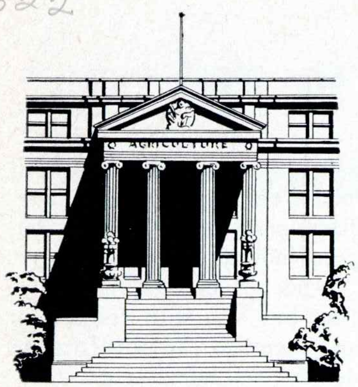

Role of Nitrogen, Phosphorus and Potassium Fertilizers in Continuous Corn Culture on Nicollet and Webster Soils

by A. J. Englehorn, John Pesek and W. D. Shrader
Department of Agronomy

AGRICULTURAL AND HOME ECONOMICS EXPERIMENT STATION
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FOREWORD

This publication reports the results obtained from continuous corn experiments conducted on the Iowa State University Agronomy Farm near Ames, Iowa. Reported are corn yields from an experiment where corn was grown each year on the same set of plots since 1915. Reported also are corn yields from another experiment where corn has been grown continuously since 1953. The two continuous corn experiments are on soils with quite different original levels of productivity. Included in the experiments are fertilizer treatments, and the results from these are also given. These data indicate that corn can be grown continuously satisfactorily on either of the two soils if an adequate fertilizer program is followed.

While the growing of continuous corn was explored in these experiments, the reporting of the results is not intended to imply that continuous clean culture is to be promoted without regard for related economic and physical considerations. Farmers are, however, intensifying their corn culture because of changes in agricultural patterns and because of improved techniques. Data from these experiments point out the kinds of results that may be obtained from growing corn more intensively and the fertilizer practices that may be needed. The findings help to indicate how and where a farmer may widen his avenue of choices, not only with respect to crop patterns, but also with respect to the use of soils of differing potentials. In some cases, certain factors unfavorable to continuous corn may operate to prevent complete specialization. Susceptibility of soil to erosion under clean tillage will require erosion-prevention practices, probably including crop rotations on many soils. Other factors, many of them economic, some related to the need for diversified enterprises, could limit any extensive growing of continuous corn.

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The possibility of growing continuous corn is receiving increasing consideration with the changing agricultural patterns. Farmers are devoting more and more acres to intensive cropping sequences in which corn follows corn more often. The practice of continuous corn—growing consecutive corn crops on the same land—is on the increase. This is because corn is the most profitable crop generally grown in the Corn Belt, because limitations in production technology have been eased, and because farm product demands or values have altered.

Early research with crop rotations generally resulted in conclusions that continuous culture of intertilled crops, especially of corn, was less profitable than other alternatives and resulted in decreasing soil fertility and continuously declining yields. The early experiments indicated that a crop rotation, including a nitrogen-fixing legume, was needed to increase or even maintain fertility levels. These experiments usually did not explore the use of N, and, if they did, the N usually was used in low amounts, probably because of the high cost. Forage-producing crops were also necessary for the livestock program, which then included draft horses, and the manure byproduct from the animals helped maintain fertility levels.

LITERATURE REVIEW

Hopkins (11)[2] in 1908 reviewed 30 years of crop rotation results at the Illinois experiment station and concluded, "The fertility of the soil can be maintained or even increased by a proper system of grain farming including a legume in the rotation." In the experiments reviewed, continuous corn yields were reduced to 35 bushels in 12 years from a base of 70, but by only 8 more bushels over the next 16 years. Corn yields in a corn-oats-clover rotation, however, were reduced by only 4 bushels below the 70-bushel base in the first 10 years and by an additional 8 bushels in 16 more years.

Working in Iowa, Stevenson and Brown (30) in 1916 concluded, on the basis of 6 years of results, that "the continuous growing of crops decreases the fertility of the soil and leads to rapidly declining crop yields." The average yields of corn obtained varied from 40 bushels per acre for continuous corn to 56 for a corn-oats rotation and 64 for a corn-oats-clover rotation.

Similar conclusions were drawn at other experiment stations. Arny (1) at Minnesota compared continuous corn with corn in rotation with wheat, oats and hay. Continuous corn yields were equal to rotation yields at the beginning of the experiment but were not maintained over a 7-year period even with manure. Chen and Arny (6) found that yields of corn in rotations that included a legume-grass hay were generally higher than when mixed hay crops were not included. Average yields of corn were 36 percent higher in a 5-year rotation including a meadow crop as compared with continuous corn.

Bauer and associates (4) reported corn yields on the Morrow Plots at the Illinois experiment station were considerably lower from continuous corn than from corn-oats and corn-oats-clover rotations. In another publication (13), the Morrow Plot yields taken over a period of 52 years are shown to have decreased with continuous corn and in a corn-oats rotation, while they increased in a corn-oats-clover rotation. The yield trend was upward in all cases where the plots had been fertilized with manure, lime and P. Haynes and Thatcher (9) concluded that yield effects due to rotation take place in the first few years and then tend to level off. They found that continuous corn yields continued downward to a rather low point before reaching equilibrium and, further, that most of the other Corn Belt rotation systems except for continuous corn, will maintain the crop-producing capacity of the soil at a rather constant level.

Hobbs (10) analyzed trends in soil productivity resulting from different rotations and soil treatments for the period 1911-52. Yields of corn obtained during this period were not maintained when the corn was not fertilized, except in rotations including a legume. The yield of continuous corn, when not fertilized, definitely decreased over the period. Miller (17), reporting 30 years of experiments with crop rotations, showed yields decreasing with continuous corn, both with and without

[1]Projects 1148 and 1205, Iowa Agricultural and Home Economics Experiment station.

[2]Numbers refer to Literature Cited.

manure, while corn yields in 3-, 4- and 5-year rotations including legumes were maintained or even increased, especially with manure.

In an experiment started at the Ohio Agricultural Experiment Station (19) in 1915, there was a rapid decrease in the yield of continuous corn during the first 5 or 6 years, followed by a continued slight decline through 1935. Throckmorton and Duley (32), reporting 20 years' results from 1911 to 1930, concluded that continuous corn yields did not decline. The spread between yields obtained with continuous corn, however, and those with rotations increased in favor of rotation corn as the years went by. Yield increases from N, P, K and manure were not great.

Continuous corn yields in early rotation experiments generally dropped rapidly during the first years of the trials, often to 15 or 20 bushels per acre. The yields often remained at these low levels or showed further slight declines. Yields from corn in rotations including legumes seldom dropped below those at the start of the experiments but more often were maintained or even increased.

Declining corn yields generally were attributed to N and organic matter losses because of clean tillage. At the Ohio experiment station (18, 24), soils in continuous corn for 33 years lost one-third of their original organic matter and 59 percent of the N. In the rotation experiments started in 1894, 33 years of results indicate that continuous corn yields were reduced 54 percent. Such losses in organic matter and N or reductions in yield did not occur under continuous wheat or oats, or under rotations including a legume. Soil analyses of rotation plots made by Snyder (29) indicated that percentages of carbon and N were maintained or even increased when rotations including legumes were followed, while the percentages of both carbon and N were reduced under wheat, corn and potatoes grown continuously. The use of manure tended to offset these declines.

Smith and associates (27) reported on soil samples taken in 1917 and again in 1936 from continuous corn plots. They found substantial decreases in N and organic matter. Bartholomew (3) reported on N changes occurring between 1917 and 1953 under various crop rotations. Nitrogen declines were greatest in plots planted to continuous corn, followed, in decreasing order, by plots in a 2-year corn-oats rotation, plots in a 5-year rotation of corn-corn-oats-meadow-meadow and plots in a 3-year corn-oats-meadow rotation. There was less loss of N where manure had been applied.

The need for N was recognized by most experiment station workers, but the attempt was to supply it through manure and through growing legumes in rotation or as a catch-crop. Conner (7) in 1922 wrote, "Except in those soils which still have a large portion of the unexhausted nitrogen left, the nitrogen problem is the most important fertility problem before the Corn Belt farmer." Mineral N was scarce and costly and, when used, was not supplied in sufficient amounts. The common practice as late as 1940 was to apply 2 to 6 pounds of N in mixed goods such as 2-12-6, 4-12-6, 3-12-12 and similar low analysis materials.[3] This was looked upon as a supplement to the N in the legume crop and the manure. Consequently yields of corn, particularly continuous corn, were often limited by N deficiency.

Stevenson (31) in 1924, on the basis of several years results from 43 field experiments, concluded that complete commercial fertilizer could not be recommended. Nitrogen was used at rates of 4 pounds per acre. Miles (16), reporting 9 years results from 23 experiments, found that 2 to 4 pounds of N decreased corn yields. In one comparison, 9 pounds of N increased yields. Numerous other workers reported similar results.

Scarseth (25), noting N deficiency symptoms, looked for better methods of supplying N than through crop rotation systems and low analysis fertilizers. Observing the war production of N and the large supply, he speculated, "Abundant commercial nitrogen used effectively may (soon) be more economical than legume nitrogen on nonerosive land." He obtained substantial increases from large amounts of N that, he concluded, were most effective when plowed under. Best results were obtained when all nutrients required by the given soil conditions were supplied in adequate amounts. Ohlrogge and associates (20) plowed under 200, 400 and 800 pounds of ammonium sulfate and used a 3-12-12 fertilizer in the row. Plowing under these large amounts of N proved very effective, although the maximum net profits were obtained from the first increment of N.

A number of workers following this lead have demonstrated that higher yields may be obtained from the use of larger amounts of N. Krantz (14) reported 5 years of results from 49 experiments. He used 40, 80 and 120 pounds of N per acre and increased corn yields five to seven times. Dumenil (8) concluded that profitable returns could be obtained from 20, 40 and 100 pounds of N per acre. He indicated that profitable responses from N are usually obtained on corn following grass sod, on second-year corn on poor soil and on corn 3 or more years following a legume. MacGregor (15), using 50, 100 and 150 pounds of N per acre, increased corn yields from 7 to 18 bushels per acre over a control yielding 89 bushels.

Rhoades and Lowry (23) obtained marked yield increases from 40 and 80 pounds of N on both irrigated and nonirrigated land. Hunter and Yungen (12) used N in 50-pound increments up to 200 pounds per acre. Substantial yield increases were obtained, especially with the first increment of N. Pumphrey and Harris (21), working on old rotation plots on irrigated land, increased corn yields 33, 54 and 71 bushels per acre from 40, 80 and 120 pounds of N per acre, respectively. Willard (34) plowed down 100 pounds of N per acre for continuous corn and increased corn yields by as much as

[3]The fertilizer analyses in the literature review are expressed on the oxide basis for P and K since this is the form used by the authors cited. Analyses given in relation to the experiments reported in this publication are expressed on the elemental basis.

84 percent on land yielding 22 bushels per acre without N. Nevertheless, yields from corn in rotation were much higher with the same N treatment.

Reichman and associates (22), using a 3-year rotation on an irrigated soil, obtained substantial corn-yield increases from 40, 80 and 120 pounds of N. Brensing and Harper (5) used up to 180 pounds of N on irrigated soil. They obtained substantial increases but found the higher amounts of N to be the least efficient.

