PATTERNS AMONG SEEDING RATES, REMOTELY SENSED DATA, AND YIELD ON A MISSISSIPPI DELTA COTTON FARM

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Abstract

Costs for biotransgenic cottonseed have increased in recent years to levels of over $50/acre, making it one of the highest input costs to American cotton farmers. To understand the relationships among seeding rate, within-field geographical variation, and yield, the NASA Commercial Remote Sensing Program and ITD-Spectral Visions are working with Perthshire Farms in Gunnison, Mississippi to conduct an inductive experiment aimed at shedding light on this increasingly expensive input. This variable-rate seeding experiment revealed that plots seeded at a rate of 3 seeds/foot (39,000/acre) produced 2% to 10% more yield, saved 31% to 66% in seeding costs, and increased profit margins by 7% to 13%, when compared to seeding rates of 4 and 5 seeds/foot. The relationship between seeding rate and yield was then measured within a series of geographical zones derived from remote sensing and field data, to determine if certain geographic features would produce a higher yield at a particular seeding rate. While certain patterns did merge, the low seeding rate of 39,000 seeds/acre generally ranked as the most economical from the perspective of the grower, regardless of geography.

Introduction

The NASA Commercial Remote Sensing Program and its agricultural support organization, ITD-Spectral Visions, both at Stennis Space Center, Mississippi, investigate potential applications of satellite and airborne remote sensing to commercial markets. One potential application of remote sensing for cotton involves the use of these data to determine geographical zones in which a certain seeding rate would maximize yield and minimize seed costs. The requirement driving this research is the increasing costs of cottonseeds. According to the USDA Economic Research Service, seed expenses have nearly tripled between 1975 to 1997, from $5.88 to nearly $16/acre. As such, this does not represent a major input expense for American cotton farmers; costs for fertilizers and chemicals were about three times higher than seed costs in 1997. However, with the advent of biotransgenic seeds and their associated technology fees—representing about $40/acre above the seed cost—the total expense for seeds is now comparable to the highest costs of production encountered by American cotton producers. Some seed companies charge their technology fee on a per-bag basis rather than a per-acre basis, providing another economic incentive for farmers to conserve seed while maximizing yield.

To determine patterns of seeding rate, yield, and geography, the researchers collaborated with Mr. Kenneth Hood, a nationally recognized cotton producer and owner of Perthshire Farms in Gunnison, Mississippi, to set up an applied experiment during the 1999 growing season. The study area comprised 12 plots covering 58 acres across a field near the Mississippi River, north of the town of Cleveland. The 12 plots were seeded at three different but constant seeding rates—3, 4, and 5 seeds/foot—each replicated four times. At 40-inch row spacing, these rates correspond to 39,000, 52,000, and 65,000 seeds/acre, already adjusted for germination rates. Figure 1 shows the configuration of the plots. A seeding prescription was prepared using ESRI ARC/INFO and ArcView GIS software and planted on May 4-7, 1999, using an eight-row vacuum planter equipped with a Rawson Accu-Rate controller and a Vision System controller/satellite receiver. The seed planted was 458 Biotransgenic RoundUp Ready seed, which cost $53.95 for a 50 lb. bag (containing 5200-5600 seeds per lb.) plus a technology fee of $177/bag charged separately to the farmer by the seed company. Thus, the total cost to the farmer was $230.95 for 270,000 seeds. There is an economic incentive to spread these seeds as efficiently as possible: at a seeding rate of 39,000/acre, a bag would cover 6.92 acres and cost $33/acre, but at a rate of 65,000/acre, a bag would cover only 4.15 acres and cost $56/acre.

For the remainder of the growing season, the seeding plots were treated under normal circumstances regarding the management of the farm; no special attention was given to them. This represents an applied experimental approach, designed to simulate actual conditions on a functioning farm, rather than the basic-research experimental approach, in which variables are well-controlled but the experiment as a whole is less representative of actual working conditions. The researchers selected the former approach because of the nature of the geographical variation of interest, and because of the emphasis on the role of remote sensing.

