VARYING NITROGEN AND SEEDING RATES OF CORN ACROSS PRODUCTIVITY REGIONS IN FIELDS

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Abstract

A field study was conducted from 1999 to 2001 to determine the effects of variable seeding rates and variable nitrogen rates on corn (*Zea mays* L.) in southern Illinois. In whole field experiments, variable seeding rates ranging from 18,000 to 38,000 seeds ac^{-1} in 4,000 seed increments were planted in randomized strips (in a randomized complete block design) across the field that had soils with varying productivity based upon historical yield maps. From the yield data it was determined that the optimum seeding rate was 36,800 and 36,200 seeds ac^{-1} for 2000 and 2001, which had very favorable growing conditions. In 1999, a less favorable year due to dryness, the economic optimum was 26,700 seeds ac^{-1}. When yields were averaged over the three years and new economic optimum seeding rates were recalculated, the predicted economic optimum was 31,500 seeds ac^{-1}, which was about 5,000 seeds ac^{-1} over the customary planting rate in southern Illinois.

Small plot studies were also conducted each year to evaluate N rate and corn seeding rate effects simultaneously across the low, medium, and high productivity environments. In general, it was found that higher N rates were required to achieve optimum economic yields in the low and medium productivity soils than in the high productivity soils. Also, it was clearly demonstrated that in order to utilize all of the applied N to the soil, plant population must be at the upper end of the recommended range for each particular soil. Planting less than the optimum rate runs the risk of unused nitrogen remaining in the soil as a environmental hazard.

Introduction

Agronomists and growers have observed for quite some time the existence of modest to large variations in crop yields within individual fields. However, it is not easy to determine what is the exact causes for the variability. Numerous factors or combinations are known to impact yields. Temporal factors such as rainfall amount and distribution, dates of planting, and varying pressures of diseases, insects, and weeds all impact crop performance within fields. Then there are the spatial effects of varying soil properties including fertility levels, drainage, organic matter content and water holding capacity (Lamb et al., 1997; Porter et al., 1998). However, it is not usually any single factor behind yield variability but rather a complex of factors acting together.

Recent technological advances have made it possible for these variabilities to be pinpointed within a field. Now, with the help of yield monitors, global positioning satellites (GPS) and other GIS applications, yield variances can be mapped from year to year. Once several years of mapped data are accumulated, observable patterns usually emerge. When this occurs, one can focus on individual soil and cropping factors which may be influencing these patterns. One such factor is planting rate. It may be possible to obtain a yield increase by increasing or decreasing the number of plants per acre in relation to site characteristics. It may be beneficial to plant higher rates in depressional areas which drown out frequently or lower rates on hilltops which may be affected by low water holding capacity and presence of root restricting pans.

Another aspect to consider is the nitrogen rate being applied to a particular location. If the plants are stressed for nitrogen prior to maturity, it may be possible to apply supplemental nitrogen in those areas. Likewise, it may be possible and desirable to decrease nitrogen rates, and still obtain high yields in other areas without the risk of unused nitrogen in the soil becoming an environmental hazard. However, it is not as simple as just increasing or decreasing planting rates and nitrogen rates. Many factors are involved in choosing the optimum rates for application including management skills and risks that are to be assumed.

Review of Literature

One approach to try and understand yield variability is to manipulate the populations of the crop being grown. The optimum seeding rate is ultimately dependent upon row spacing, crop variety, latitude, soil characteristics, pressures from weeds, insects, and diseases, and competition for water, light, and nutrients (Karlen and Camp, 1985; Lamb et al., 1997; Porter et al., 1998). With new higher-yielding corn varieties emerging each year and advances in cultural, pest management, and fertilization practices, optimum planting rates are subject to frequent change. Also the optimum planting rate for corn is affected by variability that exists within the field itself. In some cases, this variability may dictate different optimum planting rates within a single field. Currently, the optimum planting rate in Illinois is 25,000 to 30,000 seeds ac^{-1} (Nafziger, 2000).

Corn grain yield can be increased simply by raising the plant population to some optimum level beyond which yields begin to decline in a parabolic relationship (Duncan, 1958; Brown et al., 1970; Lutz et al., 1971; Karlen and Camp, 1985). Plant populations can only be increased to a level in which the soil can sustain the population. If the population becomes too high, the soil will not be able to support it and the average corn ear size and kernel weight becomes reduced. In essence, the average yield of the individual plant will decrease as the population increases (Duncan, 1958). Therefore, any increase in yield at extremely high populations is due to the increased number of plants rather than individual plant performance (Karlen and Camp, 1985). However, yield is determined by the factor most limiting to productivity. Water availability and the soil fertility level are usually the main factors limiting crop yield potential. Not only do these two limiting factors behave independently but they also are interrelated (Beckie et al., 1997).

