# METHODS OF ESTIMATING AVAILABLE PLANT NUTRIENTS IN THE SOIL AND DETERMINATION OF FERTILIZER REQUIREMENTS

## I. IRRIGATED HYBRID CORN

*By*

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## INTRODUCTION

The aim of this work was to find methods of analysis to estimate the amounts of available nutrients in the soils of Israel's main agricultural regions and to determine the fertilizer requirements of irrigated hybrid corn (4, 10, 13).

## MATERIALS AND METHODS

### A. FIELD EXPERIMENTS TO DETERMINE RESPONSE TO FERTILIZERS

The first series of experiments was carried out during the summers of 1955 and 1956 in different agricultural areas of the country. Some of the soil characteristics are given in Table 1.

TABLE 1

SOME CHARACTERISTICS OF THE SOILS FROM THE EXPERIMENTAL FIELDS (*soil layer* 0—30 *cm*)

| *Field no. or name* | *Texture* | *Organic matter %* | *Electrical conductivity mmho/cm 25°C* | *pH* | *$CaCO_3$ %* |
|---|---|---|---|---|---|
| 1—10 | clay | 1.7—2.1 | 0.3—0.8 | 7.5—7.7 | 1—16 |
| 11—13 | clay loam | 1.2 | 0.6—1.5 | 7.7—7.8 | 8—9 |
| 14—16 | silty loam | 0.7—1.0 | 1.2—2.0 | 7.9—8.0 | 13—14 |
| Neve Ya'ar | clay | 1.7 | 0.3 | 7.7 | 5.1 |
| Gan Shmuel | clay | 2.1 | 0.5 | 7.6 | 16.5 |

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Each experiment was designed as a factorial experiment in 4 randomized blocks, with 3 factors (N, P, K) on 2 levels (no fertilizer vs. a heavy application) each. The fertilizers and amounts applied are shown in Table 2. Phosphorus and potassium were given before planting and nitrogen partly before planting and partly as top-dressing.

TABLE 2

FERTILIZERS AND THE AMOUNTS USED IN EXPERIMENT FOR DETERMINATION OF RESPONSE

| *Year* | *N* | | *P* | | *K* | |
|---|---|---|---|---|---|---|
| | *Fertilizer* | *kg/dunam** | *Fertilizer* | *kg/dunam* | *Fertilizer* | *kg/dunam* |
| 1955 | Kalk-ammon salpeter | 20 | Single superphosphate | 10 | Potassium chloride | 17.5 |
| 1956 | Ammonium sulfate | 20 | Single superphosphate | 8 | Potassium chloride | 10 |

* 1 dunam = approx. 1/4 acre

Each experimental plot was 50 m² and contained five rows of corn each 10 m long. For yield determinations an 8 m length from three central rows was picked. The cobs were hand-harvested, shelled on a small corn sheller, and grain yield, weight and moisture content determined. All yields were computed on a dry weight basis. Plant population was determined at harvest.

A second series of experiments was designed for 1957, in which only the response to nitrogen was tested (all plots received uniform and heavy applications of phosphorus); nitrogen application was 16 kg/dunam. The fertilizer was spread by a mechanical fertilizer spreader and yields were determined from larger areas than in the previous years (two or three rows 20 m long). The experiment was laid out in blocks with four replicates. This series included 8 experimental fields over the same areas and on similar soils as the first one.

B. Field Experiments to Determine Response to Different Rates of Application

1) In Neve Ya'ar each fertilizer was tested independently on a separate part of the field and applied in 6 different quantities, in a Latin square design, with the other two fertilizers applied at a constant level. The rates of application of the elements tested are shown in Table 3. Fertilizers given at a constant level were applied in the following quantities: 20 kg N, 10 kg P and 17.5 kg K per dunam.

2) A similar experiment was carried out in Gan Shmuel except that only N response was tested.

Soil characteristics for these two fields are given in Table 1.

TABLE 3

FERTILIZER AMOUNTS USED FOR DETERMINATION OF RESPONSE TO DIFFERENT RATES OF APPLICATION

| *Nutrient level no.* | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| N kg/dunam | 0 | 2.0 | 4.0 | 8.0 | 16.0 | 32.0 |
| P kg/dunam | 0 | 1.33 | 2.66 | 5.32 | 7.90 | 15.86 |
| K kg/dunam | 0 | 2.5 | 5.0 | 7.5 | 10.0 | 20.0 |

## C. Laboratory Tests

Soil samples were taken from all the experimental fields before the fertilizers were applied. The samples were air-dried and ground to pass a 2 mm sieve.

