SPATIAL VARIABILITY OF CASSAVA TUBER YIELD ON NEWLY CLEARED FOREST LAND IN LAMPUNG AND CONSEQUENCES FOR EXPERIMENTAL DESIGN

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ABSTRACT

Spatial variability of tuber yields on newly cleared forest land was studied by recording yield per individual plant in the first cassava crop. The standard deviation of yield per plant was 2.18 kg or 59% of the average yield and was not significantly influenced by nitrogen rate or cropping system. Yields of individual plants were largely independent of that of neighbouring plants. Low values for a serial correlation coefficient and a high value for Smith's index of heterogeneity confirmed this conclusion. No trends across plots were identified. Variability of yields per plot can be reduced by excluding a double border row from the sampling. A cropping system without intercrop resulted in a significant increase in the minimum weight per plant in a plot, but had no effect on the maximum and had a slight effect on the mean. Nitrogen application similarly increased the minimum and had no effect on the maximum.

If differences of 20% in average yield due to an experimental factor are to be detected (p 0.05), a net plot size of 100 - 200 m^2 will be needed when 4 replicates are used.

INTRODUCTION

No field is uniform. Adjacent square meters of soil, planted simultaneously to the same variety and treated as alike as possible, will differ in as many characters as one would care to measure quantitatively. The causes for these differences are numerous, but the most obvious and probably the most important, is soil heterogeneity. Spatial variability of crop yields has consequences for the design of experiments, aimed at testing hypotheses or at estimating treatment means. As the discriminating power of an experiment increases when the error variance is reduced, efforts to control variability are essential for successful experiments (Gomez and Gomez, 1984; Pearce, 1985).

The traditional concern for selecting homogeneous plots to perform experiments may lead to biased results, however. Variability in the conditions in which individual plants which make up the population in a field, are growing, not only affects the reliability of conclusions, it may also affect the response surface itself. Van Noordwijk and Wadman (1992) showed that the yield response curve to nitrogen application changes in shape with increasing spatial variability of nitrogen supply. Results of relatively homogeneous field trials may thus be 'precise', but will not reflect the situation which farmers encounter in the real world. In stead of selecting homogeneous plots for doing experiments, we have to quantify field variability in truely representative situations and adapt our field plot technique to this variability.

Spatial variability may even have a positive effect on yield stability (risk reduction) if different parts of the field give good yields in different years, e.g. due to different rainfall patterns. Van Noordwijk and Van Andel (1988, 1989) gave a quantitative criterion for the degree of risk reduction on the basis of the within-year correlation of various components of a farm or parts of a field.

Newly cleared land may show more spatial variability than soil which has been cultivated for a long time, but little quantitative data exist. Therefore, we measured yields of individual cassava plants in relatively large plots on newly cleared forest land and treated the data as a 'uniformity trial'.

MATERIAL AND METHODS

The experiment was part of a project on nitrogen utilization by food crop production systems on acid, upland soils in Lampung, Sumatera (Van der Heide *et al.*, 1992). Plot size was 12 x 12 m, plant spacing for cassava was 0.5 x 2 m and 115 cassava plants were used per plot. Details of the experiment and yield data were given by Sitompul *et al.*, (1992). At the first years harvest fresh tuber yields were recorded per individual plant.

For each plot the following basic parameters were derived: minimum, maximum, average and standard deviation of weight per plant. A serial correlation coefficient r_s was derived for rows and columns from the yield per plant, Y_{ij} (row i, column j):

$$r_s = \frac{n\sum_{i=1}^{n} Y_i Y_{i+1} - [\sum_{i=1}^{n} Y_i]^2}{n\sum_{i=1}^{n} Y_i^2 - [\sum_{i=1}^{n} Y_i]^2}$$

where $Y_{n+1} = Y_1$.

Negative values of this correlation coefficient indicate that high and low yielding plants tend to alternate, positive values that high and low yielding plants occur in groups; values close to 0 indicate that plants are mutually independent.

If plants are mutually independent, the variance of plot averages decreases proportional to the number of plants in the sample and thus with plot size. If plants are partially dependent the reduction in variance with increasing plot size will be less than proportional.

