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Howard V. Jordan

Charles E. Bardsley

R. R. Bruce

Joe O. Sanford

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Ten Years' Results in a Nitrogen Fertilizer-Plant Population Experiment With Corn

MISSISSIPPI STATE UNIVERSITY
AGRICULTURAL EXPERIMENT STATION
CLAY LYLE, Director
STATE COLLEGE MISSISSIPPI

TEN YEARS' RESULTS IN A NITROGEN FERTILIZER-PLANT POPULATION EXPERIMENT WITH CORN

By HOWARD V. JORDAN, CHARLES E. BARDSLEY,
R. R. BRUCE and JOE O. SANFORD

Beginning with the early 1940's intensified research in fertilizer and management practices for corn developed new and greatly improved practices, particularly in the southern states. Production factors contributing to these more efficient methods include:

(1) Use of much higher rates of nitrogen.

(2) Application of mineral nutrients when needed. Such need frequently develops or increases when all other factors are optimum.

(3) Higher plant populations which are necessary to utilize the higher fertility levels.

(4) Hybrids adaptd to the area, most of which are prolific.

(5) Supplemental irrigation.

These production factors are highly inter-related, and maximum effectiveness is attained only when all of them are in proper combination.

These production practices have resulted in higher yields and more efficient production throughout the area. As reasonably typical of these trends, average yields of corn in Mississippi are shown in Table 1. While average yields since 1945 reflect the usual fluctuations with season, they have never been so low as the 1935-44 average, and in most years since 1948 they have shown an increase of approximately 50 percent. Supplemental irrigation has not been important among the production practices to date, although the irrigated acreage is increasing. Of the 1,614,000 acres of corn in Mississippi 100,835 acres received supplemental irrigation in 1955 (7).

While the effectiveness of these production methods has been amply demonstrated by field experiments, and while these methods have been rather widely adopted by progressive farmers, the long-time effects of these practices on soil properties have not been systematically studied. A study involving varying nitrogen rates and plant populations was made at State College, Mississippi, and is reported here. Some of these results have been reported earlier (4).

Procedure

The experiment was conducted on an area of Kaufman fine sandy loam, overwash phase. The experiment was begun in 1947 and was continued through 1956. The field has a slope of about 2 percent, and is thus not particularly susceptible to erosion.

The same treatments were superimposed on the same plots each year. The experiment was a 3 x 2 factorial involving three levels of nitrogen (0, 60, 120 pounds per acre) and two plant populations (4000, 12000 plants per acre). For the 60-pound-nitrogen treatments nitrogen from ammonium sulfate was applied at planting time, and for the 120-pound-nitrogen treat-

Table 1. Average yields of corn in Mississippi.

Period	State average yield of corn bu/acre
Average 1935-44	15.3
1945	19.0
1946	16.0
1947	16.5
1948	22.0
1949	20.5
1950	26.5
1951	21.5
1952	16.0
1953	22.0
1954	17.0
1955	30.0
1956	25.0
1957	25.0

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[1] Soil Scientists, Eastern Soil and Water Management Research Branch, Agricultural Research Service, U.S.D.A. in cooperation with the Mississippi Agricultural Experiment Station.

ments 60 pounds was applied as ammonium sulfate at planting time and 60 pounds as ammonium nitrate as sidedressing. Eighty pounds of P_2O_5 and 80 pounds of K_2O were applied to all treatments annually. Except in 1947 when an open-pollinated variety (Laguna) was grown, the experiment was planted in Dixie 17, which is a prolific hybrid. There were four replicates in randomized block arrangement.

In 1947 the soil contained 132 pounds of available (Truog) P_2O_5 per acre in the 0- to 6-inch layer and 103 pounds in the 6- to 12-inch layer. Levels of exchangeable potash were 240 and 184 pounds per acre in the corresponding soil layers.

In the eleventh year (1957) the experiment was planted to corn without any fertilizer to study cumulative effects of the ten years of treatment. Stands in 1957 were maintained at the same levels as in preceding years. The soil was sampled in the winter of 1956-1957 for the study of chemical and physical properties.

All chemical analyses of soil and plant material were made by AOAC methods (1). Bulk density was determined on undisturbed cores (8). Air-filled porosity of undisturbed soil cores was determined at 30 cm and 60 cm of water tension. Water-stable aggregates were determined after wet sieving on 0.25 mm sieve for 2 and 5 minutes respectively (6).

Shading was measured by photographing the shade pattern which corn leaves made on the ground between 9:00 and 9:30 a.m. on a bright July day. The area exposed was a rectangle 36 x 40 inches in area, whose corners were two adjoining hills of corn in each of two adjacent rows. The shaded proportion of the ground area was measured on each photographic print by a planimeter. Incident light was measured with a standard light meter.