Up to this point, research workers who were obtaining profitable returns from large amounts of N were suggesting, however, that applied N should be used as a supplement to a legume in a crop rotation. Profitable returns from substantial amounts of cheap N, however, suggested the possibility of growing corn continuously. With an adequate supply of low-priced fertilizer N, growing legumes for soil N maintenance seemed unnecessary. Nitrogen could be supplied more cheaply from inorganic commercial sources than by growing a crop of legumes. Growth of well-fertilized corn is vigorous, and it is doubtful if a rotation including a legume under moderate fertilization would produce any more, if as much, organic matter as would highly fertilized continuous corn. Hence, with adequate fertilization, soil organic matter and soil tilth would be maintained under either system.

The Morrow Plots at Illinois (13, 28) were modified in 1955 to receive large amounts of N, P and K. Phenomenal yield increases were obtained on the old continuous corn plot as well as on the rotation plots. Snider (28), citing results obtained in northern Illinois, concluded that growing corn continuously for a long period of years is possible with adequate annual fertilization, such as 120 pounds of N, 85 pounds of P and 85 pounds of K. Barber (2) found continuous corn yields were increased from 49 bushels to 94 bushels per acre from the use of 160 pounds of N per acre on an experimental plot that had had no N fertilization for 30 years. Yields in a 2-year corn-oats rotation with a sweetclover green manure crop were increased from 93 to 104 bushels per acre from the same treatment.

Triplett (33) suggests that N is the key to success with continuous corn. In an experiment at Wooster, Ohio, continuously cropped since 1896, N was added in 1954 in addition to P, K and lime. Without N, the yield of continuous corn averaged 31 bushels per acre over a 6-year period; with N, the yield was 87 bushels. The respective yields for rotation corn were 73 and 93 bushels.

Although the results now show that continuous corn is possible when adequately fertilized, there still seems to be a need for a sod crop in rotation with intertilled crops to help hold soil erosion losses within acceptable limits on some soils. There is some evidence, however, which shows that well-fertilized land in continuous corn is not as erodible as when it is not fertilized. It is yet to be established how much meadow for soil-conserving purposes may be replaced with high-producing corn crops. Developments in minimum and mulch tillage also serve to make land in corn less subject to soil erosion.

HISTORICAL AND OBJECTIVES

Growing continuous corn has been a part of the experimental program at the Agronomy Farm, Ames, Iowa, since 1915. Continuous corn has been grown on one set of plots ever since, while 2-, 3-, 4- and 5-year rotations were used on other areas to determine the contribution of legume meadows to grain production and to total farm production.

These rotation-fertility experiments were designed to include each crop each year in blocks of land large enough to permit a number of 0.1-acre plots to receive different fertility treatments. All arrangements were systematic, since modern statistical methods requiring replication and randomization were then unknown. The control plots with no treatment, however, were repeated frequently and systematically. Fertilizer, manure and lime treatments were also based on concepts current in 1915.

The treatments on certain groups of plots in two cropping systems were revised in 1953 to examine some present-day ideas on the growing and fertilization of continuous corn. The objective was to determine the extent to which a fertilization program might maintain or increase yields of continuous corn on a soil that had been in continuous corn with no commercial fertilizer since 1915. Concomitantly, a second objective was to determine if a similar fertilizer program would maintain yields at a high level on a soil that had been in a 3-year rotation with a slightly better fertilizer program during the same previous period. The first objective was pursued on a block of Nicollet silt loam that had been in continuous corn; the second, on one block of the 3-year rotation experiment (corn-oats-meadow) on Webster silty clay loam. This report presents the results of this study to date.

EXPERIMENTAL PROCEDURE

Field experiments

The continuous corn block, planted to corn each year since 1915, included five 0.1-acre plots. (This block seems to have been in corn in 1914 and may have been in corn a number of years previous.) Two of these plots served as controls, with no fertility treatment whatever, at least since 1915, while the remainder received certain fertility treatments. The plots and treatments are given in table 1. The revised fertilizer program did not include plot 910, which is on Clarion silt loam, but did include the others, which are on Nicollet silt loam.

The 3-year rotation block selected for this continuous corn experiment had been in corn 13 of the 38 years since 1915. The block is located on Webster silty clay loam. Thirteen crops of hay and 12 of oats were grown in the intervening years. This 3-year rotation block included four 0.1-acre plots which received fertility

Table 1. Plot numbers and treatments used in the old continuous corn and 3-year rotation experiments 1915 through 1952, Iowa State University Agronomy Farm.

Plot number	Treatment
	Old continuous corn
906	Control.
907	Manure, 2 tons per acre per year, plowed under every 4 years.
908	Manure as in plot 907. Ground limestone as needed to adjust the soil reaction to pH 6.0.
909	Limestone as in plot 908.
910	Control.
	Old 3-year rotation
829	Control.
830	Manure, 2 tons per acre per year, plowed under for each corn crop. Ground limestone as needed to adjust the soil reaction to pH 6.0.
831	Manure and limestone as in plot 830. Rock phosphate, 250 pounds per acre per year every 3 years.
832	Ground limestone as in plot 830.
833	Ground limestone as in plot 830. Rock phosphate as in plot 831.
834	Control.

treatments and two 0.05-acre plots which did not. Plot numbers and treatments are given in table 1. The control plots in this 3-year rotation experiment were not used in the revised experiment because they were deemed too small to be further subdivided as needed.

In each case, four 0.1-acre plots from the old continuous corn and from one block of the old 3-year rotation were selected to receive the revised fertilizer treatments. These were plots 906, 907, 908 and 909, from the "old continuous corn," and plots 830, 831, 832 and 833 from the 3-year rotation block, which shall be referred to as "new continuous corn."

Each 0.1-acre plot was divided into eight subplots, each 28 x 21 feet. Fertilizer treatments were assigned to these at random within each original 0.1-acre plot, which then served as a block or "replication" in the new set of treatments. The new fertilizer treatments are given in table 2.

The plot areas were plowed in the fall, and the fertilizers were broadcast annually, before corn planting in May, and disked in. The source of N was ammonium nitrate; concentrated superphosphate and muriate of potash were used to supply P and K, respectively.

Table 2. Fertilizer treatments used in the "old" and "new" continuous corn experiments since 1953. Iowa State University Agronomy Farm.

Treatment No.	Designation	Nutrients in pounds per acre annually N	P	K
1	N_0	0	0	0
2	N_1	40	0	0
3	N_2	80	0	0
4	N_4	160	0	0
5	N_0PK	0	26[a]	50[b]
6	N_1PK	40	26	50
7	N_2PK	80	26	50
8	N_4PK	160	26	50

[a]Equivalent to 60 pounds of P_2O_5.
[b]Equivalent to 60 pounds of K_2O.

Conventional cultural practices for seedbed preparation and corn cultivation were used. Since the beginning of the revised experiments in 1953, soil insect control was obtained by broadcast spraying aldrin at a rate of 2 pounds of active material per acre every 3 years; this material was disked in during seedbed preparation. Corn borers were controlled with DDT applied at the first indication of leaf feeding.

Open-pollinated corn was planted at the beginning of the continuous corn and rotation experiments in 1915 and was continued until 1937 when hybrid corn was introduced. The variety of hybrid was changed from time to time. However, one hybrid—Iowa 4570—was used since 1953.

Laboratory analyses

Soil samples for chemical analysis were taken from both the old and new continuous corn experiments in 1950, 1953, 1958 and 1962. Samples taken in 1950 and 1962 were obtained in October; in 1953, in May; in 1958, in November. Each 0.1-acre plot was divided into eight subplots for sampling in 1950—four in the north half and four in the south half of the 0.1-acre plot. These do not coincide exactly with the present plots. Twelve core-samples were taken to a depth of 6 inches from each subplot. In subsequent years, 12 core-samples were taken to a depth of 6 inches from each current plot.

Analyses[4] were made for pH, soluble P and exchangeable K. The pH was determined with a glass electrode, using a 1:2 soil:water ratio. P was extracted with the Bray No. 1 reagent, 0.03 *N* ammonium fluoride in 0.025 *N* hydrochloric acid, and determined on a photometer by estimating the color developed by using ammonium molybdate and stannous chloride. K was extracted with neutral normal ammonium acetate and determined with a flame photometer.

Determinations[5] for total carbon were made by the dry combustion method as described by Winters (35). Percent organic matter was calculated by using the standard factor 1.724.

RESULTS AND DISCUSSION

Early results from the old continuous corn plots

Yields of continuous corn varied considerably from year to year until 1952 (table 3). These wide fluctuations undoubtedly are due directly and indirectly to weather variations, primarily precipitation and resulting soil moisture supplies. The lowest annual yields occurred in 1934 and 1936, both dry years, while the highest yields were in 1937 and 1939. These high yields, especially for 1937, may be accounted for by an accumulation of nitrate nitrogen in the soil during the previous

[4]Determinations made by the Iowa State University Soil Testing Laboratory by procedures standardized for that laboratory.

[5]Determinations were made by K. Eik, Department of Agronomy, Iowa State University.

Table 3. Corn yields in a continuous corn cropping system, Iowa State University Agronomy Farm, Ames, Iowa, 1915 to 1952.

Year	Corn yield in bushels per acre on indicated soil and plot				
	Nicollet loam				Clarion loam
	906 Control	907 Manure	908 Manure, limestone	909 Limestone	910 Control
1915	30.0	33.4	31.0	41.3	43.0
1916	36.0	35.6	39.6	30.8	14.0
1917	48.7	50.6	51.8	47.2	40.0
1918	25.7	37.1	38.6	31.4	24.3
1919	38.6	55.7	60.0	42.8	37.1
1920	41.4	50.0	64.2	50.0	45.7
1921	34.2	48.5	50.0	42.9	35.7
1922	38.6	48.5	52.8	45.7	32.8
1923	30.0	51.3	52.5	43.8	36.3
1924	28.5	35.7	34.3	30.0	22.8
1925	50.6	53.3	57.3	45.3	25.3
1926	32.5	32.5	35.0	28.8	17.5
1927	33.3	34.7	37.3	32.0	25.9
1928	47.6	48.5	44.8	35.0	28.7
1929	39.6	44.7	45.2	36.3	30.4
1930	25.9	27.0	30.9	29.0	28.1
1931	35.8	45.5	64.7	35.1	29.7
1932	44.5	50.0	48.8	40.6	31.7
1933	44.3	49.3	47.5	35.6	26.9
1934	16.8	17.4	15.8	17.0	14.0
1935	52.6	59.1	62.7	60.4	40.4
1936	18.3	19.3	22.3	20.9	15.0
1937	74.1	79.7	78.1	75.0	53.7
1938	47.5	55.6	58.6	50.2	29.7
1939	60.0	63.4	66.5	55.0	48.5
1940	46.6	54.7	57.2	48.9	41.7
1941	52.3	63.4	66.9	57.3	43.6
1942	50.2	64.4	55.8	53.3	52.5
1943	44.5	55.8	55.2	49.7	36.4
1944	42.8	46.5	48.0	39.8	33.0
1945	30.0	55.2	55.1	34.9	29.6
1946	33.0	48.0	55.1	45.4	31.2
1947	24.7	19.0	23.4	19.6	20.4
1948	55.2	60.0	64.0	49.5	33.3
1949	34.8	46.4	47.6	34.8	18.8
1950	40.1	55.8	60.8	41.8	26.6
1951	28.1	38.0	37.7	26.6	18.6
1952	33.4	44.2	47.8	39.4	26.8
Av.	39.2	46.2	49.1	40.4	31.3

dry year and from adequate moisture supplies following the dry year. Relatively low yields also occurred in 1918, 1930 and 1947, while high yields were the rule in 1925, 1941 and 1948.

