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9. ABSTRACT

Simple experimental designs are needed for exploratory field studies and for generating data for well-defined yield response curves and surfaces. A design was developed by which a variable was increased in many small increments along corn (Zea mays L.) rows. Individual plants were handled as plots. Sweet corn was grown in rows 12 m long, along which rates of N fertilization increased in 40 increments from 0 to 220 kg/ha. Replication was obtained by repeating the layout but rotating it through 180 degrees. "Border effects" along the row could be ignored because the incremental change of applied N was very small and because the N rate increased in one direction and decreased in the other. Because there are many experimental points it was possible to show that low rates of N produced a "diluting effect" on leaf N, that N deficiency symptoms disappeared and second ear development began at about 140 kg N/ha, that lower corn leaves are the most sensitive indicators of the N status of corn, and that yield response to applied N was linear to 200 kg/ha of N applied. If a second factor is varied at right angles to the first, a well defined response surface can be obtained.

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Agronomic Investigations Using Continuous Function Experimental Designs—Nitrogen Fertilization of Sweet Corn

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Agronomic Investigations Using Continuous Function Experimental Designs—Nitrogen Fertilization of Sweet Corn[1]

R. L. Fox[2]

ABSTRACT

Simple experimental designs are needed for exploratory field studies and for generating data for well-defined yield response curves and surfaces. A design was developed by which a variable was increased in many small increments along corn (*Zea mays* L.) rows. Individual plants were handled as plots. Sweet corn was grown in rows 12 m long, along which rates of N fertilization increased in 40 increments from 0 to 220 kg/ha. Replication was obtained by repeating the layout but rotating it through 180 degrees. "Border effects" along the row could be ignored because the incremental change of applied N was very small and because the N rate increased in one direction and decreased in the other. Because there are many experimental points it was possible to show that low rates of N produced a "diluting effect" on leaf N, that N deficiency symptoms disappeared and second ear development began at about 140 kg N/ha, that lower corn leaves are the most sensitive indicators of the N status of corn, and that yield response to applied N was linear to 200 kg/ha of N applied. If a second factor is varied at right angles to the first, a well defined response surface can be obtained.

Additional index words: **Leaf composition, Foliar analysis.**

WHEN selecting the design for fertilizer trials and similar agronomic experiments, it is essential to consider seriously what kind of information is being sought. Sometimes the question is simply, "Is there likelihood of response to a particular factor or combination of factors?" Much more frequently, however, when a deficiency of the factor(s) can be assumed, the appropriate question is "How much?" All too frequently an experimental approach appropriate for the first question is applied to the second or an answer to both questions is sought from one experiment.

For example, a nitrogen rate experiment for corn might have 4 or 5 rates of N with 5 replications in a randomized block or latin square arrangement. Frequently, the statistical analysis leaves little room for doubt that nitrogen is a problem, but questions remain about the shape of the response curve. Certainly 4 or 5-point response curves are far from satisfactory. This leaves the question "How much?" somewhat in doubt, and all of this after a considerable investment in labor, land, fertilizer and other inputs.

The nitrogen composition of corn leaves can be a useful index of the nitrogen status of the crop if suitable correlations are made. For this purpose large numbers of observations on composition and associated yields have been analyzed by multiple regression techniques. Data from as many as 575 plots have been used in some studies (2, 5).

The following report describes an experimental nitrogen fertilizer layout which occupied about 0.001 acres and had an installation budget of 15¢ for fertilizer and 4 man hours of labor. The experiment generated an abundance of yield and composition data. Although the range of nutrient application was not great enough to clearly define a maximum in the response curve for the particular set of circumstances (late application) this deficiency can be corrected in future trials.

MATERIALS AND METHODS

Nitrogen deficient H-68 sweet corn (*Zea mays* L.) was thinned to one plant per 23 cm of row (about 50,000 plants per hectare). Sections of rows about 12 m long were selected in two areas. The first corn plant in each section received no N, the second plant received N equivalent to 5.5 kg/ha, the third plant 11 kg/ha and so on until the 40th plant was fertilized at the rate of 220 kg/ha. The nitrogen source, urea, was weighed for each plant on a top-loading Mettler balance. Fertilizer was applied in the row near the stalk and was covered with about 5 cm soil. The corn was about 60 cm tall when it was fertilized.

The soil, a Typic Haplustoll, Waialua series, was well supplied with nutrient cations. Phosphorus concentration in 0.01 M $CaCl_2$ equilibrated with the soil was 0.15 ppm which is about two times that required for 95% of maximum yields of corn in Hawaii. Therefore, no fertilizers other than N were applied. The field was sprinkler-irrigated 5 days after being fertilized and at weekly intervals after that.