Soil temperatures were measured at the 4-inch depth at 9:00 a.m., 11:00 a.m., 2:00 p.m. and 4:00 p.m.; and the average of these readings is termed the daily mean.

Changes in soil moisture were measured by use of Bouyoucos (2) blocks placed at depths of four inches, one foot, two feet, and three feet. Resistance readings were made four times each week during 1947, 1948, and 1949.

Results In First 10-Year Period

Yields

Yields of corn through the first 10-year period, when fertilizers were applied annually, are shown in Table 2. With the 4000-plant stand there was a mean response of 30.7 bushels of corn for the first 60-pound increment of nitrogen, however the second 60-pound increment had little additional effect. With this stand there were not enough plants to utilize nitrogen applications in excess of the 60-pound rate. With the 12000-plant stand each 60-pound increment of nitrogen was very effective. Comparing the no-nitrogen, 4000-plant treatment with the 120-pound-nitrogen, 12000-plant treatment there was a mean response of one bushel of corn for each 1.8 pounds of nitrogen.

The levels of yield fluctuated somewhat with the character of the season, and were particularly low in 1952 and 1954 which were the driest on record at State College. Among years with more favorable distribution of rainfall, yields on the various treatments did not vary widely. The highest yields generally were in the ninth year of the 10-year period, or in 1955.

Ears and Grain

The effects of treatments on some characters of ears and grain are shown in Table 3. Weight per ear, number of ears per plant, and crude protein in the grain were increased with each increment of nitrogen and reduced with the increase in plant population. Comparing the least-intensive with the most-intensive treatment, weight per ear and number of ears per plant were increased moderately while crude protein in the grain was raised by almost two percent. The effects of the treatments on ear size are also shown in Figure 1.

Table 2. Yields of corn in a nitrogen fertilizer-plant population experiment at State College, Mississippi. 1947-1956

Treatment		Acre yields of corn										
Nitrogen	Plants	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	Mean
lbs./acre	no./acre	Bu.	Bu.	Bu.	Bu.	Bu.	Bu.	Bu.	Bu.	Bu.	Bu.	Bu.
0	4000	31.4	29.3	21.2	35.8	25.2	21.8	34.6	38.7	41.8	36.0	31.6
60	4000	54.3	71.4	64.5	68.9	52.4	54.1	58.9	60.9	71.4	66.3	62.3
120	4000	56.0	73.7	67.9	77.3	70.4	49.2	57.8	57.1	68.5	68.2	64.6
0	12000	22.4	36.3	33.7	47.6	30.8	24.1	45.9	42.7	55.2	41.4	38.0
60	12000	61.8	77.6	71.2	90.2	64.8	48.6	74.6	59.6	95.0	72.4	71.6
120	12000	96.2	103.4	100.4	121.8	96.0	68.1	97.4	83.3	125.8	92.1	98.5
Character of growing season					favorable		very dry		dry	very favorable		

Table 5. Yields and nutrients absorbed by corn in a nitrogen fertilizer-plant population experiment. State College, Mississippi—1948

Treatment		Nutrients absorbed by above-ground portion of crop								Corn yield bu/A.
Nitrogen lb/A.	Plants no/A.	Nitrogen lb/A.	Phosphorus lb/A.	Potassium[1] lb/A.	Calcium[1] lb/A.	Sulfur lb/A.	Magnesium lb/A.	Zinc lb/A.	Boron lb/A.	
0	4000	36.6	13.9	27.9	8.3	3.2	5.8	0.3	0.1	29.3
60	4000	80.7	24.1	46.4	15.4	5.8	9.8	0.4	0.1	71.4
120	4000	80.9	20.0	59.2	17.7	4.7	7.8	0.4	0.1	73.7
0	12000	45.0	18.2	47.7	16.3	4.3	8.2	0.4	0.1	36.3
60	12000	87.4	25.4	63.6	29.6	6.7	12.5	0.5	0.1	77.6
120	12000	141.5	36.1	82.5	34.1	8.7	16.5	0.7	0.2	103.4
Percent in grain		70	62	23	6	57	41	51	51	

[1] At early dent stage; the content at maturity was somewhat lower. All other nutrients were measured at maturity.

Table 6. Cumulative effects of 10 years' treatments on corn yields and soil properties.