Nitrogen is one of the most influential nutrients in a corn plant=s fertility requirement as it is essential for both growth and reproduction. The amount of available nitrogen throughout the growing season can be a critical factor influencing total corn grain yield. According to Ulger et al. (1997), nitrogen is recognized in corn production as being the first major nutrient that begins to limit plant growth. Fertilizer recommendations in the Midwest are based largely on yield goals or expected yields. The average economic optimum nitrogen rate for corn in Illinois is approximately 1.2 lb N bu^{-1} grain yield historically produced. The above rate would be recommended at a corn-nitrogen price ratio between

10:1 and 20:1. If the price ratio exceeds 20:1 then the optimum rate would increase to 1.3 lb N bu^{-1} corn grain yield (Hoeft and Peck, 2000).

A study was conducted in Quebec by Liang et al. (1992) in which two corn plant population rates (26,000 plants ac^{-1} and 36,000 plant ac^{-1}), two fertilizer rates (150-90-150 vs. 360-270-360 lb N - P_2O_5 - K_2O ac^{-1}), irrigation, and two different corn hybrids were compared. The effects of these interactions were found to be very complex. The authors stated that large increases in yield mostly were the result of interactions rather than individual effects in a highly developed agriculture. Therefore, when stover is removed from the planting site through silage production or when high yields are obtained, increased fertilizer rates, crop rotations, manure applications, or any combination of the above must be practiced due to large nutrient removal. If a grower plants higher than Anormal@ populations, ie. 36,000 seeds ac^{-1}, fertilizer rates which are higher than Anormal@ must also be applied to meet crop needs. According to Duncan (1958) and later by Ulger et al. (1997), if the nitrogen rate is increased, the number of plants needed to reach a maximum yield must also be increased. In certain cases, the number of plants needed to reach a maximum yield was doubled in response to the high fertilizer N treatments. Simply put, the plant population chosen will have an impact on the rate of nitrogen chosen as well.

The objectives of this research were as follows: (1) to evaluate the effects of variable seeding rates on corn yield within a field which, historically, has a high degree of yield variability; (2) to evaluate the effects of variable nitrogen rates on variable seeding rates within portions of a field which are historically high, moderate, and low yielding areas; and (3) to determine the optimum seeding rate and nitrogen rate within a field in regards to past yield records.

Materials and Methods

Field experiments were conducted in southern Illinois to (a) evaluate variable planting rates of corn across varying levels of field productivity and to (b) study the interactive effects of variable planting and nitrogen rates in small plot environments. These experiments were conducted in 1999-2001 on the farm of Mr. Kelly Robertson, located in Franklin County, Illinois. The sites selected in 1999 and 2000 were identified by Mr. Robertson as the Adams Field and the Payne Field, respectively. In 2001 the study was again conducted in the Adams field. Soil types within both of the selected study sites were dominated by Cisne silt loam (fine, montmorillonitic, mesic Mollic Albaqualfs) and Hoyelton silt loam (fine, montmorillonitic, mesic Aquollic Hapludalfs). Each field had historical regions of high, medium, and low productivity identified by the use of a yield monitor for the previous five growing seasons. The fields selected had a mixture of high, average, and low productivity soils of sufficient size such that small plots for intensive N rate and population studies could be conducted within the boundaries of those areas. The previous crop for both years was soybean.

Whole Field Experiments

The experiments conducted at each field site were identical each year. A randomized complete block design with 6 replications was used. Each replication had a total of 6 treatments. The factors evaluated were 6 different corn seeding rates planted across three different productivity zones (high, average, and low), the area of each varying within each replication. Planting rates ranged from a low of 18,000 seeds ac^{-1} to a high of 38,000 seeds ac^{-1} increasing in increments of 4,000 seeds ac^{-1} in 30 inch row spacings. Corn, Pioneer 33G28, Pioneer 33Y09, and Pioneer 33Y09 was planted on 20 May 1999, 22 April 2000, and 26 April 2001, respectively. Variable seeding rates were controlled using a Rawson Control Systems, Inc., Accu-Rate^R unit.

Individual plot dimensions for each population within each replication were variable for each year due to field shape and waterways. In most cases plot dimensions were 30 ft wide by over 1000 ft. long. The entire plot area was harvested and used for data collection. Nitrogen was applied as side-dressed anhydrous ammonia (NH_3) at a uniform rate of 160 lb N ac^{-1} across the entire field. Phosphorus and potassium levels were maintained with applications of 100 lb ac^{-1} of diammonium phosphate and 200 lbs ac^{-1} of muriate of potash.

The entire field was divided into 30 ft by 60 ft. subareas (grid cells). Stand counts were done by counting the number of corn plants within the middle 20 ft of the two center rows of each block. The blocks in each population strip were then averaged together to find the actual population of each individual population strip. The growth stage used to assess stand counts was between the V-4 to V-6 growth stages. Corn was harvested by a combine equipped with a GPS unit and yield monitor. As described earlier, entire individual plot areas were harvested and used for data collection. Grain weights and moisture were measured simultaneously by the use of the yield monitor at the time of harvest. In addition, all grain from each plot was discharged into a certified weigh wagon and moisture was determined by the use of an electronic moisture meter. Grain moisture content was corrected to 15.5 percent to determine the final yield.