Smith (1938) defined an index of heterogeneity as the slope of a regression line of the logarithm of the variance versus the logarithm of plot size. This index was estimated for each plot according to the formula of Hatheway (1961):

$$b=\frac{\sum w_i \sum w_i \log V_{xi} \log x_i - \sum w_i \log V_{xi} \sum w_i \log x_i}{\sum w_i \sum w_i (\log x_i)^2 - \sum w_i \log x_i}$$

where:
V_{Xi} = variance between plots of size X_i
X_i = size of plot (m^2), and
w_i = degrees of freedom associated with the variance V_{Xi}.

The Smith index of heterogeneity can be regarded as a 'fractal dimension' of variability in a plot. Smith showed that a single value may hold over a considerable range of plot sizes and can be used to predict variance on intermediate scales:

$$V_x=\frac{V_1}{x^b}$$

where V_1 is the variance between basic units and V_x is the variance per unit area for a plot consisting of x basic units (Gomez and Gomez, 1984).

For all the parameters determined per plot an analysis of variance (ANOVA) was performed to test the effect of the main factors N rate and cropping system (monculture vs intercrop with maize) and their interaction.

Three sampling strategies for the plots were studied: 1. harvesting the whole plot (5 * 23 = 115 plants), 2. discarding one border row (3 * 21 = 63 plants) and 3. discarding a double border row (1 * 19 = 19 plants). For each plot the average yield and the coefficient of variation (standard deviation/mean) was determined for each sampling strategy. In an ANOVA the sampling method was tested as main effect, in interaction with cropping system and N rate.

RESULTS AND DISCUSSION

Variability of tuber yield

Tuber yields showed a high variability; the yield per plant ranged from 0.1 to 18.8 kg. Table 1 shows results for the ANOVA of mean, maximum, minimum and standard deviation of tuber yields per plot. No significant treatment effects on mean or maximum tuber yields were found, although there was a tendency ($0.10<p<0.05$) to a higher mean for the monocropped cassava. Cropping system and N fertilizer rate had a clearly significant effect on the minimum yield per plot. Monocropping and higher N rates increased the minimum. Apparently the growth of the worst plants of each plot is limited by N supply, while growth of the best plant in each plot is not. No treatment effects on the standard deviation were found, so the assumptions underlying an ANOVA (analysis of variance) are met. The average value for the standard deviation was 2.18 kg/m^2 or 59% of the average yield over all treatments and blocks.

Maps of the yield data (Nugroho, 1989) showed no consistent gradients in yield across any of the plots. The pattern of relatively low and high yields appeared to be random. A serial correlation coefficient for rows and columns is shown in table 2. All values were positive, but most were low (0.25), indicating that the yield per plant is largely independent of the yield of neighbouring plants. An ANOVA revealed no significant effects of cropping system or N rate on this correlation coefficient. The correlation coefficient was slightly higher for rows (within row spacing 0.5 m) than for columns (plant spacing 2 m).

The Smith index of plot heterogeneity, b, was high (Table 2) and also indicates that individual yields were approximately independent realizations drawn from a single distribution. For monocropped cassava the index was significantly higher than for intercropped cassava, but both situations were high in an absolute sense. In the summary of uniformity trials on which Smith (1938) based his index, only 1 out of 40 fields gave a b value as high as 0.8, the majority was much lower. We may conclude that the variability encountered in this newly cleared forest land differs from the 'average' conditions for which experimental design was developed. Variability is high, but patch size is small and the yield of individual plants is virtually independent of that of its neighbours. The type of variability encountered means that large numbers of plants are needed to obtain reliable estimates of average yield, but that no benefit is obtained from using many small plots in stead of a few large ones. For 'on farm trials' this conclusion can help to simplify the design.

Required plot size

The required plot size for an experiment of specified sensitivity is thus largely determined by the number of plants needed and not by the number of 'patches' needed. Further analysis (Nugroho, 1989) showed little effect of plot shape (rectangular versus square).

Three sampling strategies for the plots were studied: 1. harvesting the whole plot, 2. discarding one border

Table 1. ANOVA of mean, maximum, minimum tuber yield and its standard deviation per plot (115 plants). Fprob indicates the probability of the observed main effects (N rate and Cropping system) and interaction (N * C) under the null hypothesis of no treatment effect. In the lower part of the table means are given; data followed by different letters are significantly different (p 0.05).