Treatment (1947-56)		Measurements in eleventh year (1957)							pH of soil after			
		Corn yields	Nitrogen in soil		Organic carbon in soil		Bulk density		1st 6 years		2nd 4 years	
Nitrogen	Plants		0"-6"	6"-12"	0"-6"	6"-12"	0"-3"	3"-6"	0"-6"	6"-12"	0"-6"	6"-12"
lb/A.	no/A.	bu/A	%	%	%	%	gms/cc	gms/cc				
0	4000	24.5	0.06	0.06	0.60	0.65	1.22	1.52	5.8	5.9	6.4	6.4
60	4000	33.0	.06	.07	.67	.68	1.19	1.48	5.5	5.9	6.3	6.4
120	4000	45.5	.06	.06	.80	.73	1.19	1.35	5.2	5.7	6.0	6.1
0	12000	35.2	.06	.06	.71	.70	1.17	1.44	5.8	6.0	6.5	6.3
60	12000	37.6	.08	.07	.70	.70	1.22	1.38	5.5	5.9	6.3	6.2
120	12000	40.8	.06	.06	.68	.63	1.23	1.37	5.3	5.6	6.0	6.1
L.S.D. 5%		8.0	NS	NS	NS	NS	NS	*	0.3	0.3	0.14	NS
1%		11.0							0.4	0.4	0.19	

*Differences between means of nitrogen treatments were significant.

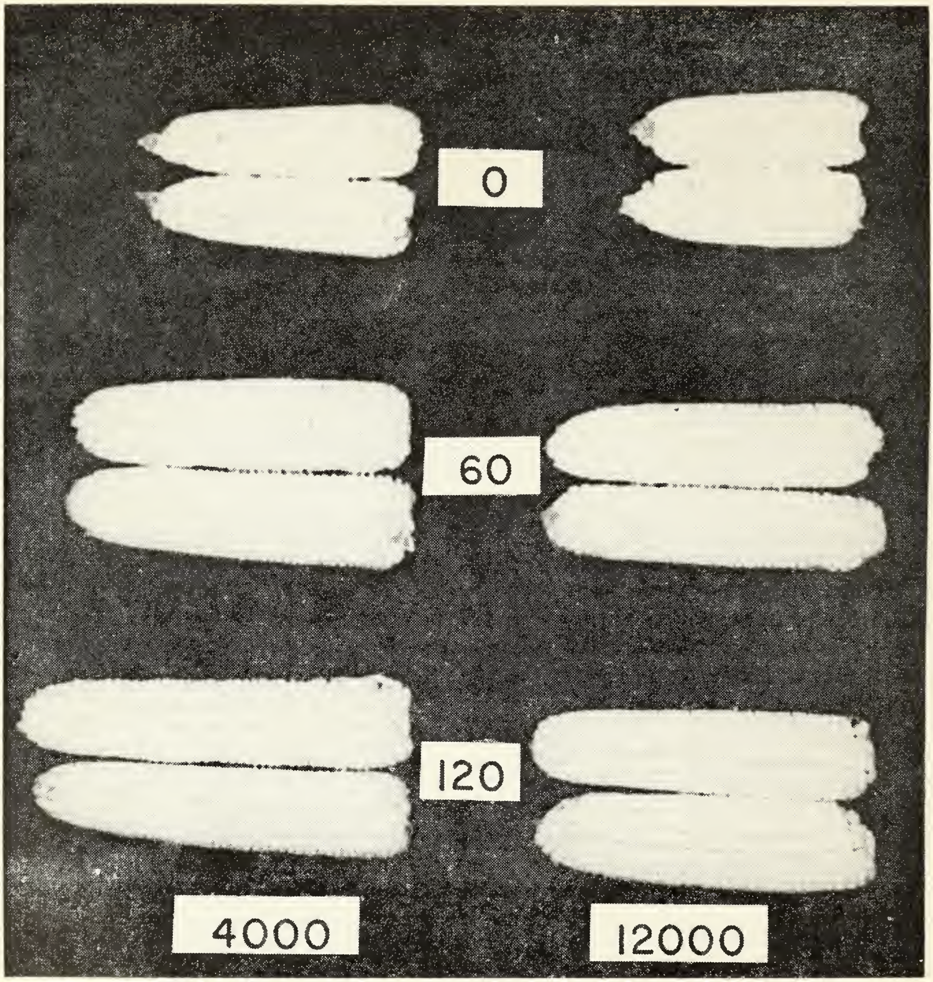

Figure 1. Size of ears as affected by nitrogen rate and plant population. Nitrogen applications of 0, 60 and 120 pounds per acre; plant populations of 4,000 and 12,000 per acre.