Organic matter was determined by oxidation with potassium chromate (1) and calcium carbonate by the gasometric method (21); pH was measured with a glass electrode and electric conductivity was measured on soil extract (16).

Soluble phosphorus was extracted by several methods: in water extract (2), in water extract in the presence of permutite (14), in bicarbonate solution (15), ammonium fluoride solution (6), sulfuric acid (20) and in solutions of the following organic acids: lactic, tartaric, oxalic, and citric, all 0.01 molar. One gram of soil was agitated with 100 cc of acid for 15 minutes.

Other methods of extracting phosphorus were also tested, particularly water containing $CO_2$, a solution of potassium carbonate, by means of fungus culture, etc. However, the results obtained by the last methods did not warrant further research.

Phosphorus was determined by the molybdic acid colorimetric method (8).

Available nitrogen was determined by a modified nitrification method (11, 12, 19). In some instances the addition of vermiculite was substituted by treatment of the soil with Krilium. The best results were obtained by the following method: 5 g of soil were mixed with an equal weight of fine sand, which had been washed previously with hydrochloric acid, and with water. This mixture was transferred to a Buchner funnel, washed 4 times with 25 ml of distilled water, and afterwards drained under a suction of 0.53 atm.

The soil and sand mixture was then incubated at 30° C for two weeks.

Nitrates were then determined in water extract by the phenol-di-sulfonic acid method (18).

No potassium determination tests were carried out, since no responses to potassium fertilization were found in the field experiments.

In addition an experiment was carried out to determine the effect of the concentration of citric acid and the time of shaking the soil sample with the solvent, on the amount of phosphorus extracted.

As a rule, soil samples were taken from eight points in the experimental fields and analyzed separately. The values presented in the tables are averages.

Calculations of correlation coefficients as well as of regresion equations and predictions of yield due to fertilizer applications were based on the Mitscherlich equation:

$$\log (A-y) = \log A - (cx + c_1 b)$$

Where $y$ represents yield, $x$ amount of fertilizers applied, $c$ proportionality factor, $A$ maximum yield under given conditions and $c_1 b$-$a$ measure of the amount of nutrient available in the soil. The mathematical procedures are described in detail in literature (3, 5, 6, 7, 9, 17).

## RESULTS

### A. Determination of Fertilizer Response

Dry weight of corn from the various experimental fields was measured. An analysis of variance was carried out on each field separately. No significant interactions between the three factors tested were found. The main factor effects are presented in Table 4.

As may be seen from this table, many of the fields responded to nitrogen, in some cases quite considerably. The phosphoric fertilizer increased yields in fewer cases and to a lesser degree. Potassium had no effect on the yields in most cases.

TABLE 4

MAIN FACTOR EFFECTS ON CORN GRAIN YIELDS

| *Field no.* | *Average yield in control plots kg/dunam (dry weight)* | *Yield obtained without fertilization (%)* | | |
|---|---|---|---|---|
| | | *Nitrogen* | *Phosphorus* | *Potassium* |
| 1 | 251 | 98 | 92 | 97 |
| 2 | 315 | 86 | 98 | 99 |
| 3 | 337 | 100 | 87 | 100 |
| 4 | 322 | 95 | 100 | 100 |
| 5 | 510 | 100 | 93 | 100 |
| 6 | 349 | 92 | 88 | 100 |
| 7 | 525 | 98 | 100 | 99 |
| 8 | 453 | 98 | 98 | 99 |
| 9 | 291 | 81 | 99 | — |
| 10 | 198 | 82 | 86 | 100 |
| 12 | 136 | 53 | 82 | 90 |
| 13 | 228 | 79 | 82 | 97 |
| 15 | 220 | 52 | 98 | 98 |

### B. Response to Fertilizer Applications

In the experiments carried out at Neve Ya'ar and Gan Shmuel the effect of graduated applications of fertilizers was examined. The average yields obtained are listed in Table 5. As the table clearly shows, only nitrogen fertilization produced