Because of these year-to-year yield variations, it is difficult to trace a yield trend over time resulting from growing corn continuously and from the fertilizers used. There appears to have been a gradual decrease in yields with time, for the period 1915 through 1936, before the introduction of hybrid corn, but no general statistical significance could be demonstrated. Immediately following the introduction of hybrid corn in 1937, yields appeared higher than in former years. The yield level after 1937, starting from a higher base, showed a more rapid decline than before, perhaps as a result of more rapid soil depletion by the hybrid corn.

The downward trend in yields was significant in both untreated continuous corn plots (906 and 910) for the 1938-52 period. A linear regression of yield on years calculated for this period indicates that yields decreased at a rate of 1.9 bushels per acre per year on plot 906 on Nicollet silt loam and at a rate of 1.5 bushels per acre per year on plot 910 on Clarion silt loam.

A further variation in yield over the entire plot area could result from soil differences. While the soil on plots 906 through 909 was mapped as Nicollet silt loam and that on plot 910 as Clarion silt loam, it is known that the change from one soil type to a closely related one is gradual, and the exact line of demarcation usually is not sharply defined. The gradation from Nicollet to Clarion silt loam in this block is an example of a gradation within the Nicollet to a soil more like Clarion than Nicollet. Considering this situation and noting that there is a control plot at each end of this experimental area, one on the Nicollet and the other on the Clarion, it is possible to adjust the yields of plots 907, 908 and 909 relative to a common control yield taken as the mean of plots 906 and 910. This is based on the assumption that the gradation of inherent productivity between plots 906 and 910 is linear. Adjusted plot yields averaged for selected periods are given in table 4. These adjustments were made according to Schuster (26), using the formula $CY = AY - N + NW$, where CY is the corrected yield, AY is the actual yield, N is the normal of each plot in its local area (calculated as the plot's proportional share of the difference between the adjoining controls), and NW is the normal for the entire area as represented by an average of all controls.

The yield of corn was increased by manure and limestone treatments. Increases, however, were not particularly large. The average increase from limestone, according to the data adjusted for inherent productivity, is 7.2 bushels per acre per year over the 38-year period. Corn yield increases averaged 9.0 bushels per acre per year from use of manure over the same period and 13.9 bushels from the manure and limestone combination.

These are yield responses that might reasonably be expected from an average annual N application of not more than 20 pounds per acre (2 tons of manure containing, on the average, up to 10 pounds of N per ton).

The unadjusted continuous corn yields for the years preceding the start of the new treatments should be noted to serve as a base for comparing with yields resulting from these heavier fertilizer treatments. The average yields for the 8-year period ending with 1952 were 34.9 bushels of corn per acre from the control (plot 906), 45.8 from manure (plot 907), 48.9 from manure and limestone (plot 908) and 36.5 from limestone alone (plot 909).

Table 4. Corn yields adjusted for a linear inherent productivity change between plots 906 and 910, by periods in a continuous corn cropping system, Iowa State University Agronomy Farm, Ames, Iowa.

Period	Corn yield in bushels per acre on indicated plot			
	906 and 910 Control	907 Manure	908 Manure + Limestone	909 Limestone
6-year averages				
1915-20	35.4	43.1	47.5	40.3
1921-26	32.0	43.1	47.0	41.2
1927-32	33.4	39.5	45.3	36.8
1933-38	36.2	43.7	47.5	46.2
1939-44	46.0	56.3	58.3	52.4
1945-50	31.4	45.0	51.0	40.1
12-year averages				
1915-26	33.7	43.1	47.2	40.8
1927-38	34.8	40.0	46.4	41.6
1939-50	38.7	50.7	54.6	46.2
38-year averages				
1915-52	35.2	44.2	49.1	42.4

Early results from the 3-year rotation block

The yields of corn in the 3-year rotation also show considerable year-to-year variation, as shown in table 5, apparently because of weather. As with the continuous corn, it is difficult to be certain of a trend in yields over the 38-year period. A downward trend seemed to occur from 1915 to 1934. Yields increased abruptly in 1937 as with the continuous corn. Then there seemed to be a drop in yields for a few years, followed by another rise.

Table 5. Corn yields in a corn-oats-meadow rotation 1916 to 1952. South block of 3-year rotation. Webster silt loam. Iowa State University Agronomy Farm, Ames, Iowa.

Year	Corn yields in bushels per acre on indicated plot					
	829 Control	830 Manure, limestone	831 Manure, limestone, rock phosphate	832 Limestone	833 Limestone, rock phosphate	834 None
1916	45.8	53.6	57.0	65.4	63.6	28.5
1919	62.8	91.4	97.2	85.7	94.2	71.4
1922	57.1	72.9	78.5	65.7	70.0	62.8
1925	69.3	85.3	88.0	81.3	84.0	80.0
1928	24.3	54.3	54.3	52.9	42.9	25.7
1931	56.3	65.3	68.0	66.2	65.7	57.4
1934	12.6	16.0	16.5	26.3	31.1	12.6
1937	86.0	98.5	100.7	95.2	90.4	87.7
1940	79.6	92.2	88.7	87.5	92.1	87.0
1943	58.8	73.8	72.6	59.4	62.6	56.0
1946	71.8	91.8	86.8	80.2	83.8	78.6
1949	64.3	81.9	82.3	71.0	73.3	69.7
1952	72.8	106.2	107.4	86.5	90.6	80.8
Av.	58.6	75.6	76.8	71.0	72.6	61.4

Yields of corn in this 3-year rotation were also increased by fertility treatments. When adjusted for a linear inherent productivity trend between plots 829 and 834, the average per-acre per-year increases over the 38-year period were 10.7 bushels from limestone and 16.4 bushels from the manure and limestone combination (table 6). The increase in yield from manure, limestone and rock phosphate was 17.1 bushels per acre, not as much as from manure and lime.

Table 6. Corn yields adjusted for a linear inherent productivity change between plots 829 and 834, by periods in a 3-year rotation block. Iowa State University Agronomy Farm.

Period	Corn yields in bushels per acre on indicated plot				
	829 and 834 Control	830 Manure, limestone	831 Manure, limestone, rock phosphate	832 Lime-stone	833 Limestone, rock phosphate
1916-25	59.8	76.4	80.4	74.4	77.5
1928-37	45.3	61.3	60.0	60.1	57.2
1940-49	70.7	86.2	83.0	74.1	76.7
1916-52	60.0	76.4	77.1	70.7	71.8

The average corn yields between 1943 and 1952 on the 3-year rotation block on which the new treatments were superimposed should be noted. On the limestone plot (832), the average per-acre yield was 74.3 bushels; on the manure and limestone plot (830), the yield was 88.4 bushels; on plot 831, receiving manure, limestone and rock phosphate, it was 87.3; and on plot 833, receiving limestone and rock phosphate, the yield averaged 77.5 bushels per acre.

The relative productivities of the continuous corn and the 3-year rotation blocks may be compared by examining the data in tables 3 and 5, and 4 and 6. Since

Table 7. A comparison of average corn yields[a] from the continuous corn and 3-year rotation blocks. Iowa State University Agronomy Farm.

Treatment	Corn yield in bushels per acre	
	Continuous corn	3-Year rotation
Control	40.8	60.0
Manure	48.7	—
Lime	41.9	71.0
Manure and lime	52.0	75.6
Manure, lime, rock phosphate	—	76.8
Lime, rock phosphate	—	72.6

[a]Yields are averages of those obtained in 1916, 1919, 1922, 1925, 1928, 1931, 1934, 1937, 1940, 1943, 1946, 1949 and 1952.

corn appeared only every third year on the 3-year block now in the new experiment, only the like years from the continuous corn may be used since comparisons must be made in years common to both to avoid introducing excessive bias from year-to-year yield fluctuations. Average yields are shown for comparison in table 7. According to these data, yields of corn from the plots of this 3-year rotation block yielded 45 to 70 percent higher than comparable plots in the continuous corn block. These differences may be attributed, for the most part, to differences in soil productivity resulting from the past cropping and soil management systems although they may also be due, at least in part, to inherent soil differences.

Results from current treatments on old continuous corn

Yields of corn obtained on the continuous corn block since 1953, when this experiment was re-designed to receive four N rates with and without P and K, are summarized in table 8. Complete data of the returns from these recent fertilizer treatments are given in table A-1 in the Appendix. The responses to recent fertilizer treatments may be observed in these data, particularly in table 8. The influence of past treatments may be noted in table A-1 in the Appendix.

The old fertility treatments have persisted somewhat in their influence on yields, particularly on the N_0 plots. Furthermore, this influence seems to have been nearly as strong in 1962 as in 1953, 10 years since discontinuing the old treatments. In most years since 1953, the highest yields on the N_0 plots were obtained where the treatment had been manure plus lime followed, in order, by manure, control and lime. The old treatment effects tended to disappear with the addition of P and K without N, perhaps indicating the former response in yield from manure may have been partly a function of the P and K in the manure. With the addition of larger amounts of N, the old treatment effects did not seem to persist as much, particularly as the number of years increased. However, the old treatment yield levels remained evident in spite of the total fertilizer application of N, P and K.

Analysis of variance indicated that differences between replications (plots in the old experiment) were generally significant only at the 25-percent level (table 9). The low probability of differences between them might indicate that the old treatments actually had little effect on

Table 8. Yields of corn from the old continuous corn experiment from 1953 to 1962 as affected by the new fertilizer treatments. Iowa State University Agronomy Farm, Ames.

Year	Corn yields in bushels per acre with different treatments							
	N_0	N_1	N_2	N_4	N_0PK	N_1PK	N_2PK	N_4PK
1953	33.6	58.8	60.5	69.8	34.3	56.8	71.5	73.4
1954	44.4	70.5	79.1	79.3	44.6	64.0	79.1	83.9
1955	44.0	77.3	87.9	89.2	45.6	72.6	88.8	100.2
1956	19.0	15.4	5.4	11.2	14.2	24.3	8.5	14.7
1957	72.6	96.4	98.6	106.6	89.3	99.8	116.6	116.6
1958	43.8	85.0	109.2	124.6	46.7	76.2	118.5	135.2
1959	29.4	53.4	83.4	105.3	33.0	49.2	88.1	117.3
1960	28.6	56.4	76.6	95.4	30.0	57.2	86.0	106.3
1961	27.6	61.1	90.0	121.4	29.0	53.2	103.9	132.1
1962	32.2	65.0	96.1	109.7	27.1	62.9	93.7	137.8
Average	37.5	63.9	78.7	91.2	39.4	61.6	85.5	101.8
Average not including 1956	39.6	69.3	86.8	100.1	42.2	65.8	94.0	111.4

Analysis of variance for table 8.