During planting, "as-applied" or "actual" data was captured to record the extent to which true seeding rates concurred with target (prescribed) rates. These data are listed in Table 1 and displayed in Figure 2.

(At first glance, some of the deviations in Table 1 may appear to interfere with the analysis of the data. However, it is noted that all analysis was done by specifically selecting the actual

Reprinted from the *Proceedings of the Beltwide Cotton Conference*
Volume 1:421-426 (2000)
National Cotton Council, Memphis TN

seeding data that fell within a range of +-3000 seeds from 39,000, 52,000, and 65,000, regardless of plot. Because of the sheer number of points (13,400), there were many thousands that fell within the above ranges. Thus, we can say with certainty that the seeding-rate measurements listed in the graphs and results below represent the ranges of 39,000, 52,000, and 65,000 seeds/foot, +-3000 seeds, regardless of the averages by plot.)

The plots were harvested on October 11-12, 1999, using a four-row picker equipped with Micro-Trak cotton-flow sensors to monitor yield. To ensure the validity of the yield-monitor data, the researchers weighed the harvest at the end of each plot. Table 2 compares the yield-monitor data to the weigh-wagon data; Figure 2 displays the yield monitor data. Table 2 shows that in all but two plots, yield monitor data and weigh-wagon data fell within 8 percentage points. A further inspection of the data revealed that there were no major spikes or troughs in the distribution of yield-monitor data.

Discussion

As an inductive experiment, the goal here is not to verify a hypothesis but to observe patterns that may be tested as a hypothesis in a future deductive experiment. The patterns of interest are summarized by the question, *Which seeding rate produced the maximum yield at the minimum seed cost, and in what geographical zones did this occur?* ESRI ARC/INFO GRID, a cell-based GIS processing environment, and ERDAS Image, an image-processing software package, were used for the geographical analysis.

To answer the above question, the actual seeding rate data were queried to select those points seeded within 3000 seeds/acre of the original targets of 39,000, 52,000, and 65,000. Thus, all points between 36,000-42,000, between 49,000-55,000, and between 62,000-68,000 were isolated out and compared to their corresponding yield-monitor data points. This was done throughout the entire 28-acre study area, regardless of plots. The following results assume a lint percentage of 38%, based on previous results, and a price of \$0.50/lb for lint cotton, based on December 1999 prices. In the following findings, "net" implies gross revenue minus seed costs *only*, and "marginal net gain" is the difference between (1) the deviation of seed cost at a given rate from the average seed cost, and (2) the deviation of revenue earned at that seeding rate from the average revenue produced at all three rates. See Graphs 1-2.

- The lowest seeding rate (average 39,650/acre) produced the highest yield (1075 lbs/acre lint), highest net revenue (\$503.59/acre), and highest marginal net gain (+\$30.12/acre gain).
- The medium seeding rate (average 51,997/acre) produced the lowest yield (979 lbs/acre lint), lowest net revenue (\$444.77/acre), and the lowest marginal net gain (-\$28.70/acre loss).
- The highest seeding rate (average 65,856/acre) produced the medium yield (1057 lbs/acre lint), medium net revenue (\$472.06/acre), and medium marginal net gain (-\$1.42/acre loss).

In terms of geographical variation, the researchers analyzed the above data within the zones of four different data layers derived from remote sensing and field data. These layers are (1) soil-color classes based on a classification of a bare-soil image; (2) a vegetation index calculated from an image taken the previous year; (3) topographic curvature, and (4) soil texture (particle size). See Figure 3. The goal here is to observe the relationship of seeding rate to yield within the zones contained in these four data layers. If a particular data-layer zone is found to produce high yield at a certain seeding rate, this may form the basis of a future seeding prescription, and may be of interest to both the cotton community and the remote sensing community.