Crop Residues

The treatments also had a marked effect on weight and composition of corn stalks which constitute the crop residues for return to the soil (Table 4). Each increase in nitrogen and plant population caused an increase in both weight and nitrogen content of the corn stalks. Compared with the no-nitrogen, 4000-plant treatment, the 120-pound-nitrogen, 12000-plant treatment increased annual crop residues by more than two tons per acre and these residues contained an additional 23.5 pounds of nitrogen. This is probably important in the sustained productivity of soils cropped to corn under a high-fertility system. A view of the least intensive and most intensive treatments in the experiment is shown in Figure 2.

Shading

The amount of sunlight penetrating the vegetative canopy was markedly reduced by the more intensive cropping treatments. Measurements show that the ground area shaded ranged from 24 percent with the no-nitrogen, 4000-plant treatment to 62 per cent with the 120-pound-nitrogen, 12000-plant treatment. Incident light measured at ground level was only one-eighth as intense in shaded as in non-shaded areas.

As a result of the increased shade, weeds and grass were much depressed in the more intensive treatments. This is evident in Figure 2. Growing corn by these methods will eliminate at least one cultivation each year.

Soil Temperature

Accompanying the increased shading, and probably resulting from it, soil temperatures were lower under the more intensive treatments. Measurements at the 4-inch depth on a typical summer day show there was a reduction in daily mean temperature from 88.3° F. under the least intensive treatment of 83.8° F. under the most intensive treatment.

Water Requirements

There were pronounced differences in total water requirements of corn on the various treatments. It has been amply demonstrated that an increase in fertility will lower water requirements **per pound** of dry matter (5), but where increased fertility is accompanied by higher plant populations the water requirement **per acre** may be increased. This was true in this experiment as demonstrated by measurements of soil moisture. In 1948, for example, soil moisture at the 1-foot depth was exhausted by July 1 on the more intensive treatments and not until August 5 on the least intensive treatment. Available soil moisture at the 3-foot depth was exhausted by July 10 on the former treatments, while on the least intensive treatment available soil moisture was maintained at the 3-foot depth throughout the growing season.

The early and complete exhaustion of soil moisture in the surface three feet of soil by the 120-pound-nitrogen, 12000-plant treatment suggested that this treatment was near the upper permissable limit in cropping intensity, although the yield was 103.4 bushels per acre (1948, Table 2). The validity of this conclusion was confirmed in the very dry years of 1952 and 1954 when yields on the same treatment

Table 3. Effects of nitrogen and stand rates on ears and grain.

Treatment		Weight per ear	Ears per plant	Protein in grain (N x 6.25)
Nitrogen	Plants			
lb./A.	no./A.	lb.	no.	%
0	4000	0.40	1.13	8.2
60	4000	.49	2.10	9.8
120	4000	.50	2.13	10.9
0	12000	.22	0.69	7.6
60	12000	.34	1.10	8.7
120	12000	.43	1.28	10.0

Table 4. Dry weights and nitrogen contents of crop residues.

Treatment		Crop residues returned to soil annually	
Nitrogen	Plants	Dry weight	Nitrogen content
lb./A.	no./A.	lb./A.	lb./A.
0	4000	1737	8.6
60	4000	3842	19.3
120	4000	4093	20.1
0	12000	3024	13.0
60	12000	5325	21.6
120	12000	6405	32.1

were reduced to 68.1 and 83.3 bushels per acre respectively.

Growth Rates and Nutrient Uptake

Growth rates and uptake of N, P, and K for each of these treatments were measured in a parallel experiment, and these data have been published (3). Uptake of N, P, K, Ca, Mg, S, Zn, and B were measured in this experiment in 1948, and results are summarized in Table 5. In each case plants were sampled at five stages of growth; namely, knee-high, tassels emerging, roasting ear, early dent, and maturity. The samples were separated into leaves, stems, husks, cobs, and grain, and data obtained for each. Patterns of uptake, translocation, and distribution of nutrients among plant parts were generally the same in the 1948 study as in the published report (3).

It is of interest to compare the nutrients removed by the above-ground parts of a corn crop under the least- and most-intensive cropping systems included in this experiment. This comparison can be made from Table 5. The uptake of nitrogen was approximately quadrupled and that of phosphorus multiplied by 2.6. Further, these nutrients were predominantly removed in harvested grain. Requirements for nitrogen and phosphorus in continuous corn culture are high with this high-fertility treatment. The potassium balance is somewhat more favorable; while uptake was increased to approximately three fold only 23 percent of the potassium was removed in the harvested grain. These increased removals were counter-balanced by heavier rates of fertilization.