Ears from 4 rows (replications) were individually harvested, husked, and weighed fresh. Second ears, if present, were harvested one day later. They were included in the sample only if they bore a significant amount of grain.

Leaves 3, 7 (ear leaf), and 11, counting the flag leaf as No. 1 were sampled immediately after harvest for N analyses by the Kjeldahl method modified to include nitrates.

RESULTS AND DISCUSSION

Nitrogen deficiency symptoms progressively disappeared as the rate of N fertilization increased along the corn row (Fig. 1). Viets (4) presented a regression equation which predicted that visual symptoms of

Fig. 1. Disappearance of N deficiency symptoms along a row of corn in which successive stalks received increasing increments (5.5 kg/ha) of N. Note the "firing" of lower leaves on plants on the left.

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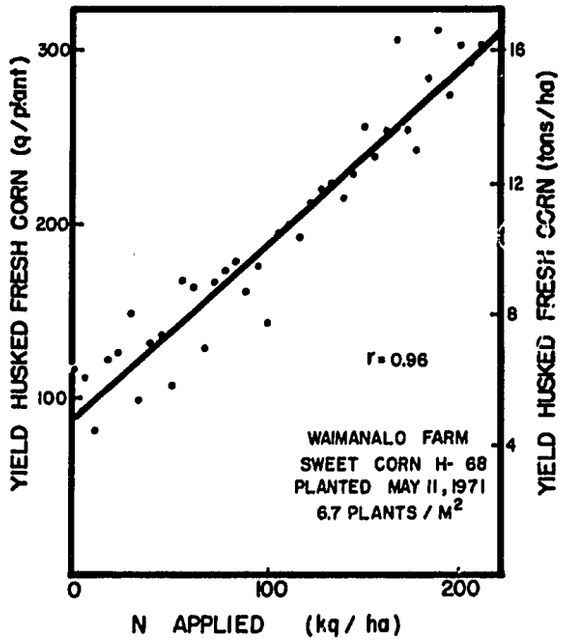

Fig. 2. Relationship between N applied and yield of fresh, husked sweet corn. Each point is a mean of 4 stalks.

nitrogen deficiency would disappear if N in the second leaf below the main ear, sampled at silking, is greater than 2.28%.

Although there were no longer visual deficiency symptoms when N rates exceeded 140 kg N/ha, yields continued to increase to the highest rate used. The response was nearly linear over the entire range 0 to 220 kg (Fig. 2). The yield data were subjected to an analysis of variance with rows as replication (Table 1). Correlation and regression statistics are presented in Table 2. It is assumed that fertilizer N became available too late for maximum effectiveness, thus the linear response curve. A second ear became a factor in yield at about 140 kg N/acre. This was also the point at which visual N deficiency symptoms disappeared (Fig. 1).

The experimental design described here provided many levels of applied N which were useful for plotting N concentration in leaves in relation to nutrient supply. Data for three leaf tissues, taken subsequent to harvest, are presented in Fig. 3. Leaf N concentration tends toward a constant value when the N

Table 1. Analysis of variance for yield of sweet corn in relation to fertilizer N applied.

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F
Total	159	1,129,872	--	--
Reps	3	13,861	4,620	1.64
Treatments	39	806,639	20,683	7.8**
Due to Regression	1	643,572	643,572	243.**
Dev from Regression	38	163,067	4,291	1.62*
Error	117	309,372	2,644	

Table 2. Correlation and regression statistics for sweet corn yield as a function of N applied.

Statistic	Replication 1	2	3	4	Mean
r	0.863	0.757	0.606	0.826	0.960
a	40	101	118	107	92
b	1.55	1.02	0.76	1.10	1.11

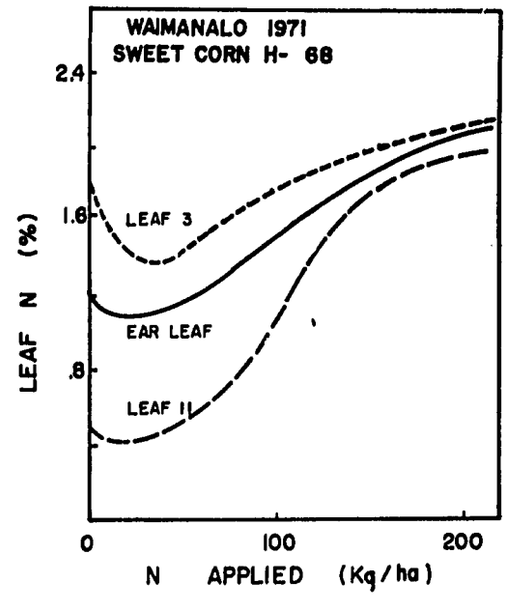

Fig. 3. Relationship between N applied and leaf N of sweet corn. Replicates were composited for analyses. Each free hand curve is based on 40 N determinations.