TABLE 5

CORN YIELDS OBTAINED FROM EXPERIMENTAL FIELDS IN NEVE YA'AR AND GAN SHMUEL, WITH VARIOUS AMOUNTS OF FERTILIZERS (*kg/dunam, dry weight*)

| *Location* | *Nutrient tested* | *Nutrient level no.* | | | | | | *Coefficient of variation %* |
|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | |
| Neve Ya'ar | N | 574 | 597 | 609 | 609 | 631 | 630 | 4.8 |
| | P | 613 | 609 | 622 | 672 | 679 | 635 | 5.1 |
| | K | 644 | 652 | 652 | 644 | 660 | 636 | 5.6 |
| Gan Shmuel | N | 262 | 427 | 480 | 485 | 467 | 484 | 10.3 |

a statistically significant response. The response was much more prononounced at Gan Shmuel than at Neve Ya'ar.

TABLE 6

AMOUNTS OF PHOSPHORUS IN VARIOUS EXTRACTS (*ppm*)

| *Field no.* | *Soil depth (cm)* | *Na-HCO₃* | *NH₄F + HCl* | *Permutite* | *H₂O* | *H₂SO₄* | *Lactic acid* | *Citric acid* |
|---|---|---|---|---|---|---|---|---|
| 1 | 0—30 | 5 | 3 | 26 | 2 | | | |
| | 30—60 | 5 | 3 | | | | | |
| 2 | 0—30 | 8 | 9 | 36 | 4 | 52 | 45 | 94 |
| | 30—60 | 2 | 1 | | | | | |
| 3 | 0—30 | 18 | 11 | 54 | 6 | 99 | 159 | 340 |
| | 30—60 | 2 | 3 | | | | | |
| 4 | 0—30 | 8 | 5 | 49 | 3 | | | |
| | 30—60 | 3 | 4 | | | | | |
| 5 | 0—30 | 15 | 4 | 31 | 1 | 197 | 218 | 340 |
| | 30—60 | 2 | 2 | | | | | |
| 6 | 0—30 | 17 | 10 | 77 | 4 | | | |
| | 30—60 | 5 | 2 | | | | | |
| 7 | 0—30 | 12 | 5 | 37 | 2 | | | |
| | 30—60 | 3 | 1 | | | | | |
| 8 | 0—30 | 14 | 8 | 32 | 3 | 100 | 97 | 100 |
| | 30—60 | 4 | 4 | | | | | |
| 9 | 0—15 | 8 | 3 | | 1 | 290 | 332 | 329 |
| | 15—30 | 5 | 2 | | 1 | 285 | 297 | 375 |
| | 30—60 | 8 | | | | | | |
| 10 | 0—15 | 15 | 7 | | 3 | 52 | 40 | 91 |
| | 15—30 | 6 | 4 | | 0.5 | 20 | 30 | 94 |
| | 30—60 | 7 | | | | | | |
| 12 | 0—15 | 4 | 3 | | 2 | 17 | 6 | 100 |
| | 15—30 | 8 | 2 | | 0.5 | 12 | 5 | 90 |
| | 30—60 | 2 | | | | | | |
| 13 | 0—15 | 5 | 4 | | 1 | 17 | 9 | 41 |
| | 15—30 | 5 | 1.5 | | 0.5 | 5 | 7 | 78 |
| | 30—60 | 3 | | | | | | |
| 15 | 0—15 | 10 | 8 | | 1 | 39 | 26 | 82 |
| | 15—30 | 6 | 3 | | 1 | 20 | 26 | 102 |
| | 30—60 | 5 | | | | | | |

### C. Laboratory Tests

In conjuction with the field experiments, laboratory determinations of soluble phosphorus were carried out with different extraction agents (Table 6). Correlation coefficients were computed between the response to phosphoric fertilization in the field and the results of the various laboratory determinations (3, 5, 17). In no case was the correlation coefficient statistically significant.

The experiment, where the influence of citric acid concentration, soil-solvent ratio and time of shaking were tested, showed that all factors had a strong influence on the amount of phosphorus extracted (Table 7). The results of the nitrate tests carried out on the soil samples taken from the experimental fields in 1955 and 1956 appear in Table 8.