Source of variation	Not including 1956				Including 1956			
	Degrees of freedom	Sums of squares	Mean squares	F	Degrees of freedom	Sums of squares	Mean squares	F
Total	71	62,715			79	90,695		
Treatments	7	44,093	6,299	58.87**	7	38,739	5,534	26.10**
N	3	43,200	14,400	134.58**	3	37,913	12,638	59.61**
PK	1	347	347	3.24 n.s.	1	354	354	1.67 n.s.
N × PK	3	547	182	1.70 n.s.	3	471	157	n.s.
Years	8	10,961	1,370	12.80**	9	38,600	4,284	20.23**
Years × treatment	56	7,660	137	n.s.	63	13,356	212	2.16**
Pooled error	189	18,658	99		210	20,583	98	
Total error[a]	245	26,318	107					

[a]Since years × treatment for "not including 1956" was not significantly different from pooled error, this total error was used being a summation of years × treatment and pooled error.
*P=0.05.
**P=0.01

Table 9. Levels of significance of replication and fertilizer treatment effects on old continuous corn by years.

Years	Probability expressed as percent[a]				
	Replication	Treatment	N	PK	N × PK
1953	25.0	0.5	0.5	25.0	25.0
1954	2.5	0.5	0.5	n.s.	n.s.
1955	10.0	0.5	0.5	n.s.	n.s.
1956	25.0	25.0	10.0	n.s.	n.s.
1957	n.s.	0.5	0.5	2.5	n.s.
1958	2.5	0.5	0.5	n.s.	25.0
1959	0.5	0.5	0.5	25.0	n.s.
1960	25.0	0.5	0.5	25.0	0.5
1961	10.0	0.5	0.5	n.s.	n.s.
1962	25.0	0.5	0.5	25.0	2.5

[a]Probability of obtaining an F ratio as high as, or higher than, that obtained experimentally in taking a random sample from a homogeneous population. Probabilities above 25 percent are indicated as nonsignificant (n.s.).

yields or were overshadowed by the added fertilizer treatment.

There was some variation in stand, possibly due to blocks and treatments. An analysis of covariance, however, indicated that stand level within the ranges present had no significant effect on yield.

The addition of N at 40, 80 and 160 pounds per acre increased yields at all three of these levels in all replications even though the previous fertility treatments were still influential (see tables 8 and A-1). Yields generally were not increased, however, by P and K applied at 26 and 50 pounds per acre, respectively, during the first few years of this experiment. In more recent years, response to P and K has increased somewhat, particularly with the higher N rates, indicating that the high yields of corn may be reducing the amount of these nutrients available in the soil.

While the highest average yield of corn resulted from 160 pounds of N per acre per year, the largest increase per unit of N resulted from the first increment of 40 pounds per acre. The increase in yield over control ranged from 24.0 bushels per acre in 1959 to 41.2 in 1958, with an average increase of 29.7 bushels per acre for the 10-year period. (Yields obtained in 1956 are not considered in most statements or comparisons in this publication since the drouth of that year controlled all yields.) The percentage increase ranged from 33 to 121, with the average at 75 percent.

The second increment of N, doubling the amount applied in the first, further increased the yields of corn. This increase over control ranged from 26.0 bushels per acre in 1957 to 65.4 in 1958, averaging 47.2 bushels for the 10-year period. The percentage increase over no N ranged from 36 to 226, averaging 119 percent. The 160 pounds of nitrogen increased corn yields by an average of 60.5 bushels per acre over the control. This increase ranged from 34.0 to 93.8 bushels. This increase averaged 153 percent, with a range of 47 to 340 percent.

Yield trends over time, with no more than 10 years to observe, may not be entirely reliable. Control plot yields for 1959, 1960 and 1961, however, appeared somewhat lower than for earlier years; yields from N, on the other hand, definitely appeared to be increasing with time. The yield data indicate that these increases are greater over time as the N rates are increased.

All N yield responses were highly significant at the 0.5-percent level in all years except 1956 (table 9). There were no real responses of any kind in the dry year, 1956. The extreme yield variations in 1956 are difficult to explain. The higher yields may have resulted from more favorable moisture conditions remaining from the previous season.

The over-all responses to P and K added to the old continuous corn plots were low in most years, and yield increases were generally not statistically significant. Levels of significance for all treatments are given in table 9. Yield responses to P and K were negligible in all years except 1957 when there were responses amounting to 16.7 bushels per acre without N and to 18.0 bushels with 80 pounds of N. When P and K were applied with 40 pounds of N, a slight depression in yield generally resulted. As amounts of N were increased, however, larger returns from P and K resulted, indicating that the plant food deficiency developed over the past 40 years of continuous corn is primarily one of N. Corn yield increases from N_4PK over N_4 ranged from 3.6 bushels per acre in 1953 to 28.1 bushels in 1962, while the average for the 10-year period was 11.3 bushels.

While yield increases obtained in 1953 and for several subsequent years were primarily from N rather than from P and K, the latter two nutrients are becoming more important. The increase due to N_4PK over N_0 averaged 45.1 bushels per acre in 1953, 1954 and 1955. The increasing need for P and K in addition to N is reflected in the increase due to these same treatments in 1958, 1959 and 1960. The average increase in these 3 years was 85.7 bushels per acre, while the increases in 1961 and 1962 averaged 105.1 bushels. The average yield obtained during the period 1945-52 was 34.9 bushels from control and 48.9 from manure and lime.

While the yield data indicate that the fertilizer need in this instance is primarily one of N, it is apparent that there is an increasing NxPK interaction over time. This interaction was significant at the 5-percent level in 1960 when the N_4PK treatment resulted in a 10.9-bushel-per-acre increase over N_4 (table 9). Increases from N_4PK in other years were substantial, but the NxPK interaction was not significant. It would appear that P and K fertilization may become more important year by year since high yields resulting from high N fertilization will result in the removal from the soil of considerable quantities of available P and K.

Results of current treatments on new continuous corn

Yields of corn obtained on the new continuous corn block (formerly 3-year rotation) since 1953, when this experiment was redesigned to receive four N rates with and without P and K, are given in table 10 and in table A-2 in the Appendix. Fertility differences resulting from the treatments applied during the time this block was in the 3-year rotation system seemed to have some influence on yields subsequent to 1952. An analysis of variance indicated differences among replications (old plots) to be significant at the 0.5-percent level in 1953 and 1955, at the 5-percent level in 1958, and at the 25-percent level in 1954. Fertility levels from the previous manure and rock phosphate treatments apparently still influenced yields in 1958 after several years of high corn yields. The influence of past treatments may be noted in table A-2 in the Appendix.

There was some variation in stand due to blocks and treatments. An analysis of covariance, however, indicated that the stand, within the range observed, had no significant effect on yield except in 1953 and 1960. Adjustments for stand are not reported, since they did not materially change the yield data.

During the first 5 years of this experiment, yields from N were generally negative, especially when N was

Table 10. Yields of corn from the new continuous corn experiment (formerly 3-year rotation) from 1953 to 1962 as affected by the new fertilizer treatments, Iowa State University Agronomy Farm, Ames.

Year	Corn yields in bushels per acre with different treatments							
	N_0	N_1	N_2	N_4	N_0PK	N_1PK	N_2PK	N_4PK
1953	93.6	92.4	90.5	88.3	100.3	97.5	102.4	106.2
1954	82.4	79.3	79.4	86.3	86.9	86.5	92.6	85.0
1955	96.8	83.9	89.5	93.2	96.1	98.0	99.8	103.4
1956	25.4	12.1	10.0	34.0	20.3	22.4	37.4	6.0
1957	100.2	97.0	96.9	99.2	105.4	111.5	117.2	103.5
1958	107.5	110.7	119.4	121.1	97.7	126.4	133.3	136.0
1959	77.1	79.3	102.4	109.4	68.3	91.6	103.6	115.2
1960	70.9	68.5	92.2	98.5	52.6	73.2	94.6	112.8
1961	88.4	90.5	106.2	120.2	68.9	100.6	124.6	139.1
1962	67.1	73.0	94.7	110.7	59.6	87.2	108.7	121.8
Average	80.9	78.7	88.1	96.1	75.6	89.5	101.4	102.9
Average not including 1956	87.1	86.1	96.8	103.0	81.8	96.9	108.5	113.7

Analysis of variance for table 10.

Source of variation	Not including 1956					Including 1956				
	Degrees of freedom		Sums of squares	Mean squares	F	Degrees of freedom		Sums of squares	Mean squares	F
Total	71		22,136			79		64,373		
Treatments	7		8,063	1,152	12.26**	7		7,495	1,071	9.23**
N		3	6,270	2,090	22.23**		3	5,653	1,884	16.24**
PK		1	877	877	9.33**		1	818	818	7.05**
N × PK		3	916	305	3.24*		3	1,024	341	2.94*
Years	8		8,004	1,000	10,64**	9		49,354	5,484	47.28**
Years × treatment	56		6,070	108	1.22 n.s	63		7,523	121	1.06 n.s.
Pooled error	189		16,859	89		210		24,001	114	
Total error[a]	245		22,929	94		272		31,524	116	

[a]Since years × treatment was not significantly different from pooled error, this total error was used being a summation of years × treatment and pooled error.
*P=0.05.
**P=0.01.

Table 11. Levels of significance of replication and fertilizer treatment effects on new continuous corn by years.

Years	Probability expressed as percent[a]				
	Replication	Treatment	N	PK	N × PK
1953	0.5	0.5	n.s.	0.5	25.0
1954	25.0	25.0	n.s.	2.5	25.0
1955	0.5	25.0	n.s.	5.0	n.s.
1956	n.s.	25.0	n.s.	n.s.	5.0
1957	n.s.	2.5	n.s.	0.5	25.0
1958	5.0	0.5	0.5	0.5	0.5
1959	n.s.	0.5	0.5	n.s.	25.0
1960	n.s.	0.5	0.5	n.s.	0.5
1961	n.s.	0.5	0.5	25.0	10.0
1962	n.s.	0.5	0.5	10.0	25.0

[a]Probability of obtaining an F ratio as high as, or higher than, that obtained experimentally in taking a random sample from a homogeneous population. Probabilities above 25 percent are indicated as nonsignificant (n.s.).

used without P and K. Increases in yield were not significant. However, increased yields from N were obtained in 1958 and in subsequent years. These were significant at the 0.5-percent level (table 11).

While the highest yield of corn from N, without P and K, resulted from 160 pounds of N per acre, the greatest response per unit of N, when used without P and K, was from 80 pounds of N per acre. Where used with P and K, however, the greatest increase in yield per unit of N generally came from the first 40 pounds of N, although the highest yields again were from 160 pounds of N. The highest yield from N alone was in 1962 when there was an increase of 43.6 bushels per acre from N_4 over N_0 representing a 65-percent increase.

Over-all responses to P and K were generally significant, at least at the 2.5-percent level, more often at the 0.5-percent level through 1958. Since then, average responses from these two nutrients were significant or only slightly so (table 11).