1. Soil-Color Classes An airborne multispectral image captured by ITD-Spectral Visions' RDACS camera on April 16, 1999 (about three weeks before planting) was processed through an unsupervised classification to break out ten classes, depicting darker-colored soils in the lower classes to brighter-colored soils in the higher classes. No inference as to soil class, moisture, texture, or other property is made; the classes only are said to represent darkness (color). These classes were then crossed with the seeding and yield data to determine what seeding rate produces what yield in each zone. The results are shown in Graphs 3-4.

The data in Graphs 3-4 show that the low seeding rate yielded the most in darker soils, while all three seeding rates yielded about the same in brighter soils. When adjusted for the costs of seeds incurred at the various seeding rates, it appears that the low seeding rate of 39,000 was the most economically sound, regardless of soil-color variation.

2. DVI Zones Next, an RDACS multispectral image captured the previous season (September 8, 1998, a month prior to harvest) was processed into a normalized difference vegetation index (NDVI), in the hope of finding zones of vibrant vegetation in last year's crop that may produce extra yield if seeded at a certain rate. NDVI is a ratio between near-infrared-band reflectance and red-band absorption, producing an index of values between –1 and +1, where values closer to –1 indicate less-vibrant and less-healthy areas, and values closer to +1 mark areas that are most vibrant. In this case, the NDVI was sliced in five equal-interval zones and the average NDVI value for each zone was computed (x-axis in graphs below). These zones were then crossed with the seeding and yield data to determine what seeding rate produces what yield in each zone. The results are shown in Graphs 5-6.

The analysis in Graphs 5-6 shows that low seeding rates did best in zones that had low NDVI values in the previous September, and also did best in high NDVI zones, but to a lesser extent. When adjusted for the cost of seeds incurred at the various seeding rates, it appears that the low seeding rate of 39,000 was the most economically sound, regardless of previous-season NDVI zones.

3. Curvature Zones Curvature is a measure of the convexity and concavity of a topographic surface, and may be used to identify poorly drained versus well-drained areas. The lower the negative numbers in a curvature model, the more concave (water-collecting) the surface; the higher the positive number, the more convex (water-shedding) the surface. Zero is flat. Curvature was determined using the CURVATURE algorithm in ESRI ARC/INFO GRID, performed upon a one-meter-resolution LIDAR digital elevation model of the field, which first had to be smoothed to remove excessive micro-scale drainage detail. The curvature model was then sliced into five equal-interval zones and the average curvature was computed for each zone. These zones were then crossed with the seeding and yield data to determine what seeding rate produces what yield in each zone. The results are shown in Graphs 7-8.

Graphs 7-8 show little variation in yield when the three seeding rates are planted on various curvature zones. However, it appears that, once again, the low seeding rate yielded the most, regardless of topography. When adjusted for seed costs incurred at the various rates, the low seeding rate was especially economical from the farmer's perspective.

4. Soil Texture Zones Soil texture was measured through field data taken on a one-acre grid by Dr. Jac Varco of Mississippi State University. The data were processed to form a surface of average particle size, ranging from 0.23 mm to 0.71 mm in diameter (between silt and sand). This data layer was sliced in five equal-interval zones and the average particle size for each zone was computed. These zones were then crossed with the seeding and yield data to determine what seeding rate produces what yield in each zone. The results are shown in Graphs 9-10.

Despite the fact that certain soil-texture zones produced an erraticness in the corresponding yield, there appears to be no strong pattern between seeding rate, yield, and soil-texture zones, as revealed in Graphs 9-10. Nevertheless, an overall yield benefit was produced by the low seeding rate, with little regard to geographical variation. This became more apparent when the data were adjusted for the cost of seeds.

