Statistical Prospects of Environmental Issues in Sub-Saharan Africa - A Study from Niger

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1. Introduction

Crop production in the Semi Arid Tropics (SAT) of West Africa depends upon highly variable weather and soil conditions. Beginning of the planting season, distribution of rainfall and its amounts are irregular. Millet is the major cereal crop for the region with a production zone that is increasingly moving to drier areas, normally used as pasture land. High variability of crop growth and yield within fields is typical in these production systems. In particular, it is characterised by a high short range variability in yield, ranging from 0 kg ha^{-1} to 3000 kg ha^{-1} within a field. In the past ten years, researchers have studied variability to identify its causes in experimental plots and in farmers fields (Mutsaers *et al.*, 1986).

In this study we distinguish between within field variation and variation between fields. Variation within fields in plant growth occurs at a scale varying from 1 or 2 m to tens of meters. The processes by which yield variability occurs are observed as soon as seedlings emerge. Sand blasting and burial of young seedlings are responsible for high levels of variability in early millet stands. In fields in Western Niger, variation coefficients of yields may exceed 50% (Gandah *et al.*, 1998). Yield patterns, however, may vary during successive years whereas for farming practices it is important to know at an early stage the amount and pattern of yield that a farmer may expect (Gandah *et al.*, 2000). For that reason, attention recently focused on scoring (Buerkert, 1997). Scoring patterns are easily obtained on an individual hill basis during the growing season.

The objective of this study was to characterize variability in crop growth (expressed by measured hill scores) and yield (grain), within and between a site in Niger, and to explore implications for precision agriculture. We focused on two successive years (1995 and 1996) to have an impression of changes in variation between various years caused by varying environmental and field conditions.

2. Fields and data

During the rainy seasons of 1995 and 1996, experimental fields at research stations in Sadoré and Tchigo Tagui were selected in Western Niger and planted with millet (*Pennisetum americanum*). Field sizes in Sadoré were 6750 m^2 and in Tchigo Tagui 20 on-farm fields had sizes ranging from 1 to 10 ha. Plots with a size of 5 × 5 m were laid out inside the fields, without dividing alleys. The local millet variety adapted to the local soil type was planted. Planting density was 1 × 1m (25 hills per plot) and stands were thinned to three plants per hill during the first weeding. Field sites and management activities at each site have been described elsewhere (Gandah *et al.*, 1998). Millet was harvested manually at maturity. Millet heads were air dried during two weeks before threshing and residual millet straw was harvested and dried in the field during 2 to 3 weeks before weighing. Final weight was obtained by correcting for moisture, using oven dried samples. Grain yield, number of hills, number of harvested heads, and head yield per plot were measured. No fertilizer or organic matter was applied nor was there any land preparation other than the removal of shrubs and old millet plants from the previous crop to comply with local practices restricted by inputs. When necessary, weeding was done manually with a hoe.

3. Scoring

Scoring is a simple, low-tech method to measure spatial variability in crop growth during the growing season. Scoring is based on the observation that, at a given time, the millet hills present various development stages due to the reaction of the plant to its environment and to the variability in that environment (soil, climate, pests, and human action). Scoring is done by touring each field and visually evaluating the development of millet hills or hills vigor. A scale of hill vigor is set, being an estimate of the above ground development on the basis of a combination of plant height and biomass. Scoring assigns class values to performance of plants in individual hills. Classes of hill development have been identified with an increasing step size ranging from 0 (no millet plant present) to 8 (best millet hill in the field). Reference hills are tagged to allow comparison during scoring. Collected data are geo-referenced by *x*- and *y*-coordinates of each hill. Hill scoring in 1996 was done at about the same number of days after sowing as in 1995 at all sites. At Tchigo Tagui, scoring was done similarly as in the other 3 sites, but at three dates: July 3-5, August 7-8, and Sept 3-4 1997.