TABLE 7

EXTRACTION OF PHOSPHORUS FROM THE SOIL CITRIC ACID

| *Time of shaking (min.)* | *Molarity of citric acid* | *Soil-solvent ratio* | *Soil no. 5* | | *Soil no. 10* | | *Soil no. 13* | |
|---|---|---|---|---|---|---|---|---|
| | | | *ppm P* | *pH* | *ppm P* | *pH* | *ppm P* | *pH* |
| 1 | 1/50 | 1:200 | 360 | 2.6 | 160 | 3.3 | 70 | 2.8 |
| | | 1:100 | 285 | 2.7 | 82 | 3.8 | 46 | 3.3 |
| | 1/100 | 1:200 | 300 | 2.7 | 240 | 3.8 | 146 | 3.1 |
| | | 1:100 | 270 | 3.0 | 84 | 4.3 | 85 | 3.8 |
| 5 | 1/50 | 1:200 | 410 | 2.8 | 280 | 3.6 | 95 | 3.1 |
| | | 1:100 | 350 | 2.9 | 106 | 4.3 | 61 | 3.5 |
| | 1/100 | 1:200 | 440 | 3.0 | 280 | 4.2 | 105 | 3.5 |
| | | 1:100 | 345 | 3.2 | 110 | 4.9 | 49 | 4.2 |
| 15 | 1/100 | 1:100 | 370 | 3.2 | 93 | 5.4 | 75 | 4.3 |

TABLE 8

AMOUNTS OF NITRATES IN WATER EXTRACT OF SOIL

| *Field no.* | *Soil depth (cm)* | *ppm $NO_3$ in soil mixtures with:* | | |
|---|---|---|---|---|
| | | *Sand* | *Vermiculite* | *Vermiculite + Krilium* |
| 1 | 0—30 | 172 | 146 | 176 |
| | 30—60 | 78 | | |
| 2 | 0—30 | 146 | 204 | 226 |
| | 30—60 | 113 | | |
| 3 | 0—30 | 180 | 201 | 325 |
| | 30—60 | 166 | | |
| 4 | 0—30 | 178 | 134 | 246 |
| | 30—60 | 65 | | |
| 5 | 0—30 | 248 | 304 | 233 |
| | 30—60 | 254 | | |
| 6 | 0—30 | 130 | 149 | 253 |
| | 30—60 | 195 | | |
| 7 | 0—30 | 220 | 175 | 254 |
| | 30—60 | 274 | | |
| 8 | 0—30 | 244 | 195 | 230 |
| | 30—60 | 222 | | |

The equation $\log (A-y_0) = \log A-c_1b$ was used as a basis for correlation and regression calculations between estimated available nutrients in the field and various analytical methods. The average yield obtained from plots receiving ample, nitrogen fertilization was taken as $A$ (the maximum yield obtainable under given conditions), and given a value of 100. The yields on plots which received no nitrogen fertilizer were calculated relatively to the maximum yield and inserted as $y_0$ into the equation. Thus $c_1b$ was calculated for the series of field experiments and used as an estimate of the available nutrient in the field.

The highest correlation was obtained for the method where soil was mixed with sand. Among the various soil layers in which nitrates were determined, the 0-30 cm layer gave the highest coefficient of correlation ($r=0.8$). The following regression was obtained, which gives the relationship between $c_1b$ in nitrogen fertilizer experiments and the amount of nitrates in ppm in the 0-30 layer: $c_1b = 0.0105\ (NO_3) — 0.25$. A test of significance showed the coefficient of regression to be highly significant, ($t < 0.001$), while the intercept on the ordinate (0.25) is not, and thus was not taken into consideration.

Thus $c_1b = 0.0105\ (NO_3)$ was entered into the Mitscherlich equation thereby obtaining $\log (A-y) = 2—0.0105\ (NO_3)$ the graph of which is shown in Fig. 1. Upper and lower fiducial limits for the curve were analogously computed using the fiducial limits (95%) of the regression coefficient.

With the aid of soil-nitrate determinations carried out according to the above described method, Fig. 1 makes it possible to predict plant response to fertilization. An example of a possible prediction of response to fertilization based on experimental values is presented in Table 9.