Returns from P and K, when used without N, were low during the first few years of this experiment and were negative in later years. The yields from P and K were increased, however, when used with N. The average yield increase from the N+PK was similar, regardless of the amount of N used. That is, yields from N_4PK over N_4 were no greater than yields from N_1PK over N_1. Statistical analyses indicated a highly significant interaction between N and PK in 1958 and 1960. This interaction was significant at the 10- and 25-percent levels in other years. It would appear that, as this soil is being continuously cropped to corn, the need for N will be increasingly present and that returns from P and K will depend on the presence of N to a greater extent. Initially, the soil supplied all the N necessary to assure adequate responses to P and K; after 10 years, part of the N has to be supplied by fertilizer, and responses to P and K are low without added N.

Yield equations for continuous corn

Recommendations for optimum fertilization of corn in this continuous corn system can best be determined from yield equations expressing the expected yield as a function of the fertilizer variables. Interpretation of these equations, however, should be restricted to conditions similar to those under which the experiments were conducted. The equations are presented to show the observed relationships in mathematical form. The equations are given to show how they may be used in an economic interpretation, but no exhaustive economic estimation of optimum fertilization is attempted.

The major treatment effects included in these experiments were those of N, PK and NxPK as indicated in tables 8 and 10. The results presented in tables 9 and 11 indicate that each of these effects was significant at least at the 0.025 level of probability in at least one crop during the period. Thus, the chances are good that all three effects are real, even though they were not large in some years.

On the basis of these observations, any yield function of fertilizer inputs for these experiments could logically include N, PK and NxPK terms. Yield equations or yield response curves, however, have been shown to exhibit diminishing returns when observed over a wide range of inputs. The design of this experiment does not permit an estimation of a curvilinear effect of PK since there were only two levels of PK. There were four levels of N, however, and a curvilinear effect of N can be estimated. If the yield equation is restricted to the second degree, the linear N by linear PK (NxPK) interaction effect can be estimated. (The other 2 degrees of freedom for NxPK in tables 8 and 10 are for the N^2x PK and N^3xPK interactions and are of degree 3 and 4, respectively, and therefore not included.)

The relevant terms in the yield equation,

$$Y = a + b_1N + b_{11}N^2 + b_2PK + b_{12}NPK,$$

were fitted to the data for each year from each experiment. The coefficients (a, b_1, etc.) for the equations that are relevant or significant at the 0.25-probability level are presented in table 12. Relevant coefficients are defined as coefficients of those terms that must appear in the equation on the basis of logic or because other

Table 12. Yield equations for continuous corn by years, continuous corn experiments. Iowa State University Agronomy Farm.

Years	(Bu./a.)	Coefficient of[a]				Coefficient of determination
		N	N2	PK	NxPK	
Old continuous corn						
1953	34.33	23.42	—3.74	1.10	1.27	0.966
1954	44.81	25.74	—4.14	......	......	0.982
1955	45.61	32.16	—4.99	......	......	0.970
1956	18.79	—5.81	1.04	......	......	0.271
1957	75.16	19.26	—2.92	12.02	......	0.974
1958	45.07	44.26	—6.07	—2.05	3.17	0.988
1959	28.64	31.38	—2.64	0.40	......	0.970
1960	28.31	32.00	—3.82	0.86	2.72	0.997
1961	26.03	41.05	—3.92	......	......	0.973
1962	34.14	36.64	—4.29	—10.24	8.49	0.993
New continuous corn						
1953	95.05	—2.38	0.16	4.16	3.08	0.962
1954	79.81	1.07	0.03	4.74	0.67	0.831
1955	91.36	—3.38	1.03	8.45	......	0.697
1956	15.35	2.78	0.03	11.68	—6.02	0.182
1957	96.28	4.34	—1.06	12.18	—0.61	0.755
1958	101.61	15.23	—2.81	2.56	4.83	0.972
1959	72.25	19.13	—2.46	—1.91	2.15	0.932
1960	65.49	14.55	—1.60	—11.50	7.00	0.940
1961	81.57	18.55	—2.42	—7.76	8.42	0.943
1962	63.02	21.79	—2.48	—1.76	3.54	0.938

[a]In units of bushels per 40-pound units of N per acre and bushels per unit of PK containing 26 pounds of P and 50 pounds of K per acre.

terms appear. The coefficients for N^2 are in this category, since diminishing returns are not possible without this term. On the other hand, if the NxPK interaction appears in the equation because of significance at accepted odds, the N and PK terms appear. In effect, the significant NxPK interaction says that there are N and PK effects regardless of whether the main effect of either is significant over all levels of the other.

The coefficients of determination (R^2) listed in table 12 show, with the exception of 1956, that the fitted regression equations presented will express the relationship between yield and fertilizer satisfactorily. The values of R^2 are not as high for the new continuous corn regressions as for the old. This is because the plot to plot variation was larger relative to the fertilizer effect, especially of nitrogen, in the new experiment than in the old. As nitrogen becomes more yield-limiting in the new experiment, the value of R^2 should increase to levels similar to those in the old experiment.

Diminishing returns to nitrogen fertilizer are shown in all equations for old continuous corn, except the equation for 1956, as evidenced by the negative coefficient for N^2. Hence, economic optima for nitrogen may be calculated. Dimishing returns to nitrogen were not exhibited in the new continuous corn experiment until 1957, the fifth year of new treatments. This is probably because of the higher original organic matter content of the Webster soil and the cumulative effect of the rotation on soil nitrogen supplies.

The economic optimum for nitrogen is determined by equating the first partial derivative of yield with respect to nitrogen to the ratio of the unit price of nitrogen to the unit price of corn. Taking the 1957 equation for continuous corn, assuming nitrogen to cost $0.10 per pound and corn valued at $1 per bushel, and remembering that the nitrogen unit is 40 pounds, leads to

$$\partial Y/\partial N = 19.26 - 5.84N = \$4/\$1 = 4$$

$$N = 2.61 \text{ units or } 104 \text{ pounds per acre.}$$

It should be noted that the optimum rate of N is independent of the PK application. Since the PK treatment gives a response of 12.02 bushels per acre in this case, it is profitable and would be applied. The PK treatment was not profitable in 1954 and should not have been applied. Since the PK treatment is applied each year, the decision regarding its use should be based on its average effect, which has not been as great as its cost—about $9 per acre per year.

In cases where the NxPK interaction is present, the first partial derivative of yield with respect to nitrogen contains a PK term, and the optimum rate is not independent of the PK applied. Taking the 1958 equation for the new continuous corn,

$$\partial Y/\partial N = 15.23 - 5.62N + 4.83PK = 4.$$

This cannot be solved for a unique rate of N, because N may be 2.00 units (80 lb.) per acre or 2.86 units (114 lb.) per acre, depending upon whether PK is or is not applied.

Since the N rate depends upon the PK, some determination must be made concerning the use of PK. Because of the nature of the experiment and, therefore, the PK term, the only decision that can be made is to apply P and K at the experimental rate or not at all. The PK unit should be applied if its total effect is profitable, and this effect is profitable if the first partial derivative of yield with respect to the PK unit is greater than the price ratio of this unit to a unit of corn. The unit of PK costs $9, and corn is worth $1 per bushel. Therefore, from the equation for 1958,

$$\partial Y/\partial (PK) = 2.56 + 4.83N = 9$$

$$N = 1.33 \text{ units or } 53 \text{ pounds.}$$

Hence, the PK unit can be applied profitably only if the rate of N applied exceeds 53 pounds per acre. In the case of 1958, it would be applied. It should be remembered that the PK treatment is applied each year and that results for a single year cannot be interpreted directly for making recommendations. Neither can a most profitable level of PK, if indeed one exists, be deduced from these data.

Average response equations for 2 or more years can be obtained by taking arithmetic averages of the coefficients of respective terms. The statistical significance of the coefficients in the resulting mean response equation is not readily determined without additional analyses.

Effect of fertilization on nutrient status of soil under continuous corn

It would be expected the continued addition of ammonium nitrate would increase the soil's acidity and lower the pH value. Thus far, however, there has been no appreciable change in pH resulting from the annual additions of 40, 80 and 160 pounds of N in the form of ammonium nitrate in either of these continuous corn experiments (table 13). The pH values from soil samples taken in 1958 from the plots having had higher nitrogen applications were slightly lower than samples taken in 1953. These decreases were more persistent as the amounts of ammonium nitrate were increased, especially with the old continuous corn. Although some of these values were raised slightly in 1962 as compared with 1958, they were still generally lower than in 1950. This was particularly true where the rates of N were the highest. It is believed these slow changes in pH values do indicate a trend, even though the results thus far are not statistically significant.

The buffer capacity of these soils is known to be high, and the addition of large amounts of organic matter as a result of greater plant growth because of high nitrogen fertilization could have increased the exchange capacity of these soils somewhat. The net effect, however, has been one of maintaining pH levels, even though large

Table 13. Effect of fertilization on surface soil pH.[a] Continuous corn experiments. Iowa State University Agronomy Farm.

Pounds of nutrients per acre			Old continuous corn					New continuous corn				
			Plot No.	pH values				Plot No.	pH values			
N	P	K		1950	1953	1958	1962		1950	1953	1958	1962
0	0	0	906-1	6.1	6.2	6.4	6.4	830-5	6.1	6.0	6.2	6.3
			907-7	6.0	5.8	6.0	6.1	831-1	6.5	6.3	6.4	6.5
			908-3	6.6	6.6	6.6	6.7	832-7	6.5	6.5	6.6	6.6
			909-8	6.4	6.0	6.2	6.3	833-1	6.5	6.0	6.4	6.5
40	0	0	906-8	6.0	5.8	6.0	6.1	830-3	6.2	6.2	6.0	6.2
			907-3	6.4	6.4	6.4	6.5	831-6	6.5	6.6	6.6	6.7
			908-6	6.6	6.4	6.3	6.5	832-3	6.6	6.5	6.5	6.6
			909-4	6.6	6.5	6.5	6.6	833-8	6.5	6.0	6.4	6.6
80	0	0	906-5	6.5	6.5	6.6	6.5	830-6	6.1	6.3	6.0	6.1
			907-5	6.2	6.2	6.0	6.1	831-5	6.5	6.6	6.5	6.6
			908-5	6.6	6.7	6.4	6.5	832-8	6.5	6.3	6.3	6.5
			909-5	6.5	6.4	6.4	6.4	833-5	6.5	6.2	6.4	6.5
160	0	0	906-4	6.2	6.2	6.1	6.1	830-2	6.2	6.1	5.8	6.1
			907-1	6.3	6.3	6.0	6.2	831-4	6.6	6.6	6.2	6.4
			908-2	7.0	7.0	6.6	6.5	832-2	6.5	6.4	6.2	6.3
			909-2	6.6	6.6	6.2	6.2	833-2	6.5	6.4	6.2	6.3
0	26	50	906-6	6.5	6.1	6.2	6.3	830-1	6.2	6.0	6.1	6.2
			907-2	6.3	6.2	6.4	6.6	831-7	6.5	6.6	6.5	6.6
			908-8	6.6	6.2	6.3	6.4	832-4	6.6	6.5	6.6	6.6
			909-3	6.6	6.4	6.5	6.6	833-7	6.5	6.5	6.5	6.6
40	26	50	906-2	6.1	5.9	6.0	6.2	830-8	6.0	6.1	6.0	6.2
			907-8	6.0	5.9	6.0	6.1	831-3	6.6	6.6	6.4	6.6
			908-1	7.0	7.0	7.0	7.0	832-5	6.5	6.4	6.4	6.5
			909-6	6.5	6.4	6.2	6.3	833-4	6.6	6.5	6.5	6.5
80	26	50	906-3	6.2	6.0	6.0	6.0	830-4	6.2	6.0	6.0	6.2
			907-4	6.4	6.2	6.0	6.3	831-2	6.5	6.6	6.4	6.4
			908-4	6.6	6.6	6.4	6.5	832-1	6.5	6.2	6.2	6.2
			909-1	6.6	6.7	6.4	6.5	833-3	6.6	6.0	6.4	6.5
160	26	50	906-7	6.0	5.9	5.7	5.8	830-7	6.0	6.2	5.8	6.0
			907-6	6.2	5.8	5.8	5.9	831-8	6.5	6.5	6.2	6.2
			908-7	6.4	6.4	6.0	6.0	832-6	6.5	6.4	6.4	6.3
			909-7	6.4	6.2	6.0	6.0	833-6	6.5	6.2	6.2	6.3

[a]Measured in 1:2 soil:water ratio.

amounts of ammonium nitrate were added. These soils also have free calcium carbonate within the normal rooting zone of corn, and the vigorous growth of this crop may help to replenish the surface soil with calcium, since the stover is not removed.