Small Plot Experiments

The small plot studies were conducted in 1999-2001 within selected strips of the larger whole field studies described above. A split plot design was used. Main plots consisted of six corn populations and subplots consisted of five N rates giving 30 plots per replicate. A total of six replications was employed, two replications in each of the three levels of soil productivity: high, average, and low. The six main plot treatments ranged from a low of 18,000 seeds ac^{-1} to a high of 38,000 seeds ac^{-1} planted in increments of 4,000 seeds ac^{-1}. Subplot N rates were 0, 50, 100, 150, and 200 lb N ac^{-1}. Nitrogen was applied as a 28 percent N solution of UAN (urea-ammonium nitrate) and injected into the soil in alternate rows using a knife applicator. Individual plots were 30 ft in length by 15 ft in width (6 rows spaced 30 inches). The center 20 ft portion of the middle 2 rows was utilized for crop measurements. The corn varieties planted and the dates of planting were identical to the whole field studies described above. Variable planting rates were controlled using a Rawson Control Systems, Inc. Accu-Rate^R unit. Variable N rates were controlled using a small-plot liquid N applicator. Grain weights and moisture were measured by hand at the time of harvest. Grain moisture content was corrected to 15.5 percent to determine the final yield.

Statistical analyses were performed on all measurements using the Statistical Analysis Software program (SAS Institute, Inc., 1999). An analysis of variance (ANOVA) was performed to determine significant treatment differences affecting population and grain yield. Regression analysis with quadratic curve fitting was done to determine population and nitrogen rate responses and optimal rates.

Results and Discussion

General Comments

There was higher than normal rainfall in the Spring of 1999 (Table 1). This resulted in excessively wet soil conditions which delayed planting until mid-May. Above normal temperatures and dry seasonal conditions occurred following planting, with the exception of July which had near normal rainfall. Lack of soil moisture in August and September caused plants in high seeding rate treatments to die prematurely. These combined conditions resulted in lower than normal yields for 1999.

In early Spring of 2000 and 2001, below average rainfall (Table 1) and favorably mild temperatures resulted in earlier than normal planting. However, heavy rainfall in June 2000, 5.2 inches higher than average, caused severe flooding in low areas of the field and resulted in a high number of killed plants. These areas were replanted when soil conditions allowed. Higher than normal rainfall continued for the majority of the growing season. The July and August period which is the most critical portion of the growing season, had rainfall that was 1.5 and 1.9 inches above normal, respectively, in 2000. July 2001 was also well above average. September was dryer than normal both years which aided in drying and harvesting of the crop. All of these conditions combined resulted in very high yields in 2000 and 2001.

Whole Field Experiments

Planting rates were higher than the targeted rate at the lower rates of seeding but tended to be less than the targeted rate at the higher seeding rates as evidenced by stand counts (Table 2). Apparently, the corn planter dropped more seed than the calibrated settings indicated at the lower seeding rates but less seed than the calibrated settings at the higher seeding rates. Crowding of plants at the higher planting rates may have resulted in some stand loss and could account for the lower percent stands than was intended. According to Nafziger (2000), a ten to twenty percent loss in stand compared to seeds planted is not unusual due to insects, diseases, and adverse soil and weather conditions. Over the three years of this study, the amount of loss was within this range at eight percent.

Corn grain yield increased significantly as the seeding rate was increased during each year of the study (Tables 3 and 4). Yield followed a positive quadratic trend across populations (Figures 1-3). In 1999, yield increased steadily up to 34,000 seeds ac^{-1}, the highest yielding population, then it declined. At 38,000 seeds ac^{-1} the plants were extremely crowded and became so stressed due to droughty conditions that they died prematurely. In 2000 and 2001, yields increased as planting rates increased (but at a diminishing rate) with 38,000 seeds ac^{-1} being the highest yielding population. Even though the data suggested populations of 34,000, 38,000, and 38,000 seeds ac^{-1} to be the highest yielding in 1999, 2000, and 2001, respectively, they were not the most economical populations. Using a model derived from Nafziger et al. (1984), the economic optimum planting rate for 1999 was 26,700 seeds ac^{-1} (Figure 1). For 2000 and 2001 the economic optimum planting rate was 36,800 and 36,200 seeds ac^{-1} (Figures 2 and 3). Clearly the conditions in 2000 and 2001 were more favorable for corn production and responses were higher than in 1999.

Data from all three years of the study were averaged and a new quadratic response surface was derived from the combined data set. When data were combined, the optimum economic population was determined to be 31,500 seeds ac^{-1} (Figure 4). Note this is different from averaging the optimum rates over the three years. The optimum seeding rate of 31,500 seeds ac^{-1} was higher than the normal planting rate for corn in southern Illinois which is usually less than 26,000 seeds ac^{-1}.