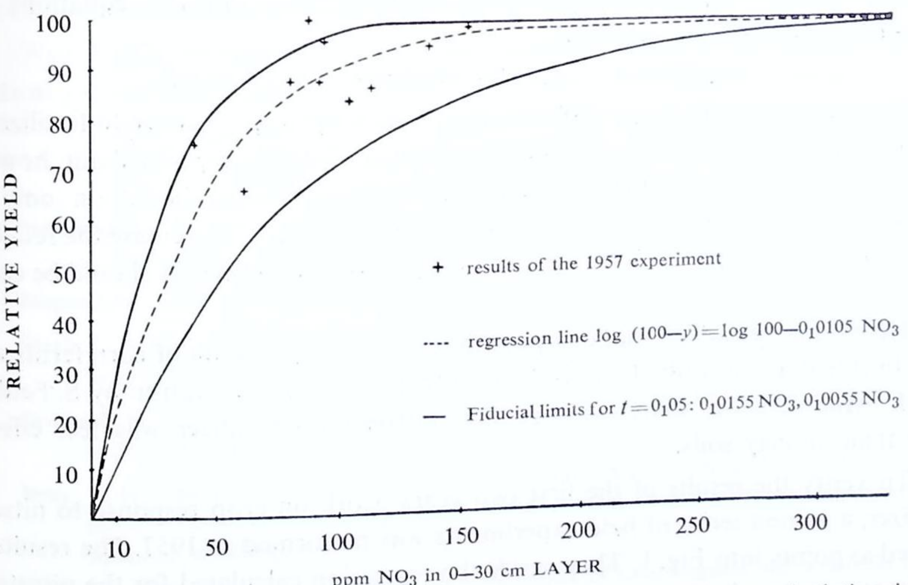


*Figure* 1. Relation between the amount of $NO_3$ (ppm) in 0–30 cm soil layer and relative yield.

TABLE 9

FORECAST SAMPLE OF CORN RESPONSE TO FERTILIZER BASED ON PRESENT INFORMATION

| *Laboratory determination of nitrates (ppm)* | *Estimate of available N in soil* | *Prediction of response to nitrogen fertilizer* | *Recommended application N kg/dunam* |
|---|---|---|---|
| 50 | low | strong | 10—15 |
| 100 | medium | strong in some cases weak in others | 5—10 |
| 150 | medium to high | in many cases there will be no response to fertilizer, in a few cases there will be a weak response | 2—5 |
| 200 | high | no response | 0 |

The results of the above mentioned experiments and calculations make it possible to predict, within certain fiducial limits, the crop response to nitrogen fertilization; they do not indicate, however, how much fertilizer should be applied to obtain the desired yield.

The experiments carried out at Neve Ya'ar and Gan Shmuel, where various levels of fertilizer were applied, were designed to determine fertilizer requirements (9).

The following equations were obtained from the experimental results:

Neve Ya'ar: $\log(100\text{-}y) = \log 100 - (0.131x + c_1b)$

Gan Shmuel: $\log(100\text{-}y) = \log 100 - (0.119x + c_1b)$

Since the $c$ values of the two equations are similar, it was considered justifiable to use their average value.

Following the solution of these equations as regards fertilizer response and nitrogen fertilizer requirement, the values obtained from the two equations were entered into the general equations:

$$\log(100\text{-}y) = \log 100 - (0.125x + 0.0105\ NO_3)$$

This last equation makes it possible to predict not only crop response to fertilization, but also indicates the amount of fertilizer to be used. It must be pointed out, however, that the conclusions dealing with fertilizer requirments are based on only two experiments, both carried out on clay soils, and that in order to increase the reliability of estimate of nitrogen fertilizer requirements, further experiments should be carried out.

Here it may be added that computations carried out on data of corn fertilization experiments done on a silty loam in 1956/57 (personal communication by S. Feldman and I. Arnon), show some evidence that nitrogenous fertilizer was less effective there than on clay soils.

To verify the results of the first two years' work on crop response to nitrogen fertilizer, a second series of field experiments was performed in 1957. The results are entered as points into Fig. 1. They verify the regression calculated for the nitrate test and response to nitrogen fertilizer.

## SUMMARY

1. Experiments were carried out in several locations to investigate a) the response of corn to N, P and K; b) the fertilizer requirements of corn, and c) the possibility of estimating potential response to fertilizers by laboratory tests.
2. No response to potassium fertilization was found. In a number of fields there was a response to phosphorus, though slight. A response to nitrogen fertilization was usually found, though there were instances where no response was produced.
3. One nitrate test was found to be correlated with available N. It can, therefore, be used to predict response to nitrogen fertilization. No such method was found for phosphorus.
4. The amount of nitrogen required to achieve a given yield was determined for two locations. The data were fitted to a logarithmic equation.



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