Summary

This applied experiment was designed to observe patterns among (1) three cotton seeding rates, (2) the yield produced by each rate, and (3) geographical zones determined from remote sensing and field data. The hope was to identify certain geographical zones and seeding rates which would maximize yield and minimize cost. The data reveal that the low seeding rate of about 39,000 seeds/acre (3 seeds/foot) produced the highest yield and incurred the least seed costs compared to higher seeding rates. This low rate produced 2% to 10% more yield, saved 31% to 66% in seeding costs, and increased profit margins by 7% to 13% within the 58-acre study area, when compared to seeding rates of 52,000 and 65,000. The low rate produced the highest yield (1075 lbs/acre lint), highest gross-revenue-minus-seed-costs ($503.59/acre), and highest marginal net gain (+$30.12/acre gain) over the other rates. (These results generally concur with trials reported by the University of Georgia College of Agricultural and Environmental Sciences Cooperative Extension Service, in which "rates as low as 2 seed/foot resulted in plant stands ranging from 1.2 to 1.9 plants/foot and [produced] maximum lint yield over the 3 year study.") However, the positive economic pattern described in our experiment occurred with little regard to the four layers of geographic variation tested herein. While there was some additional yield benefit in planting less seeds in darker soils, brighter previous-season NDVI zones, and other areas, there was also yield benefit in planting at low seed rates in other areas. In sum, then, the low seeding rate did well in maximizing yield and minimizing seed costs *with little regard* to the four layers of geographic information tested here. It remains to be seen if remote sensing may play a role in developing variable-rate seeding prescriptions.

It should be noted that these results, while positive from the perspective of the farmer, represent a documentation of patterns rather than the verification of a hypothesis. In an inductive experiment like this, carried out on a functioning farm, there may have been unaccounted-for variables which may explain why certain rates outperformed other rates. It is hoped that the even distribution of plots across the field, the replication of the plots, and the analysis of the data at five levels (the field level plus four geographic-zone levels) would have minimized the effects of such variables on the observation of patterns.

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Acknowledgements

Special thanks to the NASA Commercial Remote Sensing Program, Michael Seal, Kelly Dupont, Dr. Jac Varco, and other project team members, as well as the staff of the Institute for Technology Development-Spectral Visions.

Figure 1. Three seeds/foot were planted in the white plots(#1,4,7,10); four seeds/foot in the gray plots(# 2,5,8,11), and five seeds/foot in the dark gray plots (#3,6,9,12). Each plot measures 16 rows (40" each) in width, totaling about 53 feet, and averages 4000 feet in length.

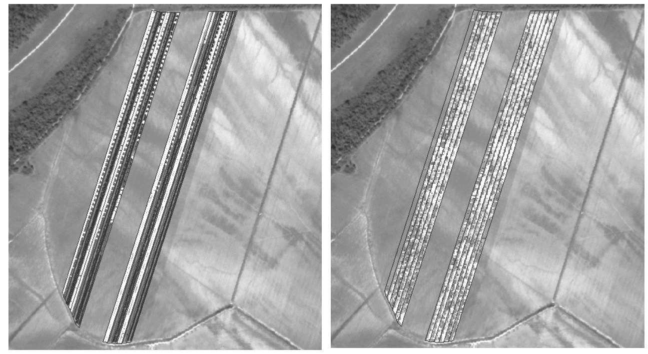


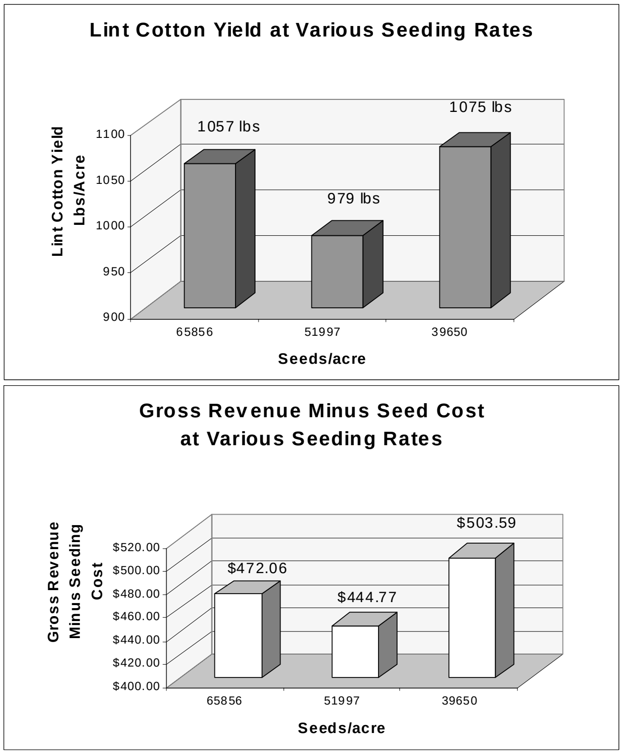
Figure 2. Actual ("as-applied") seeding data from the May 1999 planting (left), and yield monitor data from the October 1999 harvest. Darker colors indicate higher rates/yields.