A comparison was made of costs and returns associated with the optimum planting rate of 31,500 seeds ac^{-1} versus the customary planting rate of 26,000 seeds ac^{-1}. Assumptions in the calculations were that the corn price was \$2.00 bu^{-1} and that seed corn price was \$1.25 per 1000 kernels. In 1999, when yields were lowered by weather effects, there was little difference in yield between these two planting rates and therefore the corn producer would have been out the cost of additional seed (Table 5). In 2000 and 2001, there was a substantial penalty in choosing the customary planting rate over the optimal rate, amounting to \$17.06 and \$19.08 ac^{-1}, respectively. When combined over the three-year period, there was a two-to-one return over cost advantage for the higher planting rate. This would indicate that a change in planting rates would be profitable.

The effects of historical yield levels of field productivity were determined by taking the average of five years of normalized yield data. Normalization was based on percent of field average yield for each year. Yield levels were determined as follows: low (less than 95% of normalized yield, medium (95 to 105% of normalized) and high (greater than 105% of normalized). The medium yield level seemed to be the most variable in our study, yielding lowest in 1999 and 2001, but highest for the most part in 2000 (Figures 5-7). The medium yield level appeared to occur on the areas of the field most subject to drought. In 1999 and 2001 low rainfall in July and August probably provided less than adequate moisture for grain production. The low yield levels are probably associated with wet areas, but in 1999 with low rainfall, these soils proved beneficial. The high yield levels were always high yielding and are associated with deep, well drained areas of the field with high water holding capacity. Therefore, they do well under most conditions.

In 1999, only the high yield level areas responded to planting rates with an optimal planting rate of 28,000 seeds ac^{-1} (Figure 5). In 2000 and 2001, each yield level responded to increasing planting rates, with variable optimal populations for each year and yield level and no clear-cut relationship, except that each of the optimal populations were well above the customary rate of 26,000 seeds ac^{-1} (Figures 6 and 7).

Small Plot Experiments

The overall corn yield response to nitrogen (across planting rates and soil productivity levels) was different for all three years of study (Figures 8-10). No response to N was observed in 1999 (Figure 8), but significant yield increases to N were observed in 2000 and 2001 (Figures 9 and 10). Calculated optimum N rates were 133 and 109 lb N ac^{-1} for the two N responsive years, which would have been slightly less than recommended.

The response of corn to nitrogen (averaged across planting rates) on low, medium, and high productivity soils is shown in Figures 11, 12, and 13 for the three years of study. On average, corn was more responsive to N (needed a higher amount of N to achieve optimum economic yields) on the low and medium productivity soils than high productivity soils for all three years. Higher N losses in the lower productivity soils and greater amounts of mineralizable N in the high productivity soils may have accounted for this response.

The interactive effect of nitrogen fertilizer rate and planting rate on corn yield across the three years is given in Figure 14. As can be readily seen, the highest yields were achieved only when corn was planted at the higher seeding rates (30,000 to 38,000 seeds ac^{-1}). At lower rates of seeding, an insufficient number of plants was present to most efficiently use the applied N. Hence, it is of utmost importance that the highest recommended seeding rate be planted to most efficiently utilize the applied N and minimize residual soil N as an environmental hazard.

Acknowledgement

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Table 1. Growing Season Rainfall (inches) at the Franklin County, IL Field Site for 1999-2001.

Month	1999	2000	2001	30-Year Ave. (Benton, IL)
April	6.29	2.89	1.79	4.09
May	4.67	4.12	4.87	4.50
June	1.52	8.79	3.26	3.62
July	3.45	4.97	5.46	3.41
August	1.58	5.15	2.22	3.27
September	0.50	2.96	2.58	3.07
October	2.01	0.42	9.58	3.20

Table 2. Effect of planting rates on plant stands, Benton, IL

Planting Rate	1999	2000	2001	Average
(Intended seeds ac^{-1})	--------------------------% of Intended--------------------------------------			
18,000	102	101	101	101
22,000	92	95	94	94
26,000	88	94	91	91
30,000	85	93	89	89
34,000	86	89	88	88
38,000	86	92	88	89

Table 3. Analysis of variance and significant responses (Pr > F) for planting rate effects on corn grain yield, Benton, IL

Source	1999	2000	2001
Planting rate	**	***	***
Linear	***	***	***
Quadratic	***	***	***
Cubic	NS	NS	NS
Coefficient of Variation (%)	4.6	3.4	5.8

*, **, *** refer to significance at the 10%, 5%, and 1% level, respectively. NS refers to non-significant.

Table 4. Effect of planting rates on corn grain yield, Benton, IL.

