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Crop management trials using the Continuous Variable Design

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The literature concerning crop management experimentation using continuous variable designs (CVD) is reviewed. Some modifications and advantages and disadvantages of the CVD are discussed based on field trials with vegetable, grain, and root crops. The results for three experiments with cassava in Puerto Rico using the CVD are discussed. In the first, on a Udic Chromustert, the yield response to nitrogen levels was linear up to approximately 30 kg N/ha. In the second and third, on a Cumulic Haplustoll, there was little or no discernible response to nitrogen levels from 0 to 44 kg N/ha or to phosphorus levels from 0 to 37 kg P/ha. The CVD appears to be an efficient but underutilized technique that has merit for use in management trials for various crops, especially where space and funding are limiting factors.

Keywords: Experimental design; Cassava; N and P fertilizers

Introduction and Literature Review

This paper has two purposes: 1) to present the concept of the continuous variable technique and some advantages and disadvantages inherent in the CVD when applied to crop management experimentation and 2) to discuss the results of three fertilizer trials with cassava using the CVD at Lajas, Puerto Rico. Nature almost always confronts the ecologist with continuous variables in the field. Ecologists therefore have to devise methods of handling this data. However, most agronomists and horticulturists have for many reasons avoided continuous variable designs in favor of field designs employing selected discrete levels of the chosen variable(s). Very few researchers have employed continuous variable designs in fertilizer rate or other crop management studies.

Fox (1973) determined leaf N and grain yield of sweet corn treated with 40 levels of N applied sequentially down the row to single-plant plots and recommended the use of continuous function experimental designs in agronomic investigations. Treatments were replicated four times and occupied an area of less than 50 m^2. Fresh corn yield was highly correlated with leaf N and increased with each increment of N; yield response was nearly linear throughout the range of applied N.

This was the first of only six papers in English (none in Spanish or German) on CVD application to fertilizer trials found in the literature since 1970. Fox suggested the use of a CVD for studying interactions in two- and three-variable experiments and Hundtoft et al. (1974) used it in a two-variable experiment varying one factor in one direction and a second at 90 degrees. More recently Shoulders and Tiarks (1983) modified Fox's design to accommodate experimentation with N and P as continuous variables applied to young pine plantations. They are testing 11 levels each of N and P from 10 to 1000 and 5 to 500 kg/ha, respectively, with rates increasing on a logarithmic scale. The N levels are applied sequentially in one direction and the P levels are superimposed at 90 degrees.

Bauder et al. (1975) compared response surfaces generated using a CVD with response surfaces developed from a randomized complete block, split plot design on two soils with soil water and fertilizer N as variables applied to field corn. In the CVD both water and N treatments were applied as continuous variables, one at 90 degrees to the other. The two designs gave yield functions that, when used to predict yield values, led to the same conclusions. Although the authors recommended caution in drawing conclusions from the application of statistical analysis, their results suggest that the lack of randomization in the CVD is not always a serious limitation. A major advantage of the CVD was that more treatments were possible on less land while a disadvantage was that the small plot size led to large variation between replications and it was necessary to smooth the data by pooling treatments. Experiments using a similar design and with the same variables, water and N, applied to field corn were conducted at Isabela, Puerto Rico (Beinroth, 1982).

In the two experiments by Bauder et al., as well as those in Puerto Rico, water was applied to the CVD plots using a drip irrigation system with the amount of water delivered varying sequentially from row to row; nitrogen levels were applied across the rows. The drip system gave good control of the water treatments but was expensive and required considerable manpower. Hanks et al. (1976) improved the method of applying water treatments by developing a line source sprinkler system for continuously variable irrigation-crop production studies. This system uses a single row of closely spaced sprinklers down the center of the plot. This method applies a uniform water gradient varying from highest next to the line source to zero at the outer margins on both sides of the line. It is a relatively simple design that has stimulated interest in continuous variable designs and proven useful in studies involving soil water management (Hanks et al., 1976; Miller and Hang, 1980), leaching (Stark et al., 1982, 1983), continuously variable N levels applied through the line source sprinkler (Lauer, 1983), cultivation timing (Sorensen et al, 1980), and cultivars (Beinroth, 1982; Hanks et al., 1980).

