. 4) predicted densities which are much lower than those observed (dotted lines, fig. 5). The binomial sampling model proposed by Nachman (1984) was a better predictor of mite densities when leaves were not saturated. The fitted con-

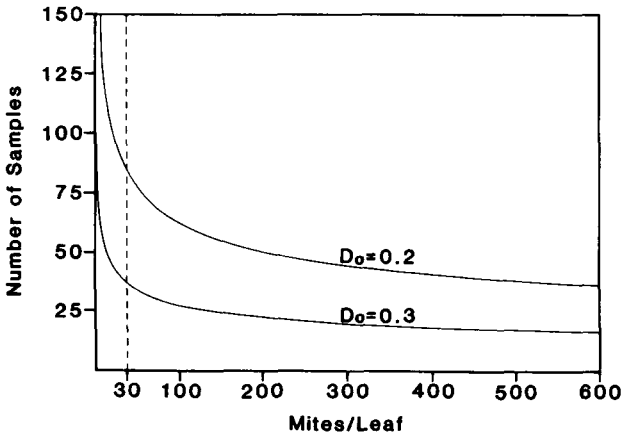

Fig. 3. Number of samples required to estimate mites per leaf using an enumerative sampling procedure at high *M. tanajoa* densities for a given level of precision, D_0. The dashed line indicates the density above which enumerative sampling is used

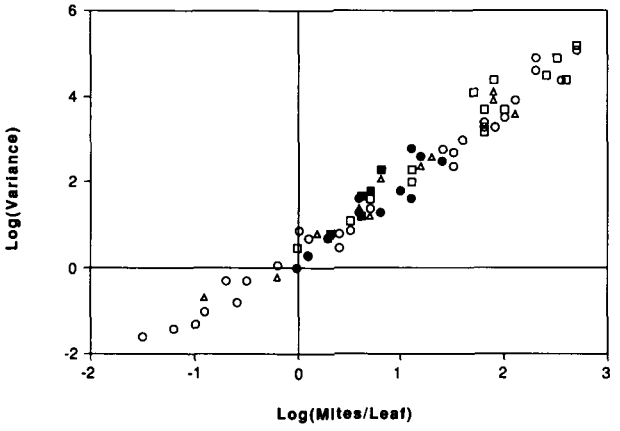

Fig. 2. Log(variance) to log(mites per leaf) relationship of observed *M. tanajoa* densities; described by Taylor's power law as: variance = $2.604\bar{x}^{1.689}$; N = 73 samples from five fields (each indicated separately), representing a range of sampling periods, planting times, seasons and locations.

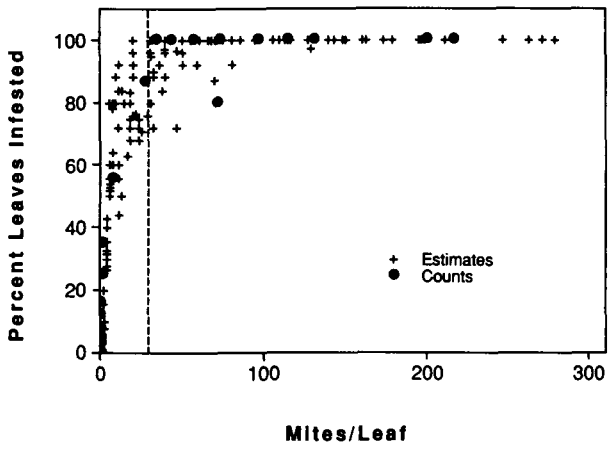

Fig. 4 Percentage of leaves infested versus observed mites per leaf for laboratory mite counts (N = 23 field samples) and 'quick count' estimates (N = 159 field samples). The dashed line separates low and high mite densities.

Table 1. Sources, degrees of freedom (Df), sum of squares (SS). F values (F) and the percentage explained variation (r^2) in a three factor fully crossed ANOVA of mite life stages, and leaf position in the foliage (Level) nested in sampling dates (Dates) for *M tanajoa* found on cassava planted in April, July and October during 1984.