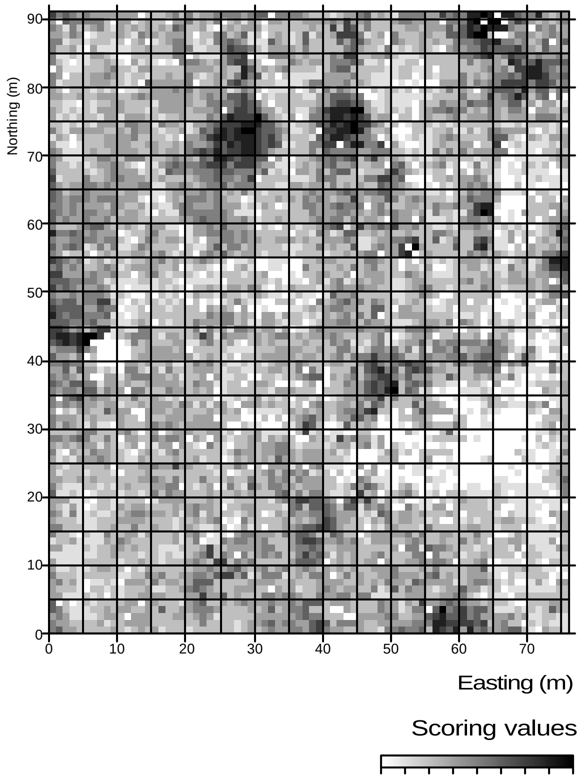

Figure 1 Individual scoring values in the Sadoré field

Multi-scale measurements of field variability allow to consider a range of exploratory factors. Choice for any scale is based upon simplicity of measurement, labor and financial cost. In this study, scales of measurement vary from individual hill, via plot and aggregated plots, to entire fields. Easily obtained data such as scoring were measured at a fine scale (1 × 1 m). Yields were measured at the plot scale (5 × 5 m) to save labor costs. The plot scale served as the matching scale between yield and scoring, where we used the median scoring value observed within the plot to make comparisons.

4. Pattern comparison

We applied various procedures to quantitatively compare observed yield patterns with scoring data and with measured soil properties.

- The taxonomic distance method (Davis, 1986) relates patterns of grain yield with median scores. The taxonomic distance method compares standardized values at the nodes of a grid mesh. Corresponding pattern portions are viewed by a window of a fixed size. A window size of 25 nodes was used in this study.
- Cross-correlograms were used to analyze lagged patterns, i.e. to compare shift in patterns (Stein *et al.*, 1997). The cross-correlogram between two patterns *i* and *j* is defined as

$$r_{ij}(h)=\frac{C_{ij}(h)}{\sqrt{s^2_{i-h}.s^2_{j+h}}}\in[-1,+1]$$

where $C_{ij}(h)$ is the covariance function and s^2_{i-h} and s^2_{j+h} are the variance of the *i*th and the *j*th variable, respectively, for those points involved in calculating $C_{ij}(h)$.

A spatial sensitivity analysis of modeling the relation between scoring and yield was done by calculating the plot specific mean m_P and the standard deviation s_P of the 25 scoring measurements. A random, plot-specific value was drawn from the normal distribution with parameters m_P and s_P. This was done for all plots. With values thus obtained, the cross correlation function was re-calculated. The procedure of drawing random values and re-estimating the cross-correlation function was repeated 200 times. At each lag distance the interval between the 3rd and the 197th cross correlation value served as the 95% confidence interval.

5. Results and discussion

Grain yields in Sadoré equal 379 ± 208 kg ha^{-1} in 1995 and 301 ± 177 kg ha^{-1} in 1996, whereas scoring data equal 2.9 ± 1.78 in 1995 and 2.5 ± 1.52 in 1996, respectively. An example of the scoring data is given in fig. 2, showing clear variability, but some pattern as well with high yields corresponding to high scoring values, and vice versa. We also note that a termite hill at the centre left of fig. 1 appears as a low scoring sub-area in fig. 2. For the pattern comparison we notice that the percentage of field area with similar patterns equals 65 and 63.5 in the two years, respectively. The procedure slightly overestimates the similar patterns, as there is a band around the edges always identified as similar due to edge effects.