Table 1. Target vs. Actual Seeding Rates

Plot	Target Seeding Rate	Actual Average Seeds Planted	Deviation
Plot 1	39000	43360	11%
Plot 2	53000	57621	9%
Plot 3	65000	55607	-14%
Plot 4	39000	43998	13%
Plot 5	53000	57467	8%
Plot 6	65000	62194	-4%
Plot 7	39000	40109	3%
Plot 8	53000	51074	-4%
Plot 9	65000	62679	-4%
Plot 10	39000	41324	6%
Plot 11	53000	51085	-4%
Plot 12	65000	63285	-3%

Table 2. Comparison of Yield (Seed Cotton Lbs/Acre) As Measured by Yield Monitor vs. Weigh Wagon

Plot	Yield Monitor	Weigh Wagon	Deviation
Plot 1	3484	2568	-26%
Plot 2	2956	2740	-7%
Plot 3	3340	2662	-20%
Plot 4	2810	2666	-5%
Plot 5	2742	2726	-1%
Plot 6	2992	3028	1%
Plot 7	2856	2624	-8%
Plot 8	2384	2504	5%
Plot 9	2668	2622	-2%
Plot 10	2454	2514	2%
Plot 11	2680	2768	3%
Plot 12	2484	2584	4%



Graphs 1-2. Comparison of lint yield (top), and gross revenue minus seed costs, at the three seeding rates.