Hanks et al. (1980) present data from an experiment with three winter wheat cultivars as influenced by irrigation using the line source sprinkler system. With the cultivars randomly assigned to strips across the line source a statistical analysis was valid and showed a significant irrigation-cultivar interaction as well as differences in yields among cultivars.

Stark et al. (1982, 1983) described a modified line source sprinkler system for use in leaching studies and conducted experiments with water as the continuous variable and N sources as a second variable applied randomly at 90 degrees to the sprinkler line to determine the effect of N sources and irrigation rate on celery yield and to determine the effect of these variables on NO3 - leaching. Lauer (1983) further modified the design to facilitate the application of N as the continuous variable through the line source sprinklers while maintaining the water applied at a uniform level. He employed three laterals spaced 13.8 m apart, one sprinkler wetted radius, with an in-line sprinkler spacing of 4.5 m, one-third the wetted radius. By injecting nitrogen fertilizer into the irrigation water entering either the central or the two side laterals, uniformity of application of N throughout the desired range of the N variable was produced. This design also gave uniform application of the water over the experimental.area.

Possibly the most important advantage of the CVD is the conservation of space, material and equipment, labor and the technician's time. The small size of each experiment reduces the labor and other resource requirements, so multiple sites can be installed and because a large number of levels of the variable can be applied it is possible to include extreme levels, thus obtaining more information (Shoulders and Tiarks, 1983). The continuous variable technique is also considered by most of the authors cited above to be useful for the study of possible treatment interactions.

The most serious disadvantage associated with continuous variable designs is a consequence of the nonrandom arrangement of the treatment levels. A method of statistical analysis of data from experiments using the line source sprinkler system was described by Hanks et al. (1980) and could apply to other CVD layouts as well. They conclude that the influence of irrigation using the line source sprinkler system cannot be assigned a probability level because of the nonrandom application of the water, but that irrigation effects are usually large and statistical analysis is not critical. It was recommended that the line source sprinkler design not be used where irrigation effects are expected to be small. Treatments imposed on randomized and replicated plots laid out at right angles to the irrigation variable could be tested statistically for treatment and treatment - irrigation interaction effects.

In Puerto Rico, food crops are grown on a wide range of soil types in various parts of the island and the fertilizer recommendations developed at the Agricultural Experiment Substations are not always applicable to farmers' conditions. Techniques need to be developed for conducting more fertilizer trials on sites more representative of farmers' field conditions and in more agroecological zones, but with limited funds. Because of this need and considering the apparent potential of the CVD, in spite of obvious inherent limitations, fertilizer trials have been conducted with varying degrees of success with sweet corn, okra, cabbage, green bean, sweet pepper, pumpkin, sweet potato and cassava (Spain, 1984 - 1987) in Puerto Rico using modifications of the technique advanced by Fox (1973). The results of three fertilizer experiments with cassava are reported in this paper.

Materials and Methods

One experiment with cassava (*Manihot esculenta*) was planted August 9, 1984 and harvested June 27 - 28, 1985 on a Fraternidad clay (Udic Chromustert) on the Agricultural Experiment Substation, Lajas, Puerto Rico to test a modified CVD with single-plant-plots for measuring crop response to applied N. On a San Anton clay (Cumulic Haplustoll), also on the Lajas Substation, experiments with N and P were planted to cassava on June 25, 1986 and harvested April 22 - 23, 1987. Stem cuttings of about 2.5 cm in diameter and 18 - 20 cm long with three or more buds were positioned at a 45 degree incline in the same hole where the fertilizer was placed but separated from the fertilizer by about 5 cm of soil and covered to within 2 - 3 cm of the upper end. Plant spacing was 1 x 1 m. All plots were flood irrigated at planting and thereafter as needed. Nitrogen rates in 1984 - 1985 were 0 - 30 g/plant of ammonium sulfate applied sequentially in 1 g increments down the treatment row and replicated three times, reversing the gradient with each replication. In 1986 - 87, N and P rates were 0 - 17.5 and 0 - 15 g/plant of ammonium sulfate and triple superphosphate, respectively, applied in the same manner, but in 0.5 g increments and not replicated. The nutrient not varied was applied uniformly to all plots at the highest level. Reference rows with the zero level of the nutrient under study were included along side the treatment rows to detect possible natural gradients already existing in the field. Treatment - reference -row assignments were random.