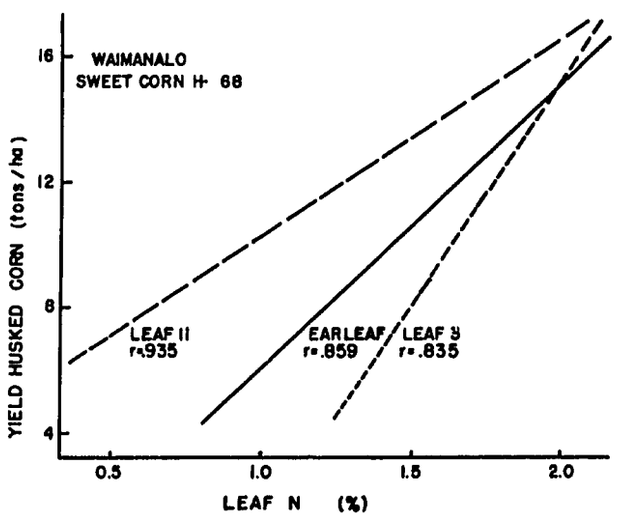

Fig. 4. Yield of sweet corn in relation to leaf N of individual plants.

supply is abundant. Details of the curves can be plotted with confidence because each curve represents 40 data points. Small amounts of fertilizer N were associated with depressed N, especially in the number 3 leaf. This is a special case of the "diluting effect" of extra ear production. In this case N, a very mobile nutrient, was withdrawn from leaves to make ears, the effect being most noticeable when insufficient nitrogen was applied to complete ear development. Similar effects have been noted in N percentages of wheat (*Triticum aestivum* L.) grain (3).

Leaf nitrogen was highly correlated with yield (Fig. 4). Within the range 0.5 to about 2% the relationship was linear. The wide range in N for leaf 11 suggests that lower leaves would be superior to the ear leaf as index tissues for estimating the adequacy of N nutrition. Viets (4) also found that corn yields were linearly related to leaf N at silking, with little evidence

of departure from linearity that could be called the critical N percentage. However, for one experiment where corn followed alfalfa (*Medicago sativa* L.) and N was added, high leaf N was obtained. For that experiment maximum yield was predicted at about 2.8% N in the second leaf below the ear. Dumenil (2) examined the results of 93 fertilizer experiments and concluded that at silking, the critical N level for 95% yield was a range from 2.7 to 2.85%. Daigger and Fox (1) concluded that the critical level for nitrogen in the ear leaf of irrgiated sweet corn was about 2.9%.

The low values for leaf N of this study may reflect lateness of sampling. Viets (4) found that the correlation between leaf N and yield of corn improved as maturity advanced.

The more important point for this discussion is that these data came from a plot area of less than 50 m^2, the area usually devoted to one unreplicated treatment. Investments in land, equipment, time and materials for the field operations were almost nil. The physical layout can be modified so that permanent plots can be established and maintained without undue concern about shifting of soil across plot boundaries by cultivation. Fertilizer can be applied as narrow strips, each strip differing from the next by a small increment. Cultivation will tend to create a continuously varying function.

The design seems especially suitable for field plot investigations with crops such as banana, that have widely spread root systems. In this case, border effects can be ignored if the incremental increase of applied nutrient, or other variable, is kept small in comparison with the overall range. Besides, in this design border effects tend to cancel out, being positive in one direction and negative in the other.

The value of a continuous function design for demonstration purposes can be seen in Fig. 1. A farm advisor with a set of calibrated measuring spoons, a hoe, and a few pounds of fertilizer can quickly install certain kinds of fertilizer trials as the occasion demands.

The technique may be especially useful for investigating interactions. The procedure here is to vary one factor in one direction and vary a second factor at 90°. Two-factor designs can be repeated at two or more levels of a third factor. Experiments of this type are in progress with banana (NKP) and corn (N, irrigation, stand density) as experimental crops in Hawaii.

There are certain hazards in the design, the most obvious being systematic variations in soil or some other factor which is assumed constant. The design will not replace replication and/or uniformity trials.

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