Planting Rate	1999	2000	2001	Average
(seeds ac^{-1})	----------------	Bu ac^{-1}	----------------	
18,000	125	136	141	134
22,000	133	150	156	146
26,000	134	163	173	157
30,000	137	174	182	164
34,000	139	178	188	168
38,000	133	182	191	169

Table 5. Costs and returns associated with optimum planting rate compared to the commonly used planting rate.

Year	Yield @ 26,000 seeds ac^{-1}	Yield @ 31,500 seeds ac^{-1}	Return	Extra Seed Cost	Profit
	----------Bu ac^{-1}----------		---------------$ ac^{-1}---------------		
1999	135.7	137.5	$ 3.55	$6.88	($3.33)
2000	163.3	175.2	$23.94	$6.88	$17.06
2001	171.7	184.7	$25.96	$6.88	$19.08
Combined	160.3	166.8	$12.92	$6.88	$ 6.04

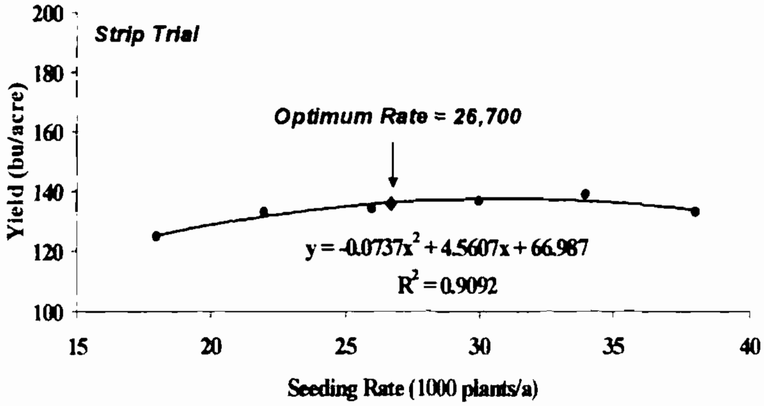

Figure 1. Effect of seeding rate on corn grain yield, Benton, 1999.

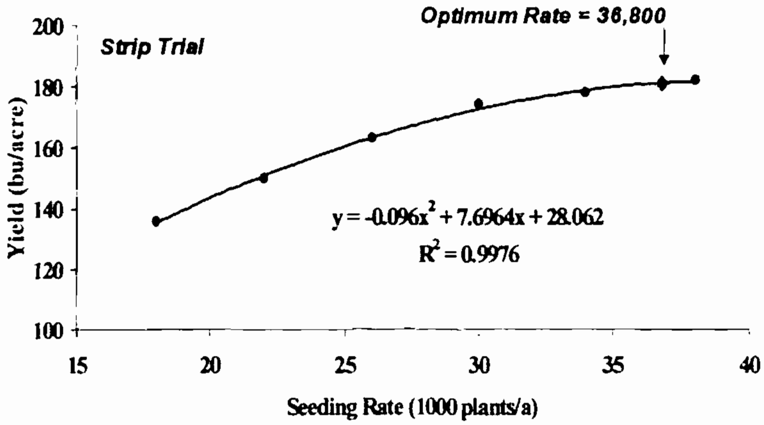

Figure 2. Effect of seeding rate on corn grain yield, Benton, 2000.

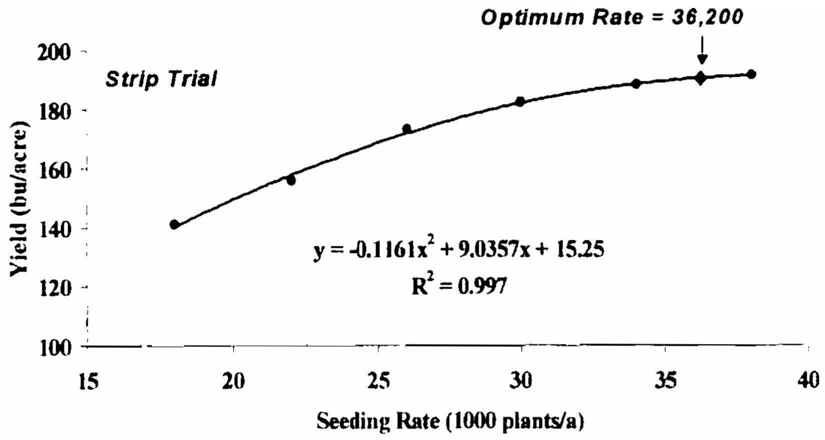

Figure 3. Effect of seeding rate on corn grain yield, Benton, 2001.