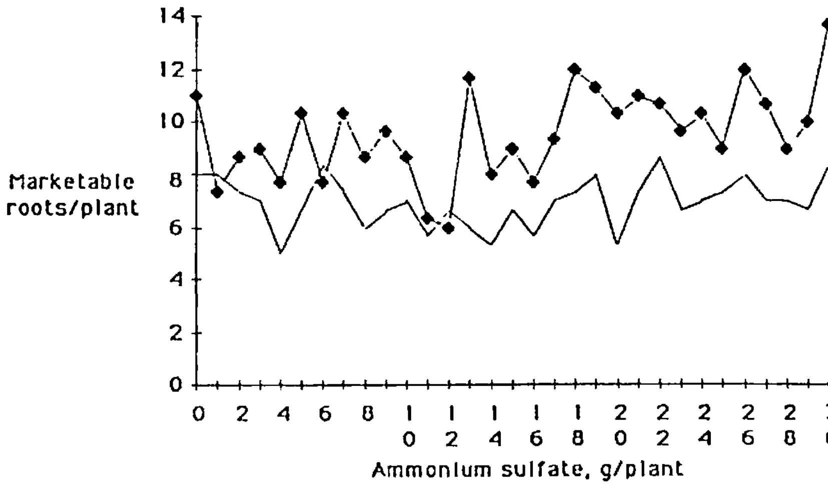

Figure 1 Marketable cassava roots per plant, treatment row ( ) vs. reference row, Fraternidad clay soil, Lajas, P.R., 1985

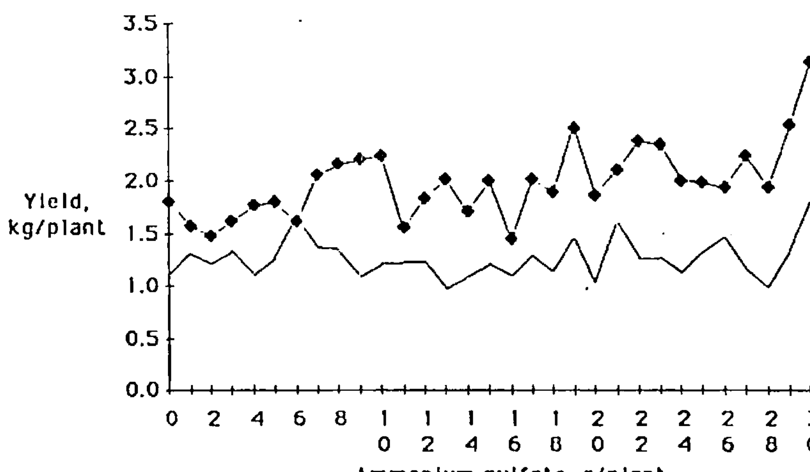

Figure 2 Mean Yields of cassava roots, treatment row ( ) vs. reference row, Fraternidad clay soil, Lajas, P.R., 1985

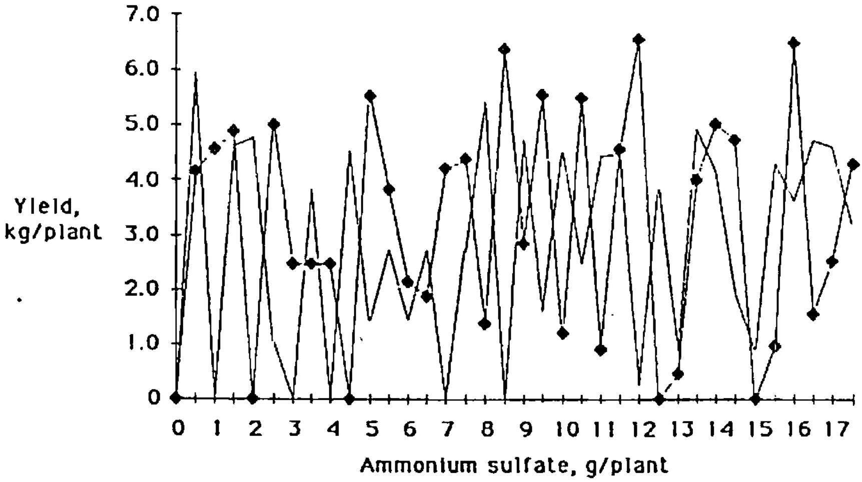

Figure 3 Cassava root yields, ammonium sulphate treatment row ( ) vs reference row, San Anton clay soil, Lajas, P.R. 1987