Soil tests for soluble P reveal the influence of fertilizer treatments as shown in table 14. Soluble P was low in 1950 in all soil samples taken from plots that had not received rock phosphate or manure in former years. These were plots 906, 909 and 832. These values continued low through 1962 where no additional treatments were made. Soluble P continued high through 1953 on all manured and rock phosphated plots in the old 3-year rotation and continued fairly high in the old continuous corn. By 1958 there was an apparent downward trend on all plots not receiving P. The analyses for 1962, however, indicate a slight increase in soluble P on most of these plots. These small variations may be due to seasonal sampling differences, to differences in the treatment of the samples before analysis in the laboratory or to minor changes in the laboratory techniques.

The amount of soluble P was increased markedly over the 10-year period by the use of P. The total amount of P added over 10 years was 260 pounds. Statistical analyses of the 1958 and 1962 results indicated that increases in soluble P were highly significant where P had been applied. This was true for both years on both experiments. The increase was generally large enough to mask the influence on soluble P of the former manure and rock phosphate treatments. There appeared to be little difference in soluble P in 1950 between plots treated similarly in the old continuous corn and 3-year rotation blocks. However, the use of P resulted in a higher amount of soluble P in the new continuous corn plots than in the old. This may have been because of soil differences. The Webster silty clay loam on the new continuous corn is a much finer textured soil with a higher content of organic matter than the Nicollet silt loam.

The soluble P on plots receiving P was high on all plots in 1962 although there was some variation. The amounts ranged from 8.0 to 25.5 pounds per acre on the old continuous corn and from 17.5 to 35 pounds per acre on the new continuous corn. Calculated as an average according to treatment, the amount of soluble P was as much as 180 percent greater on the old continuous corn in 1962 as compared with 1950. On a comparable basis, the soluble P was as much as 602 percent greater in 1962 as compared with 1950 in the new continuous corn.

The results from tests for exchangeable K are given in table 15. Past treatments of manure seemed to have had no influence on the amount of exchangeable K in the soil from either experiment according to tests on dry soils all years tested. There was a relationship with respect to the amounts of exchangeable K among the plots, however, that seemed to persist during the life of the experiments. The amounts on Plot 909 (old plot No. 909) were consistently low while those on plot 906 were consistently high. Plot 906 was formerly a check plot while 909 received lime. The two manured plots, 907 and 908, were generally intermediate. Similarly, the exchangeable K was consistently low on plot 830, which had formerly received manure treatments, and was consistently high on plot 833, which had had no manure. It is believed these latter differences may be due to soil variation.

Tests made on dried soil representing samples taken

Table 14. Effect of fertilization on soluble phosphorus[a] in surface soil. Continuous corn experiments. Iowa State University Agronomy Farm.

Pounds of nutrients per acre			Old continuous corn					New continuous corn				
			Plot No.	Pounds soluble P per acre				Plot No.	Pounds soluble P per acre			
N	P	K		1950	1953	1958	1962		1950	1953	1958	1962
0	0	0	906-1	2.75	5.0	1.00	1.75	830-5	4.00	10.00	2.25	3.50
			907-7	5.00	8.5	2.75	3.75	831-1	6.75	9.00	6.00	9.00
			908-3	12.50	14.0	4.50	7.00	832-7	2.50	7.00	3.75	3.75
			909-8	3.25	4.5	2.00	2.00	833-1	5.75	10.50	4.00	7.75
			Av.	5.88	8.00	2.56	3.62	Av.	4.75	9.12	4.00	6.00
40	0	0	906-8	3.50	10.0	2.00	2.50	830-3	3.75	6.0	2.25	2.75
			907-3	9.25	16.0	3.50	8.50	831-6	4.00	8.0	3.75	3.75
			908-6	8.25	10.0	1.75	2.00	832-3	2.25	10.0	3.25	3.75
			909-4	2.75	6.0	1.75	1.00	833-8	3.25	6.0	2.00	4.75
			Av.	5.94	10.50	2.25	3.50	Av.	3.31	7.50	2.81	3.75
80	0	0	906-5	4.00	10.0	3.50	4.50	830-6	4.00	10.0	3.00	3.50
			907-5	7.25	10.5	2.75	4.00	831-5	4.00	10.0	3.00	5.00
			908-5	8.25	9.0	2.25	1.75	832-8	2.50	7.5	2.25	2.75
			909-5	2.25	6.0	1.00	1.00	833-5	3.75	10.0	3.50	6.75
			Av.	5.44	8.89	2.38	2.81	Av.	3.56	9.38	2.94	4.50
160	0	0	906-4	4.25	8.5	1.50	2.50	830-2	3.75	9.0	2.75	3.50
			907-1	10.00	15.0	3.00	2.25	831-4	4.25	10.5	3.25	7.50
			908-2	14.50	15.0	5.00	3.75	832-2	3.75	7.0	3.25	6.00
			909-2	6.00	7.0	1.75	1.50	833-2	5.75	10.5	5.50	8.50
			Av.	8.69	11.38	2.81	2.50	Av.	4.38	9.25	3.69	6.38
0	26	50	906-6	4.00	8.5	7.00	17.50	830-1	3.75	8.5	10.50	19.00
			907-2	10.00	17.0	3.50	23.50	831-7	5.00	10.5	12.75	34.00
			908-8	8.25	6.0	9.75	15.00	832-4	2.25	6.0	14.00	26.00
			909-3	2.75	6.5	8.00	13.00	833-7	3.25	7.0	12.50	21.00
			Av.	6.25	9.50	7.06	17.25	Av.	3.56	8.00	12.44	25.00
40	26	50	906-2	2.75	6.0	7.50	12.50	830-8	3.50	7.5	11.75	28.50
			907-8	5.00	7.0	8.75	17.25	831-3	4.25	9.0	10.25	30.50
			908-1	14.50	18.0	14.50	25.50	832-5	2.75	7.5	12.00	22.50
			909-6	2.25	4.5	6.75	9.00	833-4	3.25	4.0	13.50	30.00
			Av.	6.12	8.88	9.38	16.06	Av.	3.44	7.00	11.87	27.88
80	26	50	906-3	4.25	11.0	7.75	19.50	830-4	3.75	7.5	7.00	18.00
			907-4	9.25	15.0	13.00	16.75	831-2	6.75	12.0	16.00	35.00
			908-4	12.50	12.0	12.00	17.50	832-1	3.75	10.0	14.00	18.50
			909-1	6.00	12.0	10.00	15.00	833-3	3.25	8.5	17.50	28.00
			Av.	8.00	12.50	10.69	17.19	Av.	4.38	9.50	13.62	24.88
160	26	50	906-7	3.50	10.0	7.00	12.00	830-7	3.50	10.0	10.50	17.50
			907-6	7.25	8.5	10.00	14.00	831-8	5.00	8.0	13.00	33.00
			908-7	5.75	10.0	6.50	9.50	832-6	2.75	7.5	12.00	27.00
			909-7	3.25	7.0	6.00	8.00	833-6	3.75	8.5	10.00	17.75
			Av.	4.94	8.88	7.38	10.88	Av.	3.75	8.50	11.38	23.81

[a]Bray No. 1 dilute acid extractable (0.03 N N_4HF in 0.025 N HCL).

in 1958 and 1962 indicated very slight increases in exchangeable K, even when from plots fertilized with K. However, when tests were run on the same soil samples, but in field-moist or undried condition, considerably more exchangeable K was found in soil fertilized with K than where no fertilizer had been used, although all total quantities were lower than with the air-dried soil. The differences of exchangeable K in favor of the K fertilizer applications, although not great, are consistent and apparently real since they are statistically significant at the 1-percent level for both experiments in 1962 and for the old continuous corn in 1958. Significance was at the 5-percent level for the new continuous corn in 1958.

The organic matter content in the soils of these two continuous corn experiments is shown in table 16. No very great differences due to treatment are apparent. The analysis made in 1953 indicates that the percentage of organic matter was lower in the old continuous corn experiment than in the new. Part of the difference was probably due to the original differences in the soils in these two blocks—the Webster originally having had a higher content of organic matter than the Nicollet. The rest of the difference could be due to the past cropping of the two areas. No marked change is apparent between 1953 and 1958 as a result of differential growth of corn following fertilizer treatment, and treatment effects on organic matter content are not statistically significant. A trend should be noted, however, in that the lower organic matter content in the old continuous corn plots was slightly increased during the 1953-58 period almost without exception, while the higher content in the new continuous corn plots was slightly reduced.

THE INFLUENCE OF FERTILIZER AND SOIL FERTILITY ON THE TIME OF SILKING

The growth of corn normally follows a rather fixed pattern for both vegetative and fruiting periods. Silking of a midseason hybrid in Iowa, for instance, usually occurs about 60 to 65 days after planting. The date of silking, however, may be delayed considerably by low soil fertility but may be advanced in a field of low fertility by increasing the supply of nutrients available to the plant. Other factors, such as available moisture and temperature, of course, also are operative in regulating the growth and development of the corn plant.

The time interval between planting and the date when 75 percent of the plants in these continuous corn experiments were silked is given in table 17 for 1953 and 1955. The earliness of the silking date appears to be related to yield response, and the influence of soil fertility and fertilizer application seems evident. Silking was as much as a week later on low fertility plots as compared with well-fertilized plots in the old continuous corn plots. This effect was highly significant.

An examination of the data from the old continuous corn block given in table 17 and Appendix table A-3

Table 15. Effect of fertilization on exchangeable potassium in surface soil. Continuous corn experiments. Iowa State University Agronomy Farm.

