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ORIGINAL ARTICLE

Relationship between sampling intensity and precision for estimating damage to maize caused by rodents

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Abstract

In this study we aimed to determine the relationship between sampling intensity and precision for estimating rodent damage. We used the systematic row sampling technique to provide data to achieve precision and accuracy in estimations of rodent damage in maize fields at the planting and seedling stages. The actual rodent damage to maize in 15 fields, each 0.5 ha in size, in Morogoro, Tanzania, was established at the seedling stage. These data were used to simulate the sampling intensities that would provide precision and accuracy. The variations between estimates were plotted against the sampling intervals. The results of this study show that the relationship between average standardized variances and sampling intervals is linear. The heterogeneous distribution of damage in some plots caused variations in the accuracy of the estimates between plots, but a sampling interval of five rows consistently produced estimates with a variance of less than 10%. We provide a standard curve that will allow a decision to be made on the sampling intensity as a function of required precision using the systematic row sampling technique in maize fields.

Key words: rodents, sampling interval, simulation, standard curve, systematic row sampling.

INTRODUCTION

Rodent damage to crops is a serious impediment in agriculture (Fiedler 1988; Singleton *et al*. 1999). In Tanzania, rodents cause an estimated pre-harvest loss of 15% of the annual maize crop (Makundi *et al*. 1991). It is not unusual for damage to maize to exceed 80% in certain cropping seasons and locations (Mwanjabe & Leirs 1997; Mulungu *et al*. 2003b) during rodent outbreaks (Mwanjabe *et al*. 2002). Reliable quantitative assessments of crop losses caused by pests are required to quantify the magnitude of pest problems, model the effects of rodent control strategies and evaluate different management approaches (Judenko 1973; Mwanjabe & Leirs 1997).

Many sampling techniques have been employed for rodent damage estimations at different locations and for different crops (Benigno 1979, 1980; Rennison & Buckle 1988; Key 1990). In Tanzania, a systematic row sampling technique is commonly used to assess rodent damage to seedlings in maize fields (Mwanjabe & Leirs 1997; Mulungu 2003). Typically, the assessor walks along maize rows across the field, recording damage at each plant hole in the row, and repeats this at fixed row intervals. Often an interval of five rows is used, but whether this is the most appropriate sampling intensity has not been documented. Determining the sampling intensity, or sample size, is very important because samples that are

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too large may waste time and resources, whereas samples that are too small may produce inaccurate results (Mead & Curnow 1983; Shepard & Ferrer 1990; Mulungu *et al*. 2003a).

In practice, the size of the sampling variance before damage assessment is generally not known to the researcher (Karandinos 1976; Cochran 1977). The desired level of precision can, however, be defined by the researcher based on experimental objectives and previous experience (Shepard & Ferrer 1990). The usual practice is for the researcher to define the desired level of precision in terms of margin of error, either of the plot mean or of the treatment mean (Karandinos 1976; Mead & Curnow 1983). For example, the researcher may decide that the sample estimate should not deviate from the true value in more than 5 or 10% of the samples (Cochran 1977; Mead & Curnow 1983). With an estimate of the sampling variance, the required sample size can be determined based on the prescribed margin of error of the plot mean or treatment mean and an estimate of the sampling error.

In the present study, we investigated the relation between sampling intensity and accuracy of the estimate for the systematic row sampling technique in maize fields in Tanzania. We performed this exercise based on resampling simulations of detailed actual damage data for a large number of maize fields for a range of rodent densities. The aim of the study was to provide a sound basis for damage assessment for rodent pests.

MATERIALS AND METHODS

Study plots and area

Field experiments were carried out during the cropping seasons in 1999 and 2000 at the farm of Sokoine University of Agriculture, Morogoro, Tanzania (6°50'S, 37°38'E, 510 m a.s.l). The area has a bimodal rainfall pattern. The study was conducted during the long rainy season. The maize seeds were sown in March, and the maize was harvested at the end of July.