Sources	Df	April planting			July planting			October planting		
		SS	F	r^2	SS	F	r^2	SS	F	r^2
Dates (D)	2	208 73	1199.71**	0.859	118.73	474.98**	0.646	13.80	45.45**	0.139
Within November		10.73		0.044	27.93		0.152	45.36		0.458
Stage	1	0.28	4.98*	0.001	2.76	22.78**	0.015	2.09	8.29**	0.021
Level	8	6.15	13.68**	0.025	16.05	16.54**	0.087	23.90	11 86**	0.241
S × L	8	0.26	0.58		0.38	0 39		1.23	0.61	
Within January		12.26		0.50	11.98		0.065	31.62		0.319
Stage	1	1.04	11.01**	0.004	1.30	16.23**	0.007	0.28	1.82	
Level	8	4.13	5.47**	0.017	4.86	7.57**	0.026	20.35	16.71**	0.205
S × L	8	0.28	0.37		0 05	0.07		0.03	0.02	
Within April		11.30		0.047	25.24		0.137	8.36		0.084
Stage	1	0.01	0.06		0.17	0.95		0.20	3.91	
Level	8	3 19	3 62**	0.013	12.22	8.81**	0.067	4.33	10 60**	0.044
S × L	8	0.16	0.18		0.36	0.26		0.16	0.39	
Error	216	18.79		0.077	27.00		0.147	32.78		0.331
Total	269	243.01			183.88			99.13		

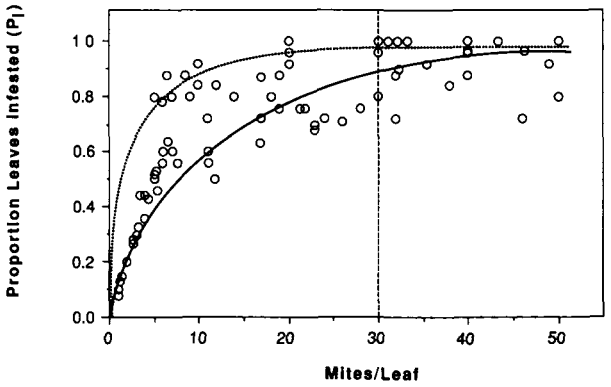

Fig 5 Proportion of leaves infested versus observed mites per leaf showing predicted densities based on Wilson & Room's (1983) model (eqn. 4) (dotted line) and Nachman's model (eqn. 5) (solid line)

stants of the model are $a' = 2.5054362$ and $b' = 1.133111$ ($r^2 = 0.81$, df = 86, $p < 0.001$). The fit of this model and the Wilson & Room (1983) model (eqn. 4) to the observed data are compared in fig. 5 for densities below 30 per leaf.

For mite densities above 30 per leaf, Green's (1970) sequential sampling method estimates the mean density in an indirect manner. The method requires that the cumulative number of mites encountered be tallied while sampling until the sampling rule is satisfied (fig. 6). 'Quick counts' may be used to estimate these cumulative densities.

Discussion

The goals of a research project are important considerations when developing sampling plans. Research objectives usually require that the data meet a specified level of accuracy, while pest management decisions are often based on problematic considerations such as the likelihood that a pest population will meet or exceed an economic level (Ruesink, 1980).

In Africa, cassava is an exotic subsistence crop grown virtually without agronomic inputs (Silvestre & Arraudeau, 1983), and few if any pest management decisions

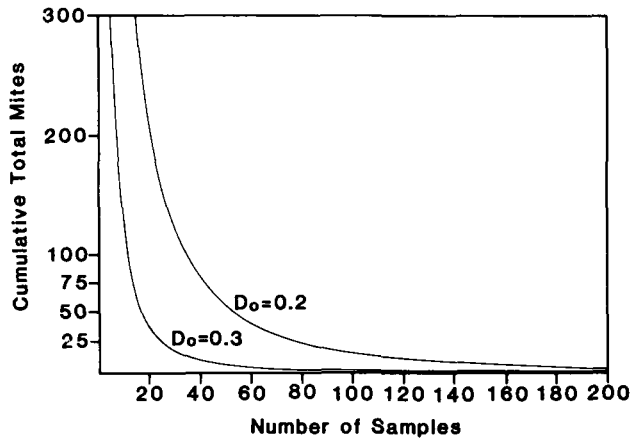

Fig. 6. Stop lines for constant-precision sequential sampling based on an enumerative procedure for a given level of precision, D_o.

are made for pests such as *M. tanajoa*. Co-evolved natural enemies of *M. tanajoa* are absent and cultivar selection for mite resistance is in its infancy in Africa (Yaninek *et al.*, 1989c). This situation contrasts with conditions in the Neotropical Region. Most of the research on *M. tanajoa* has been ecological in nature (Yaninek & Herren, 1988; Yaninek *et al.*, 1989c) with only secondary pest management objectives, hence a high degree of data reliability has been sought.