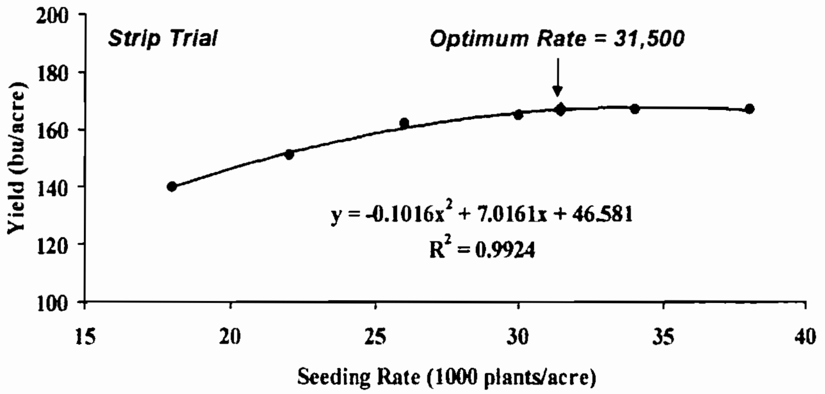

Figure 4. Effect of seeding rate on corn grain yield, Benton, 1999-2001 combined.

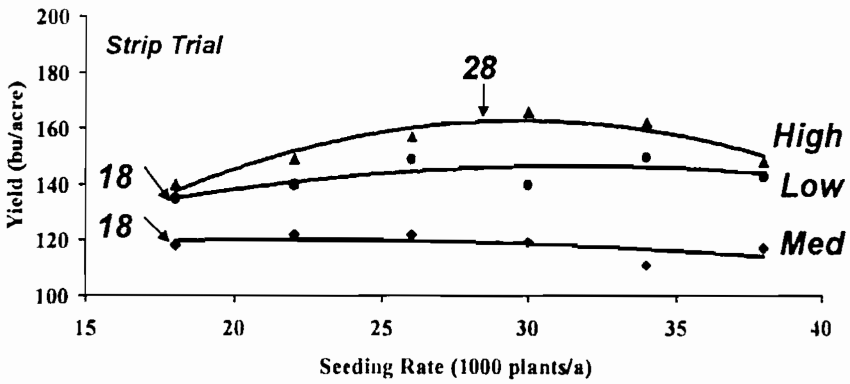

Figure 5. Effect of seeding rate and soil productivity level on corn grain yield, Benton, 1999.

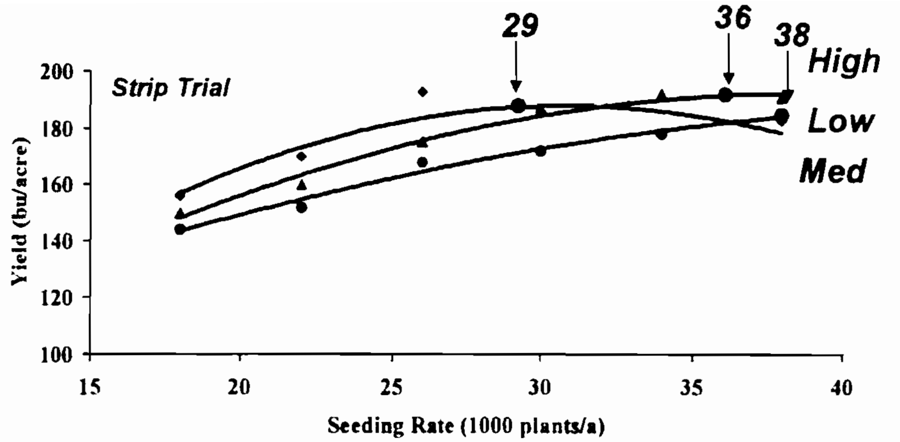

Figure 6. Effect of seeding rate and soil productivity level on corn grain yield, Benton, 2000.

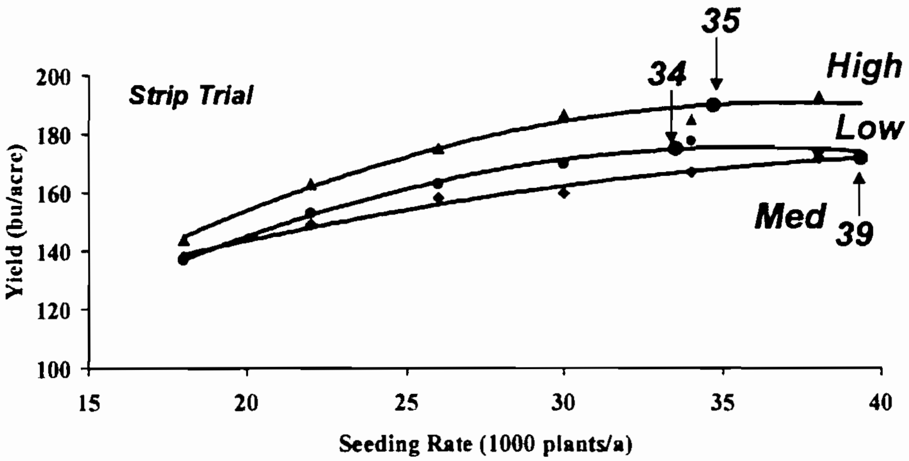

Figure 7. Effect of seeding rate and soil productivity level on corn grain yield, Benton, 2001.