Factor		Mean	Maximum	Minimum	St.dev.
Nrate	Fprob	0.368	0.463	0.003	0.480
CropS	Fprob	0.058	0.230	<0.001	0.749
N * C	Fprob	0.403	0.110	0.320	0.163
Grand	mean	3.68	12.47	0.536	2.183
Nrate	N0	3.58	13.36	0.375 c	2.096
	N30	3.72	11.87	0.464 b	2.246
	N60	3.74	12.17	0.769 a	2.207
CropS	Mono	3.77	11.84	0.705 a	2.167
	Inter	3.58	13.10	0.367 b	2.200

row and 3. discarding a double border row. Table 3 shows that excluding border rows led to a lower average yield per plant, but excluding a second border row did not affect the mean yield. The coefficient of variation of yields was reduced by excluding border rows and even by excluding a second border row. No significant interactions between sampling method and effects of cropping system or N rate were found. Excluding a double border row leads to a lower coefficient of variation of the plants included in the sample, and thus to a higher sensitivity of tests on treatment effects. Excluding a second border row, however, reduces the number of plants to be sampled on a plot of given size and increases plot size if a fixed number of plants is to be sampled. Given the plot size of the current experiment excluding a single border row is reasonable; if new experiments are established larger plots, allowing exclusion of a double border row are to be preferred. Apparently, border plants had a higher average yield than plants inside the whole plot and benefitted from additional above- and belowground resources on the edge of the plot. For plants in the second border row the average yield was similar to that of the middle rows, but their yield variability was higher. A biological explanation for these border effects may be found in the root distribution of cassava on this soil. A horizontal spread of horizontal roots of up to 5 m from the stem base (Van Noordwijk et al., 1992) may allow the plants to forage in an extensive area, which includes the border of the plot or even neighbouring plots with higher or lower N supply for plants growing in the second border row.

On the basis of the variability the (net) plot size can be calculated to detect treatment effects of specified size (Gomez and Gomez, 1984). If differences of 20 % of the average yield due to an experimental factor are to be detected the respective means should be estimated with a 10% margin of error. Using the average values for the standard deviation per individual plant (Table 1) and the index b (Table 2), the combination of 4 replicates and net plots of 100 plants is sufficient. For 2 replications plots with 250 plants are needed and for 6 replicates plots with 60 plants. If the lower value of the variation when excluding one or two border rows is taken into account (Table 3), the number of plants to be harvested, using 4 replicates, becomes 62 and 52, respectively. When excluding two border rows the total plot size has to be larger than when only one border row is excluded. The plot size and replication chosen for the current experiment is thus just enough to detect effects of about 20% of the mean cassava tuber yield. Nugroho (1989) gave similar calculations, based on individual rather than averaged estimates of variability and index of heterogeneity.

Table 2. ANOVA of serial correlation coefficient for rows and columns on data per plot and Smith index of heterogeneity, b. Fprob indicates the probability of the observed main effects and interaction under the null hypothesis of no treatment effect. In the lower part of the table means are given; data followed by different letters are significantly different (p 0.05).

Factor		R_s Col	R_s Row	b
Nrate	Fprob	0.971	0.634	0.889
CropS	Fprob	0.962	0.137	0.202
N * C	Fprob	0.618	0.451	0.329
Grand	mean	0.152	0.190	0.774
CropS	Mono	0.153	0.242	0.804 a
	Inter	0.151	0.139	0.744 b

Table 3. ANOVA of serial correlation coefficient for rows and columns on data per plot and Smith index of heterogeneity, b. Fprob indicates the probability of the observed main effects and interaction under the null hypothesis of no treatment effect. In the lower part of the table means are given; data followed by different letters are significantly different (p 0.05).

Factor		Mean	Coeff. Var.
Method	Fprob	<0.001	<0.001
Nrate	Fprob	0.067	0.043
CropS	Fprob	0.086	0.086
Interactions	Fprob	NS	NS
Grand	mean	3.40	53.92
Method	0 Row	3.68 a	58.5 a
	1 Row	3.32 b	53.3 b
	2 Row	3.21 b	49.9 c
Nrate	0N	3.36	53.2 ab
	30N	3.32	56.2 a
	60N	3.52	52.4 b

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