Although the procedures presented here were from a single institutional cassava variety, the phenology and dynamics of *M. tanajoa* populations were similar on different varieties (Yaninek *et al.*, 1989b) suggesting a wider application of the relationships and methods developed here. The dispersion of *M. tanajoa* as described by Taylor's (1961) a and b parameters proved to be stable over a range of mite densities, planting times, plant ages, seasons and locations (fig. 2). Dispersion patterns remained the same, apparently because the mites track the availability of young leaves (Yaninek *et al.*, 1989a, 1989b). This suggests that *M. tanajoa* dispersion characteristics are likely to be similar on cassava varieties with similar agronomic characteristics and grown under similar ecological conditions. Accurate estimates of mite populations found on different cassava varieties will require separate procedures. In the meantime, the procedures presented here can be used as a model while new sampling plans are developed and verified. New sampling plans are likely to be needed anyway in the future. The density and dispersion characteristics of this mite should change in Africa if effective predators are introduced into the continent and become established (Braun *et al.*, 1989a; Wilson, 1985; Wilson *et al.*, 1984), or if significant host plant resistance becomes widespread.

Accurate counts of mite densities are largely impractical, hence a simplified 'quick count' census method was developed. In this study, the first developed leaf (FDL) was selected as an index of the whole plant mite population. Binomial methods based on the relationship between the proportion leaves infested and the density of the pest, i.e., presence-absence observations, have been developed and in some cases greatly reduce sampling effort.

Wilson & Room's (1983) model (eqn. 4) was initially selected for developing the binomial sampling because much of the mite sampling literature is based on this procedure (Braun *et al.*, 1989b; Wilson *et al.*, 1983; Wilson *et al.*, 1984; Zalom *et al.*, 1984). However, Nachman's (1984) model (eqn. 5) was later included because of the poor fit between the estimates provided by Wilson and Room's model and the observed data. Nachman's model proved more accurate for predicting mite densities and is simpler than the model by Wilson and Room. This is not surprising since the model by Wilson and Room is based on parameters estimated from data on numbers of mites, whereas the parameters in Nachman's model come directly from field values. In addition, Nachman's model is more generally applicable since the parameters in his model are independent of a specific distribution, while Wilson and Room's model was derived from a negative binomial distribution.

Unfortunately, the proportion of leaves infested with *M. tanajoa* quickly saturates to unity at low mite densities, limiting the utility of the binomial sampling to den-

sities below 30 mites per leaf. The number of samples required to estimate accurately mite densities as the proportion of infested leaves approaches zero quickly becomes excessive. Since most practical work on *M. tanajoa* focuses on the high densities which occur during the dry season (Yaninek *et al.*, 1989b), indicative scores (e.g., ≤ 10, > 10 but ≤ 20, > 20 but ≤ 30 mites per leaf) provide adequate estimates for densities below 30 mites per leaf in most instances. Any artefacts inherent in estimated densities near 30 mites per leaf can be minimized by increasing the sampling frequency until the population moves clearly above or below this level.

For higher densities, the sequential sampling plan developed for use in the field minimizes the number of samples required to achieve a predetermined level of accuracy (Green, 1970). The 'quick count' method eliminates the need for total counts of mite densities. Using the sequential sampling rule based on 'quick counts' (fig. 6), the number of samples needed to meet a given level of precision can be easily determined.

Field application

In practice, an initial sample of 30 leaves should be taken and the proportion of leaves infested should be determined to estimate whether the observed density is above or below 30 mites per leaf. If the density is less than 30 mites per leaf, the sampling plan shown in fig. 5 may be used to determine mite densities based on the proportion of infested leaves. If the estimated density of the initial 30 leaf samples is above 30 mites per leaf, the sampling rule shown in fig. 6 may be used.

Simplified sampling procedures if properly developed can save time and money without compromising accuracy. However, the same sampling rule may not apply for all conditions under which a population occurs. This was the case for *M. tanajoa* in this study. An analysis of the mite's dispersion under African conditions revealed these needs, and led to the development of density-specific sampling procedures which are simple, yet practical, methods for accurately estimating mite populations.

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