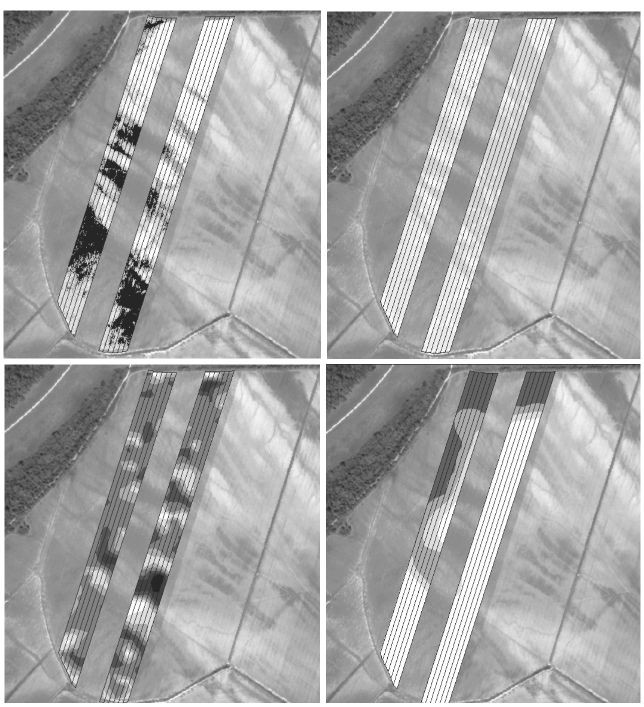
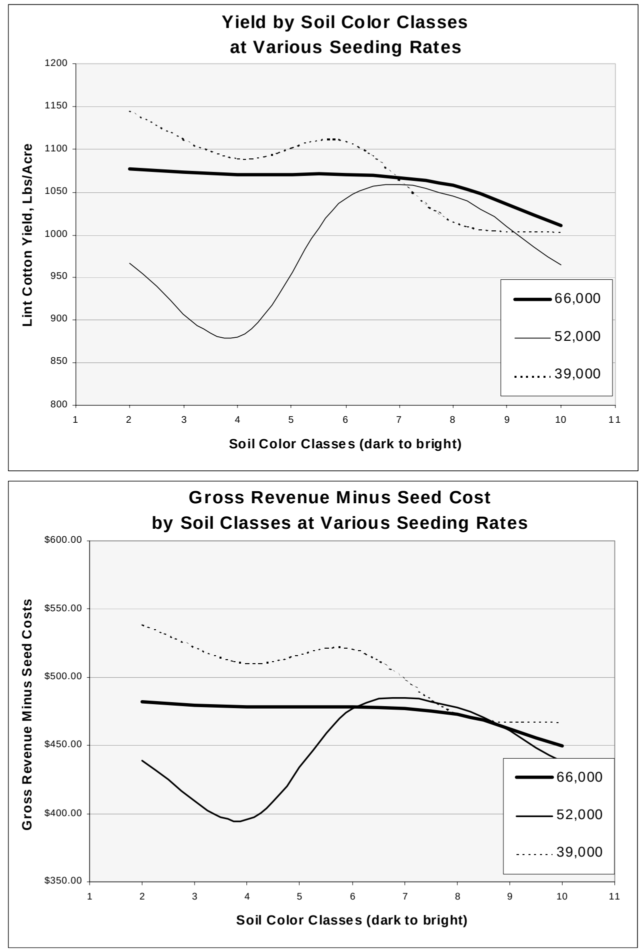
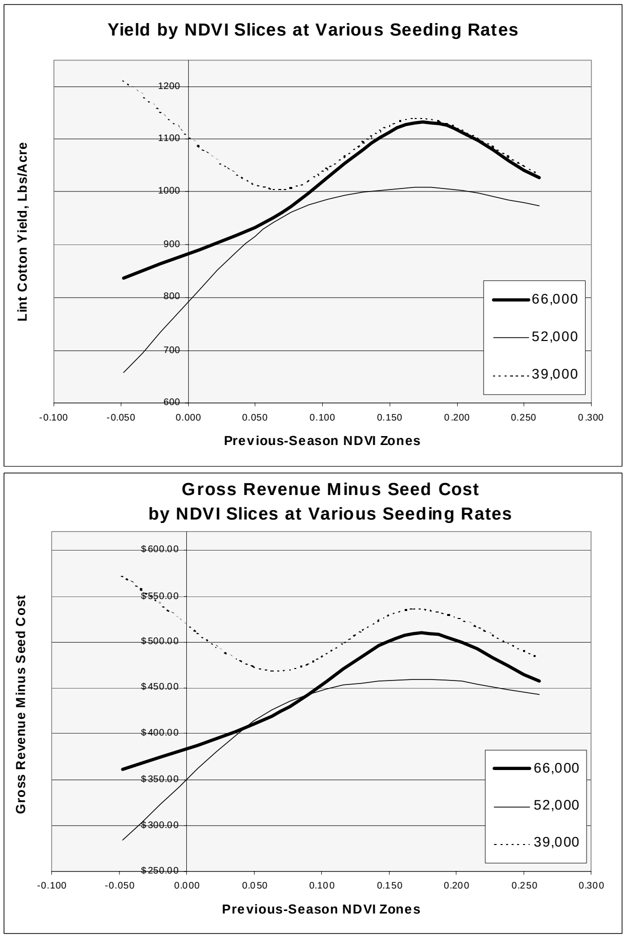