There were fifteen plots (each 70 m × 70 m). The same standard agronomic treatments were applied to each plot: early ploughing, application of triple superphosphate fertilizer (20 kg P_2O_5 ha^{-1}) before planting, and application of nitrogen fertilizer (40 kg N ha^{-1}) twice as a top dressing (three weeks after sowing and the booting stage, respectively). Three maize seeds (Staha variety) were planted per hole, with a planting space of 60 cm between planting holes along a row and 90 cm between rows. Manual weeding was carried out twice. Harvesting was carried out by hand picking when all cob silk was dry. The fields were part of several other experiments. These experiments included: (i) fields planted with maize and surrounded by fallow land; (ii) fields planted with maize and enclosed by iron sheets to prevent rodents escaping or gaining entry to the field; (iii) fields planted with maize and enclosed by iron sheets to prevent rodents escaping or gaining entry to the field and covered with a net to keep out predatory birds; (iv) open fields planted with maize with perches to attract predatory birds; (v) fields planted with maize and enclosed by chicken-wire mesh covered with nets; and (vi) fields planted with maize and surrounded by other cultivated maize fields. These treatments provided a range of rodent densities in the fields, ranging from 0 to 140 animals per ha during the assessment, and consequently also a range of damage levels, thus providing an interesting set of fields for our study. The main rodent species in the area is the multimammate rat, *Mastomys natalensis* (Smith, 1834). The plots were located at least 80 m apart, and when two fields were close to each other, at least one of them was enclosed with a rodent-proof fence. All the fields could therefore be considered independent.

Damage assessment

Crop damage assessment was performed at seedling stage, 10 days after planting. The actual damage was measured by walking along rows and recording the number of emergent seedlings at each planting hole. Typically, rodents dig up and consume germinating seeds in the period between planting and 14 days after sowing. Other factors, such as drought, water logging, mould or insect pests, may also contribute to non-emergence, but these factors were minimal during the study period, so for the purposes of the present study on sampling density, it was not considered necessary to discriminate between these different types of damage. Damage caused by other pests comprised part of the experimental error. The two outer rows (i.e. around the perimeter of the field) of each field were not sampled in order to reduce inter-field effects and to prevent sampling of abnormal damage (e.g. due to rodent movement) in relation to barriers (Kaukeinen 1984). The seeds used in this experiment were of the same age and quality; hence, they had the same germination rates. Thus, for each 70 m × 70 m field, approximately 8607 planting holes were visited, and emergence was assessed for a total of 25 833 planted seeds per field. Damage for each planting hole was separately recorded for each field. The data recorded for each planting hole were: planting row number, position in the row, and

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number of non-emerging seedlings (i.e. three minus the number of emerged seedlings).

Sampling intensity simulations

We simulated different sampling intensities by resampling from the actual damage data. Different sampling intervals (every second row, every third row, etc., up to every 20th row) were chosen, and for each sampling interval, we ran all possible simulations by choosing a different starting row every time. Obviously, choosing every single row corresponds to counting all plants, i.e. the actual damage. For all other intervals of *n* rows, *n* different starting rows could be chosen without resampling the same line twice. On the other hand, of course, large row intervals also meant smaller sample sizes (e.g. a 20-row interval corresponds to only sampling four rows in a field 70 m in width). The average estimate and its variance were measured for each interval, and variances were standardized for each field by dividing them by the actual damage count for that field. The standardized variances were then plotted against sampling interval. In order to evaluate the effect of the number of different possible starting rows, the same analysis was repeated for the different intervals but with five different starting rows only.

RESULTS AND DISCUSSION

Actual damage in the fields ranged between 17.3 and 82%, depending on the year and rodent population. In 1999, the actual rodent damage was lower than in 2000, when rodent numbers were high (Mulungu 2003). Our simulations for different sampling intensities allowed us to describe the intuitively assumed relation between sampling intensity and estimate accuracy for the systematic row sampling technique (Fig. 1). As expected, an increase in estimate variation is observed when the interval between rows becomes larger (Fig. 1) and, hence, less reliable (Cochran 1977; Mead & Curnow 1983). This pattern remained constant, also when a fixed number of possible starting lines were chosen, regardless of the interval (data not shown but similar to Fig. 1). When the numbers of random rows were chosen, however, variation in the pattern was observed.

In some plots the increase in estimated variance for larger row intervals was more dramatic than for others, indicating that damage was not homogenously distributed in all fields. Mulungu *et al*. (2005) reported that the spatial distribution of damage in maize fields is dependent on the cropping system. For example, spatial damage distribution in maize fields that are located between other maize fields is random, whereas for maize fields surrounded by fallow land damage is uniformly distributed (Mulungu *et al.* 2005). Our simulation results show that the problems with such heterogeneity can be overcome when the row interval in systematic row sampling is less than or equal to five.