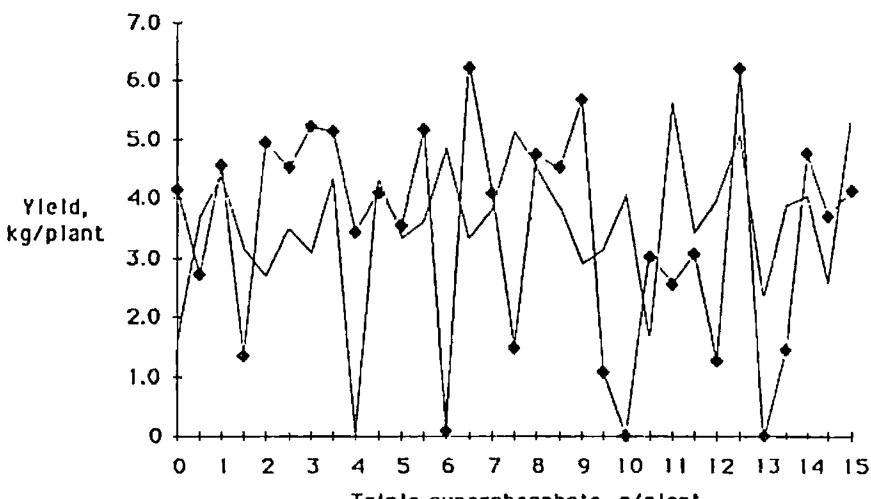

Figure 4 Cassava root yields, tripple superphosphate treatment row ( ) vs reference row, San Anton clay soil, Lajas, P.R. 1987

One early hand weeding and two passes with the line weeder gave only moderately acceptable weed control in 1984 - 85. Good weed control was obtained in 1986 - 87 by one application of paraquat between the rows 20 days after planting, and subsequent hand weeding and wick applied glyphosate to control Johnsongrass. Dicofol (*Kelthane*) was applied occasionally during both years when red spider mites were numerous.

The weight and number of marketable roots were recorded for the 1984 - 85 trial. Weights of all remaining above ground biomass at harvest time and of all marketable roots were recorded in 1987.

Results and discussion

In the 1984 - 85 trial on Fraternidad clay soil, cassava response to increasing N applications was inconsistent (Figures 1 & 2), and correlation coefficient values were small ($r = 0.31$ and 0.33 for tuber number and marketable yield respectively). However, number and weight of tubers were higher overall in N treatments than in reference rows. Number of tubers ranged from 5 to 17 with a mean of 9.55/plant among N levels versus 2 to 13 with a mean of 6.97 /plant for the reference rows. Weight of marketable tubers ranged from 0.88 to 3.24 with a mean of 1.94 kg/plant among N levels in contrast with 0.42 to 2.14 with a mean of 1.27 kg/plant for the reference rows. The mean yield of plants receiving 10 or more g of ammonium sulfate was 19,933 kg/ha, while the mean yield of reference rows (without N) was 12,700 kg/ha.

During the 1986 - 87 experiment on the San Anton clay soil there were no apparent differences in plant size as a result of either the N or P treatments. Likewise no tuber yield response was seen within the range of either N or P treatments as shown in Figures 3 and 4 which compare treatment rows with reference rows. When the differences between yield values of treatment row and reference row plant pairs were plotted with missing plants and their pair values deleted. The same lack of response was evident.

The modified continuous variable design employed in these experiments would appear effective and inexpensive for use with cassava. Two 38 m rows, with plants spaced one meter apart are adequate for testing 36 levels (a convenient number, if pooled data from 2, 3, 4 or 6 adjacent plants are desired for smoothing the response curve) of a nutrient with each extreme level duplicated to provide a buffer zone at each end of the treatment row. One more row on either side as borders would bring the total experimental area to 152 m_2, about one fifth of that required by conventional techniques for only five levels of one variable replicated four times. Materials required were almost negligible and labor during the establishment, maintenance and harvest of the experiment was minimal. These are essential features of techniques for increasing the number of experiments to include on-farm trials on various sites with limited funding.

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