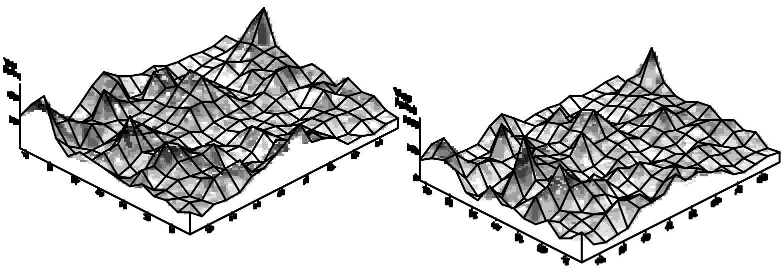

Figure 2 Yield map as 3-D graphs combined with scoring data (in grey tones) for 1995 (left) and 1996 (right).

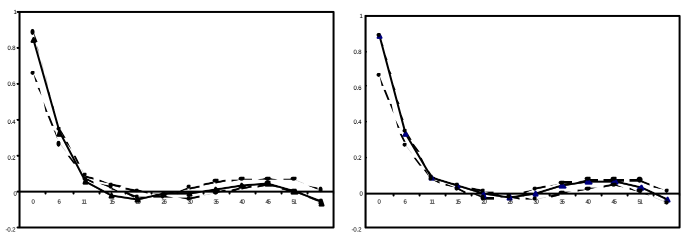

Figure 3 Cross-correlation between scoring data and millet yield. Dashed lines are 95% confidence limits obtained by spatial resampling of the original scoring data, indicating spatial confidence of the curves. Distance scaling is in m.

Cross-correlation fuinctions are given in fig. 3. The spatial sensitivity analysis of the scoring method produced plots of the cross-correlation between grain yield and mean score for the two years. The 95% confidence interval of the 200 random sample plots and the actual data are indicated. The two years had a similar trend of a good correlation over a short distance, with no correlation for distances exceeding 15 m.

6. Optimisation of soil sampling for precision farming

Three on-farm plots of 10 × 10 m were selected in the Tchigo Tagui area to analyse the benefits of scoring procedures to design optimal sampling schemes (Van Groenigen et al., 2000). Millet yield was estimated on the basis of the scoring data and interpolated over the whole plots using kriging. As the shrubs in the field enrich the soil locally by catching eroded particles, the position of shrubs was also recorded. Since small differences in elevation cause crucial redistribution of the scarce rain water, a detailed microtopography map of the plots was constructed using a level.

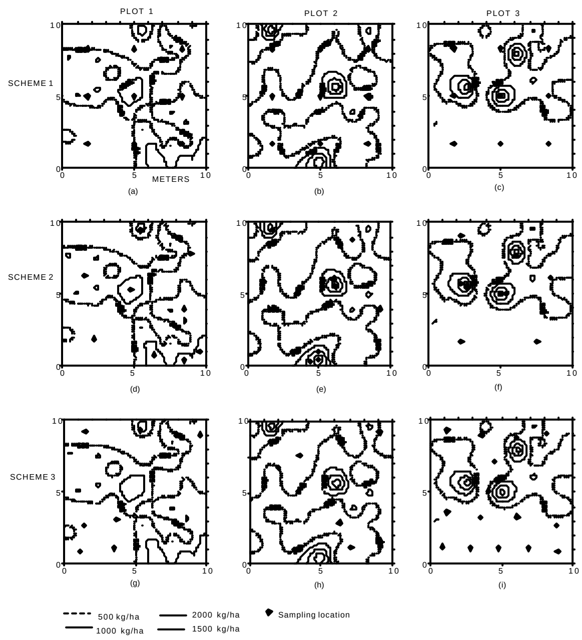

Figure 4 Optimal sampling scheme over three plots for three criteria.

Regression analysis identified the major factors influencing yield variability. Approximately 70 % of the variation in yield was explained by multivariate regression on the soil variables, micro- topography and location of shrubs using the second scheme.

The spatial simulated annealing algorithm for optimisation of spatial sampling was used to optimise the soil sampling scheme of 27 observations. Three different sampling schemes were tested. The first aimed at uniform spreading of the observations over the plot, yielding a square grid (figure 4 a-c). The second scheme aimed at optimal coverage of the observations over the whole yield range (figure 4 d-f). The third scheme aimed at uniform spreading of the observations over the low-producing areas (figure 4 g-i). Scheme 1 explained only 37 %. Therefore, scheme 2 offered a considerable improvement in terms of regression results using the Spatial Simulated Annealing algorithm.

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