The results of this study show that the relationship between sampling interval and average standardized variances is linear (Fig. 2). This indicates that as the sampling interval increases the variation in mean values relative to the actual true value of damage also increases. The average standardized variances of our simulated data show that when a sampling interval of less than six rows is used, the variation of an estimate stays below 10% of the actual damage (Fig. 2). Using this graph thus allows a decision on what sampling row interval should be chosen for obtaining a desired accuracy, or what kind of accuracy

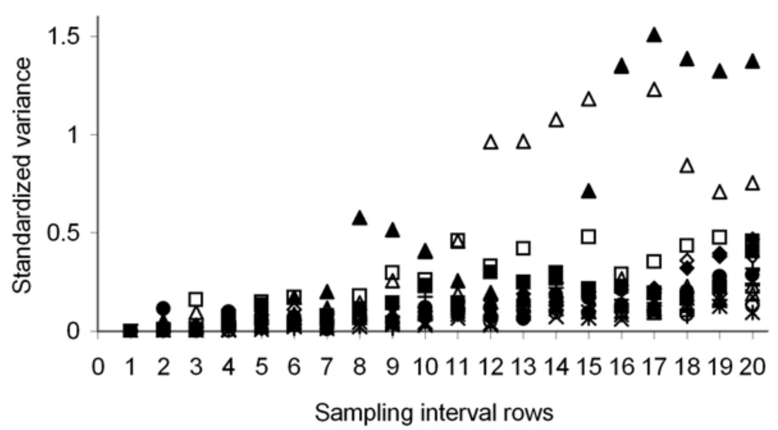

Figure 1 Relationship between sampling intensity and standardized variance of estimated damage to maize seedlings in 15 fields, for simulated sampling intervals of between one and 20 rows. Different symbols correspond to different fields (*n* = 15).

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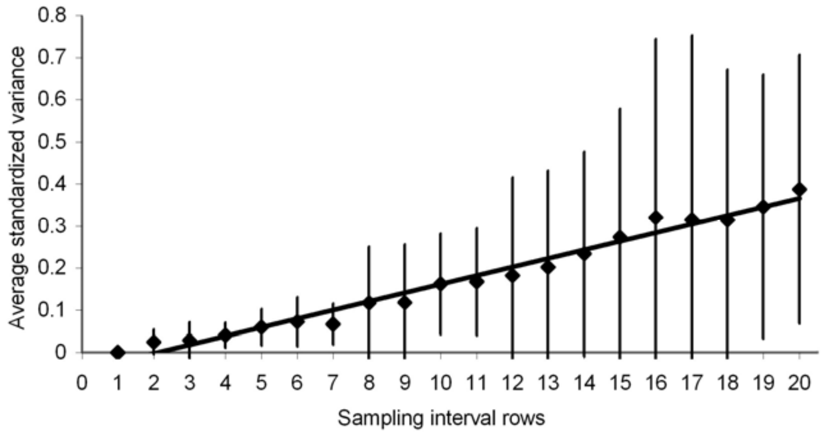

Figure 2 Average standardized variances (±SD) of estimated damage to maize seedlings for 15 fields, for simulated sampling intervals of between one and 20 rows ($y = 0.0204x - 0.0427$, $R^2 = 0.98$).

can be expected for a given sampling row interval.

The results of this study show that sampling every fifth row in a maize field, as done by Mwanjabe and Leirs (1997) is a reasonable compromise, providing results with a confidence level of 95% for various field management conditions. We showed earlier that systematic row sampling is simpler, cheaper, easier, and less time consuming than other sampling techniques for rodent damage estimation in maize (Mulungu *et al.* 2003a). The present study allows us to quantitatively determine a compromise between the need for accurate estimates and the time or resources available for obtaining the estimates.

Mulungu *et al*. (2003a) reported that among other sampling techniques, the systematic sampling technique is the most robust for rodent damage in maize fields. The sampling technique is 99% accurate in relation to measuring all the rodent damage. However, in broad-acre crops, either random sampling methods or stratified random sampling methods could be used. Random sampling methods are appropriate where the damage appears to be genuinely random in its distribution, even where the underlying landscape shows discrete structured variation. However, stratified random sampling methods are appropriate where rodent damage does not appear to be random, regardless of whether the underlying variation is discrete or continuous.

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