Pounds of nutrients per acre			Old continuous corn							New continuous corn						
				Pounds exchangeable K per acre[a]							Pounds exchangeable K per acre[a]					
			Plot	Dry				Wet		Plot	Dry				Wet	
N	P	K	No.	1950	1953	1958	1962	1958	1962	No.	1950	1953	1958	1962	1958	1962
0	0	0	906-1	196	196	160	181	84	98	830-5	222	192	176	196	60	60
			907-7	188	196	156	196	82	87	831-1	262	180	196	202	74	60
			908-3	200	200	178	188	90	86	832-7	240	200	188	216	52	57
			909-8	154	160	142	150	80	84	833-1	272	188	208	204	60	73
			Av.	184	188	159	179	84	89	Av.	249	190	192	204	62	62
40	0	0	906-8	214	188	166	188	96	96	830-3	228	172	176	186	60	61
			907-3	216	252	168	184	78	85	831-6	272	184	176	214	64	49
			908-6	160	164	152	160	86	78	832-3	278	184	222	284	72	57
			909-4	166	156	128	144	70	60	833-8	242	180	184	250	46	81
			Av.	189	190	154	169	82	80	Av.	255	180	190	234	60	62
80	0	0	906-5	206	216	162	214	66	73	830-6	222	172	166	192	56	60
			907-5	186	200	152	184	88	90	831-5	272	220	176	212	58	67
			908-5	160	164	130	138	62	70	832-8	240	172	174	204	50	66
			909-5	132	164	118	130	60	54	833-5	258	176	180	222	48	51
			Av.	171	186	140	166	69	72	Av.	248	185	174	208	53	61
160	0	0	906-4	216	220	164	196	74	90	830-2	228	180	172	186	62	67
			907-1	202	220	166	164	74	86	831-4	256	200	190	206	60	53
			908-2	236	240	180	180	82	84	832-2	258	176		196	64	52
			909-2	166	176	136	142	74	70	833-2	272	208	180	236	50	61
			Av.	205	214	162	170	76	82	Av.	254	191	180	206	59	58
0	26	50	906-6	206	192	174	222	120	88	830-1	228	172	180	214	100	121
			907-2	202	208	166	192	78	114	831-7	248	184	172	255	68	59
			908-8	160	168	164	214	118	88	832-4	278	216	212	312	68	89
			909-3	166	164	160	162	110	105	833-7	242	200	210	238	60	97
			Av.	183	183	166	198	106	99	Av.	249	193	194	260	74	92
40	26	50	906-2	196	204	186	200	118	106	830-8	214	188	176	202	88	85
			907-8	188	172	174	190	122	135	831-3	256	192	214	236	78	65
			908-1	236	260	204	218	126	124	832-5	272	192	212	272	62	83
			909-6	132	152	152	186	106	152	833-4	236	200	196	236	58	80
			Av.	188	197	179	198	118	129	Av.	244	193	200	236	72	78
80	26	50	906-3	216	204	184	224	114	122	830-4	228	188	192	202	72	86
			907-4	216	224	198	242	136	126	831-2	262	180	214	232	72	77
			908-4	200	192	176	194	130	106	832-1	258	168		206	78	87
			909-1	166	204	172	192	116	115	833-3	236	180	196	256	60	79
			Av.	200	206	182	213	124	117	Av.	246	179	201	224	70	82
160	26	50	906-7	214	184	182	186	126	124	830-7	214	180	182	184	84	89
			907-6	186	196	164	156	116	104	831-8	248	200	188	224	76	85
			908-7	186	200	166	156	138	104	832-6	272	176	196	262	60	92
			909-7	154	168	150	140	94	90	833-6	258	176	190	248	64	85
			Av.	185	187	166	160	118	106	Av.	248	183	189	230	71	88

[a]Determinations on basis of extraction after air-drying all years and before drying (field-moist), 1958 and 1962.

Table 16. Effect of fertilization on the percentage of organic matter in surface soil. Continuous corn experiments. Iowa State University Agronomy Farm.

Pounds of nutrients per acre			Old continuous corn					New continuous corn				
			Plot	Percent organic matter				Plot	Percent organic matter			
N	P	K	No.	1953	Av.	1958	Av.	No.	1953	Av.	1958	Av.
0	0	0	906-1	3.04		2.80		830-5	5.83		5.49	
			907-7	3.17		3.12		831-1	5.36		5.98	
			908-3	3.42		3.59		832-7	6.77		6.67	
			909-8	2.82	3.11	2.65	3.04	833-1	7.43	6.35	7.13	6.31
40	0	0	906-8	3.36		3.29		830-3	5.78		5.02	
			907-3	3.76		3.84		831-6	6.67		6.58	
			908-6	2.30		2.79		832-3	6.91		6.66	
			909-4	2.41	2.96	2.32	3.06	833-8	4.98	6.08	5.69	5.99
80	0	0	906-5	3.49		3.44		830-6	5.97		5.32	
			907-5	3.18		3.36		831-5	7.33		6.40	
			908-5	2.18		2.74		832-8	6.86		6.40	
			909-5	1.97	2.70	2.21	2.94	833-5	6.67	6.71	6.50	6.16
160	0	0	906-4	3.13		3.21		830-2	5.73		5.07	
			907-1	3.43		3.68		831-4	6.72		6.10	
			908-2	4.06		3.94		832-2	6.96		6.98	
			909-2	3.06	3.42	3.15	3.50	833-2	7.38	6.70	7.34	6.37
0	26	50	906-6	2.58		2.74		830-1	4.75		5.01	
			907-2	3.56		3.69		831-7	6.49		6.44	
			908-8	3.09		2.92		832-4	7.00		6.47	
			909-3	2.72	2.99	3.14	3.12	833-7	5.26	5.88	5.93	5.96
40	26	50	906-2	3.00		2.82		830-8	5.59		5.04	
			907-8	2.98		3.08		831-3	6.44		6.10	
			908-1	3.69		3.76		832-5	6.91		6.88	
			909-6	2.30	2.99	2.54	3.05	833-4	7.10	6.51	6.34	6.09
80	26	50	906-3	3.16		3.04		830-4	5.92		5.41	
			907-4	3.52		3.70		831-2	6.49		6.01	
			908-4	2.62		3.14		832-1	6.20		6.34	
			909-1	3.65	3.24	3.07	3.24	833-3	7.33	6.48	7.04	6.20
160	26	50	906-7	3.29		3.27		830-7	6.11		5.98	
			907-6	2.68		2.89		831-8	6.06		5.87	
			908-7	3.21		3.10		832-6	6.97		6.73	
			909-7	2.67	2.96	2.88	3.04	833-6	6.20	6.34	6.09	6.17

Table 17. Effect of fertilization on the number of days from planting until 75 percent of the plants were silked. Continuous corn experiments. Iowa State University Agronomy Farm.

Pounds of nutrients per acre			Days from planting to 75 percent silked[a]			
			Old continuous corn		New continuous corn	
N	P	K	1953	1955	1953	1955
0	0	0	75	84	78	78
40	0	0	70	80	76	78
80	0	0	70	80	78	78
160	0	0	70	80	78	78
0	26	50	77	86	77	78
40	26	50	70	80	76	77
80	26	50	69	79	75	76
160	26	60	70	78	75	76

[a]Corn was planted May 26 in 1953, May 5 in 1955.

shows corn consistently silked earlier when fertilized with N, either with or without P and K. This difference was as much as 11 days and tended to be greatest in favor of the higher rates of N. The silking date was generally delayed, however, when P and K were used without N. This delay was as much as 10 days although the average for all blocks, all years, was only 2 days because of the reverse in block 909 in 1955 (table A-3). The application of N reversed this trend when applied with P and K. Seventy-five percent silking was as much as 11 days earlier and averaged 8 days when larger amounts of N were used with P and K as compared with silking when nitrogen was not present with the other two nutrients. These differences were highly significant.

The influence of N, P and K on silking dates was not apparent in the new continuous corn experiment (the old 3-year rotation block) as shown in table 17 and Appendix table A-4. This is probably because of the higher fertility levels already present in this more fertile soil and a better balanced nutrient status. In this case, silking dates were generally not earlier when N only was applied, and the yields were not increased from N fertilization in the absence of P and K in 1953 and 1955. P and K, when used without N, had no appreciable effect on silking dates. Silking was generally several days earlier where all three nutrients were applied. This was especially true with the higher amounts of N and is explained by a better balanced and higher plane of fertility, allowing the corn to progress as rapidly as its potentialities and other environmental factors would permit. These effects of the N, P and K combination on silking dates were significant at the 1-percent level in 1955 but significant only at about the 6-percent level in 1953.

SUMMARY

Corn yields taken on continuous corn and 3-year rotation blocks of a rotation experiment on the Iowa State University Agronomy Farm from 1915 through 1953 show considerable variation in yield. These variations undoubtedly are due to weather fluctuation. However, a downward trend in yields seemed to exist from 1915 to 1936. The introduction of hybrid corn in 1937 increased corn yields somewhat.

Following the rise in corn yields resulting from the introduction of hybrid corn, there was a further downward trend on the continuous corn block after 1938. In the 3-year rotation block, however, there was only a slight downward trend after 1938, followed by a slight rise through 1952.

Increased corn yields were obtained from manure and manure plus lime over no treatment, both with continuous corn and with corn in a 3-year rotation. Corn yields were considerably higher in the 3-year rotation as compared with continuous corn.

Original treatments on the two blocks were discontinued in 1952, and new treatments, including four levels of N with and without P and K fertilizer applied annually, were superimposed on subplots of the original plots beginning in 1953. Effects of the former manure and lime treatments persisted somewhat, especially on the areas without added N in the old continuous corn block.

The addition of N increased yields consistently and progressively through all levels of N on the old continuous corn plots. The range in increase in recent years was as great as, if not greater than, at the start of the experiment.

The addition of phosphorus and potassium did not increase corn yields on the old continuous corn with N during the first years of the experiments. Increasing yield responses to P and K when used with N occurred in later years, however. The NxPK interaction, on the other hand, was significant only in 1960 and 1962.

Yields of corn obtained in the old continuous corn experiment were increased to high levels with large amounts of N and moderate levels of P and K. The data indicate that continuous corn can be grown successfully on soils of low fertility if an adequate fertilizer program is followed.

Fertility treatments applied to the 3-year rotation block prior to 1953 seemed to have some influence on yields in subsequent years. Most persistent yield increases were from the earlier manure and rock phosphate treatments.

Corn yields were not increased from N during the first five years of continuous corn on the former 3-year rotation block, but were obtained after 1958. When used without P and K, the greatest response to N per increment of N was from applications at the rate of 80 pounds per acre.

Yield responses to P and K without N occurred only in the first years of the experiment while, with N, they were substantial and highly significant most years. Responses were not significant in 1959 and 1960 but were again in 1961 and 1962. However, the interaction between N and PK was significant in all years except 1955, indicating that all three plant nutrients are necessary for best corn yields under the soil and fertility conditions in this experiment.

These data indicate that high corn yields on fertile soils can be maintained under continuous corn only when there is an adequate program of fertilizing with N, P and K in balanced amounts.

Yield equations expressing the expected yield as a function of the fertilizer variables are given as a basis for recommendations for optimum fertilization of corn in these continuous corn experiments. Major treatment effects included were those of N, PK and NxPK.