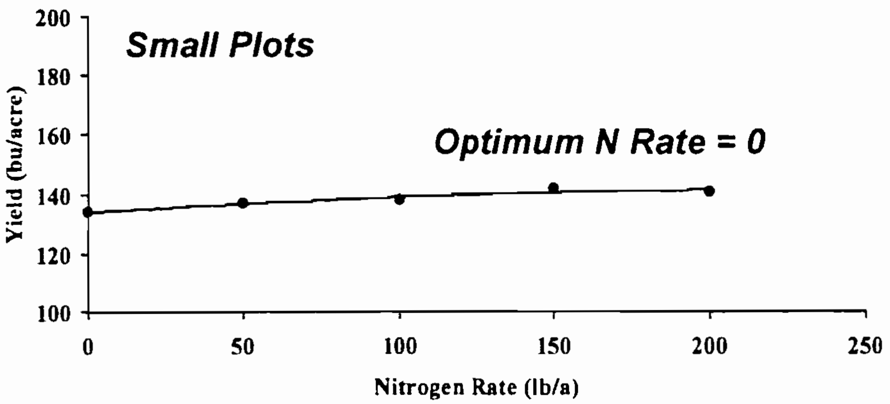

Figure 8. Effect of nitrogen rate on corn grain yield, Benton, 1999.

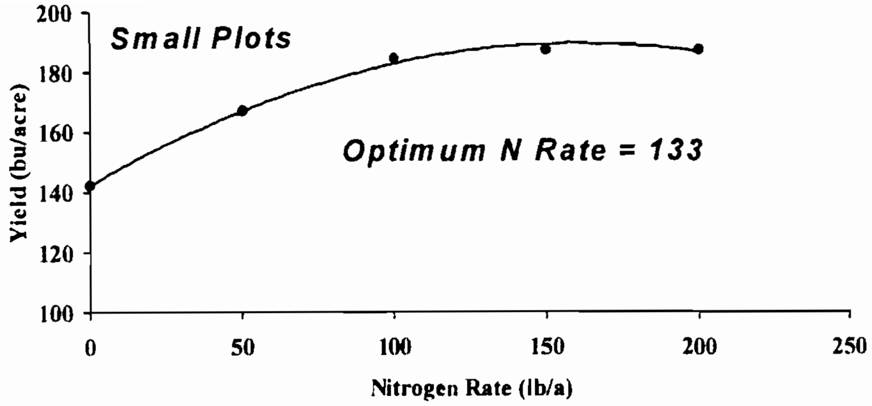

Figure 9. Effect of nitrogen rate on corn grain yield, Benton, 2000.

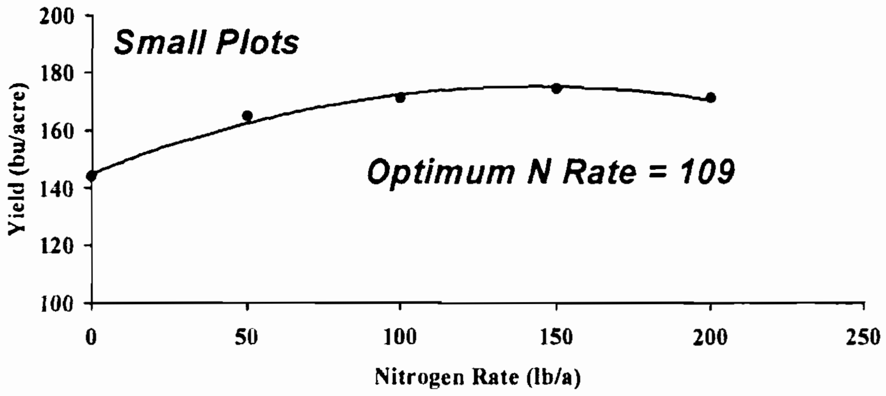

Figure 10. Effect of nitrogen rate on corn grain yield, Benton, 2001.

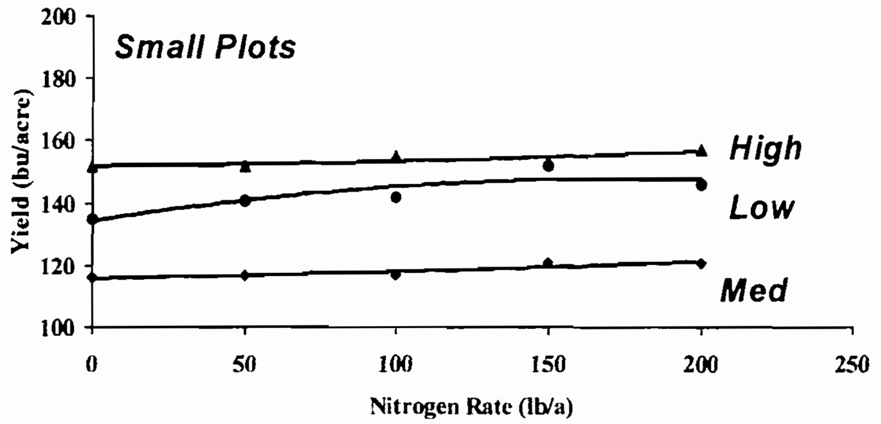

Figure 11. Effect of nitrogen rate and soil productivity level on corn grain yield, Benton, 1999.