Uptake of calcium was approximately four times as great in the high-fertility system as in the low-fertility system, but 94 percent of the calcium was returned to the soil in crop residues. Uptake of sulfur was multiplied by 2.7, and only about 50 percent of the sulfur was localized in vegetative parts. Under good soil management the increased removal of calcium is ordinarily offset by calcium applied as lime and the greater demand for sulfur by that contained in fertilizer materials of ordinary grades or in supplemental applications.

This leaves magnesium, zinc, and boron, of the nutrients here considered, with the least favorable balance. Uptake of these nutrients was doubled or tripled, and about half of that taken up was removed in harvested grain. This might lead to deficiencies of these micronutrients under some soil conditions although none was encountered in this experiment. This was demonstrated on two extra plots which received the most intensive treatment and in addition a mixture of micronutrients including magnesium, zinc, and boron. No advantage was measured for the micronutrients.

Zinc deficiencies in corn occur on some neutral to alkaline soils in the Backlands and locally on some overlimed soils in Mississippi. Such deficiencies would be aggravated by a highly intensive cropping system. The micronutrients can be supplied with fertilizer where needed.

Effects of 10 Years of Treatment

In the eleventh year, when the experiment was planted without further fertilizer, the cumulative effects of past 10-year treatments caused an increase in yield of 16 bushels of corn per acre for the most intensive treatment. Yields are given in Table 6.

In spite of the range in volume and nitrogen content of crop residues returned to the soil each year, no significant differences in soil nitrogen or organic carbon were found in the eleventh year (Table 6). The climate at State College favors rapid decomposition of organic residues, and this probably precluded measurable accumulations in the soil. Nevertheless increased biological activity accompanying decomposition of the larger volume of residues may have contributed to greater

Figure 2. View of two treatments in the experiment, photographed June 30, 1949.

Plot in foreground received no nitrogen and had 4000 plants per acre. The yield was 21.2 bushels.

Plot in background received 120 pounds of nitrogen and had 12000 plants per acre. The yield was 100.4 bushels.

Note weeds and grass in the foreground; these were shaded out by corn in the background.

productivity in the more intensive treatments during the first ten years of the experiment.

The only measured difference in soil physical properties was a reduction in bulk density of the 3- to 6-inch soil (Table 6). Measurements of bulk density of the 0- to 3-inch soil, and air filled pores and water-stable aggregates of either 0- to 3- or 3- to 6-inch soil failed to show consistent differences among treatments.

The reduction in bulk density from 1.52 for the least-intensive to 1.37 for the most-intensive treatment reflects a significant increase in the volume of pores available for air and water movement and probably is a factor of some importance in ease of tillage.

One effect of the treatments was very consistent and pronounced. With each added increment of nitrogen there was a progressive increase in acidity of the surface soil. After 6 years, pH of the surface soil in the 120-pound-nitrogen treatments had reached a near-critical level, and the plots were relimed to a uniform pH 6.3. Following a second 4-year period (end of 10th year) the pH of the 120-pound-nitrogen plots had again declined by about one-half of a pH unit. The data are shown in Table 6.

This decline in pH of the soil resulted from the use of moderate to high rates of acid-forming nitrogen fertilizers and is not specifically associated with continuous cropping to corn. In any cropping system where acid-forming nitrogen materials are applied at rates comparable to those in this experiment, periodic reliming is essential if soils are to remain productive.

Discussion

During the first ten years of this experiment the 120-pound-nitrogen, 12000-plant treatment proved very effective. Compared with the least intensive treatment, which was common when the experiment was begun, there was an increase of 67 bushels of corn per acre, and the grain was almost two percent richer in crude protein. Crop residues were increased by more than two tons per acre, and one less cultivation was required each year. The study in the eleventh year was largely concerned with whether this efficiency had been achieved without exploiting soil resources.

Few reservations need be made. Intensive cropping may aggravate deficiencies of micronutrients on some soils, although it did not do so in this experiment. Continued application of moderate to high rates of acid-forming nitrogen fertilizers increased soil acidity and necessitated periodic liming.

Except for increased acidity, the soil of the most intensively cropped plots was in no measured respect depleted in comparison with the less intensively cropped soil. On the contrary a small, though definite, improvement in bulk density of soil in the plow layer was measured. In the year after fertilizer applications were discontinued cumulative benefits were responsible for a 16-bushel increase in yield.

The data indicate that corn can be grown almost continuously by these high-fertility practices under conditions similar to this experiment. Erosion was not a problem, and the fine sandy loam soil has a single grain structure not readily subject to deterioration. The results may not be applicable to erosive soils or those with unstable structure.

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