The addition of large amounts of ammonium nitrate for a period of 10 years did not significantly lower the pH value of the soil.

The amount of soluble soil P was increased significantly by the addition of phosphorus fertilizer in these experiments. The amount of exchangeable K in the surface soil also was increased by the use of potassium fertilizer.

There were no apparent differences in organic matter resulting from the several fertilizer treatments.

The time interval between planting and the date when 75 percent of the plants were silked was observed in these experiments. In the old continuous corn plot, silking occurred earlier on corn fertilized with N either with or without P and K than when not fertilized. The silking date, however, was delayed when P and K were used without N. In the former 3-year rotation block, however, the silking date was earlier only when all three nutrients were used.

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APPENDIX

Table A-1. Yield of corn per acre from new fertilizer treatments. Old continuous corn block. Iowa State University Agronomy Farm.

Year	Block[a]	N_0	N_1	N_2	N_4	N_0PK	N_1PK	N_2PK	N_4PK	Av.
		Corn yield in bushels per acre for indicated new treatment								
1953	906	32.1	60.3	61.5	63.1	37.5	43.9	76.2	75.5	56.3
	907	35.2	60.8	60.4	71.7	32.1	52.9	62.6	68.4	55.5
	908	45.9	55.3	63.0	75.6	30.5	72.6	75.5	76.5	61.9
	909	21.4	59.0	57.0	68.7	37.1	57.9	71.6	73.3	55.8
1954	906	34.6	58.8	79.4	80.5	40.5	60.9	70.6	77.7	62.9
	907	57.3	71.8	78.5	80.2	53.0	52.6	69.3	83.5	68.3
	908	60.8	74.9	92.8	81.4	43.2	81.2	88.8	89.1	76.5
	909	30.8	76.6	65.7	75.0	41.6	61.2	87.8	85.2	65.5
1955	906	31.5	80.7	93.4	106.7	51.3	56.9	80.9	107.8	76.2
	907	52.7	71.4	82.8	77.7	49.2	66.7	90.1	101.3	74.0
	908	64.6	80.5	96.0	91.2	35.7	96.5	96.4	106.7	83.4
	909	27.2	76.5	79.5	81.3	46.3	70.5	87.6	85.1	69.2
1956	906	19.0	34.9	5.5	12.7	9.5	15.5	9.2	30.4	17.1
	907	21.1	0.2	0.8	18.2	2.3	37.7	0.3	2.8	10.4
	908	10.5	4.9	2.8	3.3	25.1	18.5	0.7	13.6	9.9
	909	25.2	21.4	12.4	10.7	20.0	25.5	23.7	12.2	18.9
1957	906	57.7	82.7	105.8	108.5	108.6	96.0	114.5	110.6	98.0
	907	78.5	109.2	102.0	109.4	104.9	84.2	116.9	118.2	102.9
	908	103.3	102.0	103.1	109.5	64.7	115.3	120.1	117.4	104.4
	909	50.7	91.7	83.7	98.0	79.1	103.9	115.0	120.3	92.8
1958	906	42.7	73.3	110.7	119.6	48.8	55.9	107.0	126.1	85.5
	907	44.8	95.6	120.0	129.3	51.7	67.2	125.8	136.4	96.4
	908	58.7	86.9	118.5	130.4	41.2	103.7	126.0	138.5	100.5
	909	29.2	84.4	87.7	119.0	45.1	78.1	115.2	139.9	87.3
1959	906	19.6	44.5	70.0	97.6	42.6	31.8	79.5	100.1	60.7
	907	44.7	53.2	88.9	112.2	33.8	44.5	95.1	120.0	74.0
	908	33.2	59.8	95.9	113.0	29.2	73.3	93.3	123.5	77.6
	909	20.1	56.0	78.6	98.3	26.6	47.4	84.5	125.7	67.2
1960	906	24.0	52.5	90.2	90.5	30.0	38.1	76.1	106.3	63.5
	907	28.9	67.3	84.2	102.6	27.4	57.5	82.6	109.9	70.0
	908	39.4	55.6	74.1	101.2	35.5	81.5	86.4	106.0	72.5
	909	21.9	50.3	58.0	87.5	26.9	51.7	98.8	103.0	62.3
1961	906	30.4	58.4	102.8	113.1	38.2	38.1	94.9	129.0	75.6
	907	16.9	76.7	90.3	125.7	34.4	41.6	104.3	130.5	77.6
	908	49.7	63.6	94.0	136.6	21.9	85.6	102.0	137.5	86.4
	909	13.6	45.6	72.9	110.2	21.5	47.6	114.5	131.2	67.1
1962	906	29.0	60.2	107.8	107.9	26.3	38.0	94.2	130.7	74.3
	907	29.3	67.8	95.2	104.5	36.8	62.2	97.8	140.7	78.0
	908	41.4	67.6	106.6	125.0	24.7	86.5	92.3	131.5	84.4
	909	28.9	64.3	74.8	101.4	20.5	64.9	100.5	148.1	75.4

[a]Block numbers are "old" plot numbers; "old" treatments were: 906, control; 907, manure; 908, manure, lime; 909, lime.

Table A-2. Yield of corn in bushels per acre from new fertilizer treatment. Continuous corn on old 3-year rotation block. Iowa State University Agronomy Farm.

		Corn yield in bushels per acre for indicated new treatment								
Year	Block[a]	N_0	N_1	N_2	N_4	N_0PK	N_1PK	N_2PK	N_4PK	Av.
1953	830	104.2	99.6	97.3	95.2	107.2	104.8	102.7	102.8	101.7
	831	100.4	102.4	100.2	101.2	113.9	101.2	106.0	111.8	104.6
	832	75.1	79.5	84.2	76.3	89.4	89.6	100.4	99.6	86.8
	833	94.7	87.9	80.4	80.6	90.7	94.3	100.6	110.5	92.5
1954	830	86.7	81.1	85.1	87.8	94.4	72.2	83.8	81.2	84.0
	831	94.8	83.9	82.8	89.0	84.0	92.0	102.1	90.9	89.9
	832	69.7	80.1	74.2	87.8	88.2	93.6	89.9	81.6	83.1
	833	78.3	72.2	75.4	80.7	81.0	88.3	94.7	86.1	83.3
1955	830	85.1	87.3	82.8	84.1	103.6	73.7	87.7	86.6	86.4
	831	98.6	71.1	68.2	84.9	94.5	101.2	98.0	100.8	89.7
	832	99.3	89.4	93.3	103.4	88.0	97.0	113.3	112.0	98.3
	833	104.0	87.7	113.8	100.3	98.2	120.2	100.0	114.3	104.8
1956	830	3.6	14.2	2.3	26.6	39.9	0.1	6.5	0.2	11.7
	831	45.3	2.3	17.3	24.7	1.2	45.4	67.8	2.2	25.8
	832	5.6	31.4	0.6	52.4	35.2	7.2	50.9	12.2	24.4
	833	47.2	0.6	19.7	32.4	4.8	36.8	24.6	9.6	22.0
1957	830	99.5	103.0	95.6	103.5	101.9	92.1	113.8	102.7	101.5
	831	110.9	97.5	97.5	97.5	102.2	120.4	115.9	87.9	103.7
	832	93.6	104.5	93.9	97.6	110.8	118.7	116.4	113.0	106.1
	833	96.8	83.0	100.7	98.0	106.8	114.9	122.6	110.3	114.1
1958	830	110.8	118.8	122.6	126.7	109.0	136.3	138.8	134.7	124.7
	831	106.8	116.7	126.5	120.8	111.4	130.0	121.5	130.3	120.5
	832	105.9	106.4	111.8	116.6	89.5	114.5	138.0	136.2	114.9
	833	106.4	101.0	116.7	120.4	80.8	124.9	134.8	142.7	116.0
1959	830	70.9	86.0	98.7	108.2	86.5	86.4	98.4	114.1	93.6
	831	83.5	88.6	101.6	112.9	64.5	104.5	112.0	116.6	98.0
	832	74.6	83.0	102.8	112.5	65.5	88.6	87.4	111.2	90.7
	833	79.5	59.5	106.6	104.1	56.8	86.8	116.7	119.0	91.1
1960	830	56.0	67.9	90.6	94.3	61.4	73.7	86.6	110.6	74.5
	831	71.6	68.4	94.0	101.6	53.2	75.3	99.0	120.0	85.4
	832	69.4	79.7	90.3	93.1	57.3	69.1	97.0	109.1	83.1
	833	86.6	58.1	94.4	104.9	38.6	74.8	95.6	111.5	73.0
1961	830	89.2	103.5	106.8	118.5	118.3	102.2	123.4	134.3	112.0
	831	94.8	96.7	110.5	115.6	62.7	117.2	115.5	145.0	107.2
	832	75.8	96.1	95.3	119.0	55.4	91.1	139.0	139.6	94.3
	833	93.8	65.6	113.2	127.7	39.3	91.9	120.3	137.5	98.7
1962	830	63.6	79.2	91.2	102.6	84.9	90.0	96.8	122.3	91.3
	831	72.8	77.6	86.1	108.3	57.8	90.6	95.2	119.4	88.4
	832	58.8	73.9	90.1	116.2	49.3	67.9	127.4	124.4	88.5
	833	73.1	61.2	111.5	115.6	46.2	100.1	115.3	121.1	93.0

[a]Block numbers are "old" plot numbers; "old" treatments were: 830, manure, lime; 831, manure, lime, rock phosphate; 832, lime; 833, lime, rock phosphate.

Table A-3. Effect of fertilization on the number of days from planting to 75 percent silked. Old continuous corn experiments. Iowa State University Agronomy Farm.[a]

Treatment in pounds per acre:			Days from planting to 75 percent silked in indicated block and year							
			906		907		908		909	
N	P	K	1953	1955	1953	1955	1953	1955	1953	1955
0	0	0	77	88	74	81	75	78	73	88
40	0	0	71	81	71	78	69	78	71	81
80	0	0	69	81	69	78	74	78	70	84
160	0	0	73	81	69	78	69	78	70	81
0	26	50	79	88	77	88	79	88	74	81
40	26	50	71	81	69	81	71	78	69	81
80	26	50	68	81	70	78	72	78	67	78
160	26	50	71	78	69	78	70	78	70	78

[a]Corn was planted on May 26 in 1953 and on May 5 in 1955.

Table A-4. Effect of fertilization on the number of days from planting to 75 percent silked. New continuous corn experiments. Iowa State University Agronomy Farm.[a]

Treatment in pounds per acre:			Days from planting to 75 percent silked in indicated block and year							
			830		831		832		833	
N	P	K	1953	1955	1953	1955	1953	1955	1953	1955
0	0	0	75	79	77	77	79	80	79	77
40	0	0	76	79	75	77	78	77	76	78
80	0	0	76	79	76	78	79	77	79	79
160	0	0	77	79	77	77	81	77	79	77
0	26	50	76	79	76	77	79	77	78	78
40	26	50	77	79	75	76	76	77	76	76
80	26	50	75	77	75	75	76	75	75	78
160	26	50	77	75	73	75	75	76	76	76

[a]Corn was planted on May 13 in 1953 and on May 6 in 1955.