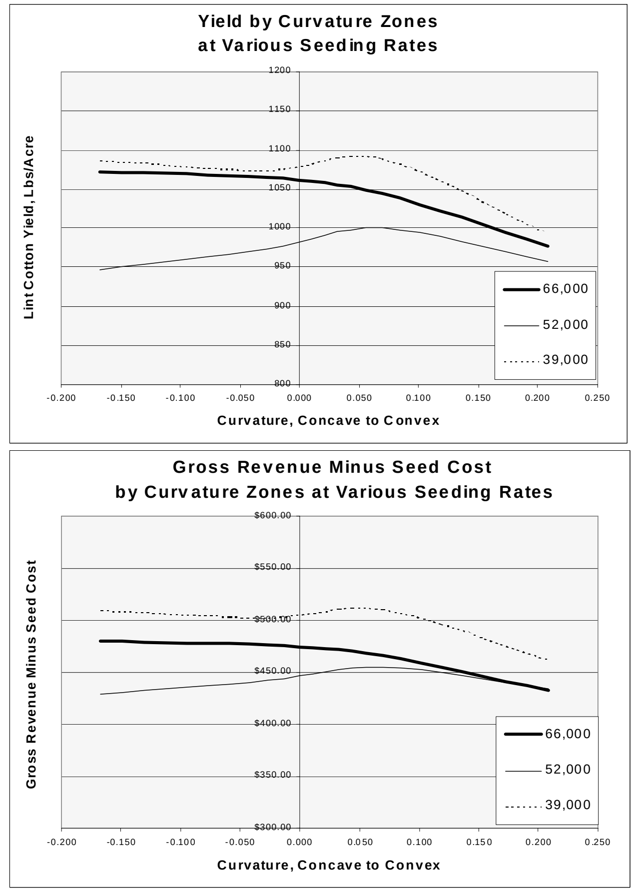
Figure 3. Soil-color classes (upper left); vegetation index from previous season (upper right); curvature zones (lower left); and soil texture zones (lower right).



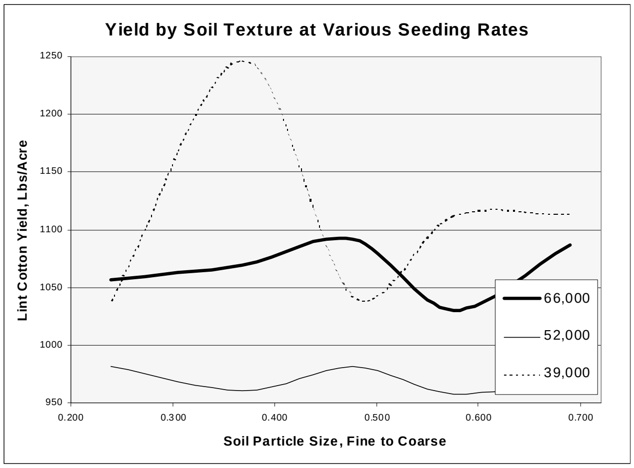
Graphs 3-4. Relationships between seeding rate and lint yield (top) and between seeding rate and revenue, within soil color classes.

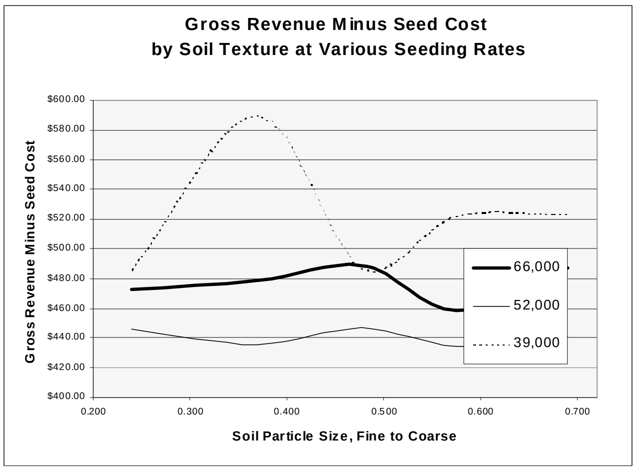


Graphs 5-6. Relationships between seeding rate and lint yield(top), and between seeding rate and revenue, within previous-season NDVI zones.



Graphs 7-8. Relationships between seeding rate and lint yield (tip), and between seeding rate and revenue, within curvature zones (poorly to well-drained).





Graphs 9-10. Relationships between seeding rate and lint yield (top), and between seeding rate and revenue, within soil-texture zones (fine to coarse).