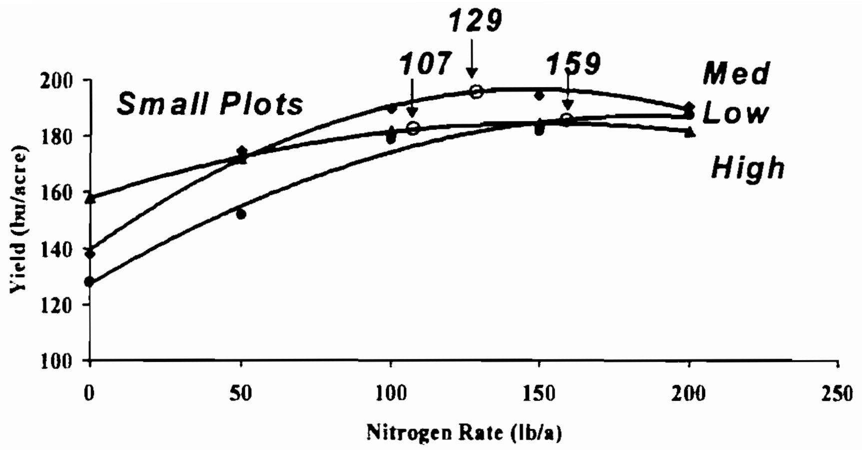

Figure 12. Effect of nitrogen rate and soil productivity level on corn grain yield, Benton, 2000.

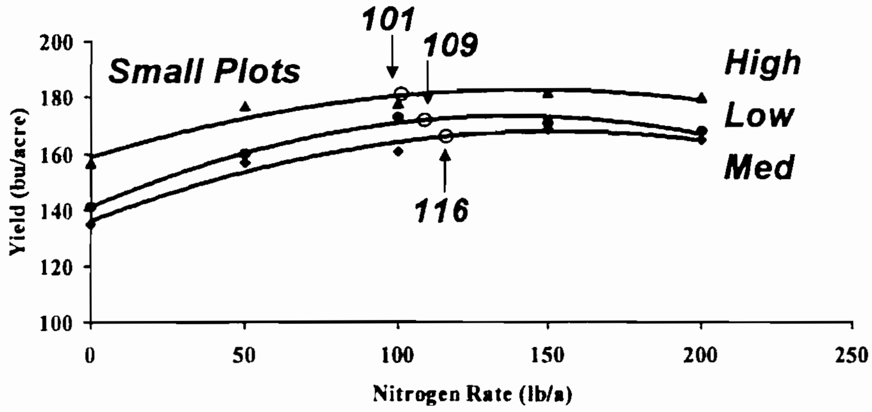

Figure 13. Effect of nitrogen rate and soil productivity level on corn grain yield, Benton, 2001.

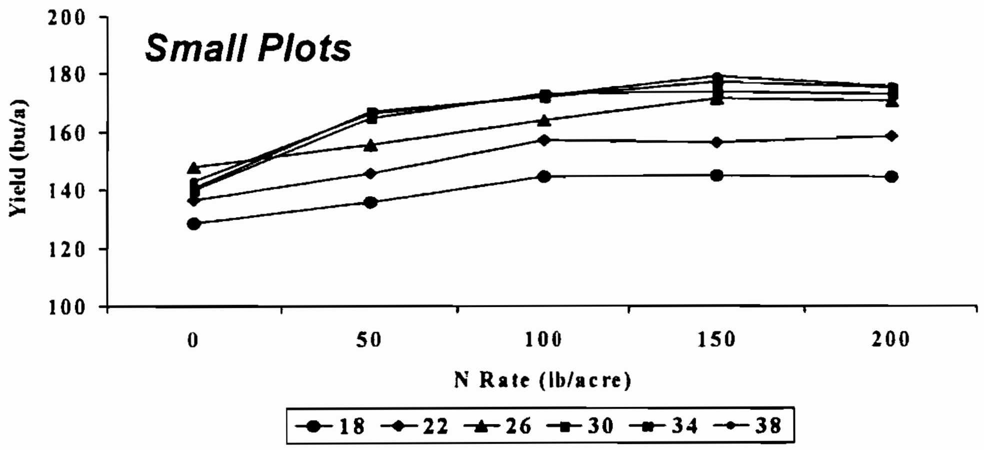

Figure 14. Seeding rate x N rate effects on corn grain yields, Benton, 1999-2001.

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