

# **Using ArcGIS for Yield Data Analysis**

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## **ABSTRACT**

ESRI's ArcMap offers farmers and crop consultants a powerful tool for viewing and analyzing crop yield data. Many farmers are collecting the data at harvest, but they do not know how to use the data to make management decisions. This presentation discusses the methods, tools, and techniques that will help farmers and their crop consultants make sense of yield data and look at it in a way that will help them better manage their farming operations. These techniques are based on the work of the Foundation for Agronomic Research as part of the USDA-CSREES IFAFS project

## **INTRODUCTION**

Booth and Mitchell (Booth and Mitchell, 2001) identified 4 steps in a GIS project. They are:

1. Identify project objectives
2. Create the project database
3. Analyze the data
4. Present the results

These steps comprise the outline of this paper. Presentation of results is limited to map layers within ArcMap.

## **IDENTIFYING PROJECT OBJECTIVES**

One of the most commonly asked questions in precision agriculture is "What can I do with all of the yield data I'm collecting?" There are, in fact, hundreds of analyses that one could do. Understanding which one(s) to select requires that we first know the questions we want to answer. We limit our questions to those appropriate for a single field with a history of geo-referenced yield monitor data. The questions we address are the types asked by farmers and their advisors as they attempt to evaluate crop production practices.

The questions we address can be divided into two primary categories: 1) those based upon yield data for one crop and 2) those based upon yield data for several crops. Within these categories are two additional groups: analyses based upon A) whole-field average yields and B) site-specific yields.

- I. Yield data for one crop
  - A. Whole field average yields
    1. On average, was the field a profitable enterprise this year?
    2. On average, did the field meet production goals?
    3. On average, what were the per-unit production costs for the field?
  - B. Site-specific yields
    1. What areas of the field were profitable this year?
    2. What areas of the field met or exceeded production goals?
    3. How did per-unit production costs vary within the field?
- II. Yield data for several crops
  - A. Whole field average yields
    1. On average, what is the profitability of the field?
    2. Has the field been a consistently profitable enterprise?
    3. On average, what is the production level of the field?
    4. On average, how have yields compared to yield goals?
    5. Has the field consistently met or exceeded production goals?
    6. On average, what are the per-unit costs of production?

B. Site-specific yields

1. What is the average profitability of areas within the field?
2. What areas in the field have been consistently profitable?
3. What is the average production level of areas within the field?
4. How have average yields within the field compared to yield goals?
5. What areas in the field have consistently met or exceeded production goals?
6. What are the average per-unit costs of production of areas within the field?

Our analyses will focus on answering these production-oriented questions.

### CREATING THE PROJECT DATABASE

The general types of data needed to perform all of the analyses required to answer our list of questions are listed in **Table 1**.

Table 1. Types of data required for answering basic production questions for an individual field.

Layer	Source	Format
Field boundary	Farmer/adviser	Shapefile
Geo-referenced, cleaned yield maps	Farmer/adviser	Shapefile
Whole-field yield goals	Farmer/adviser	Farmer/adviser records
Yield goal maps (if available)	Farmer/adviser	Shapefile
Whole-field costs of production	Farmer	Farmer records
Variable input application maps (if available)	Farmer/adviser	Shapefile
Prices received for commodities	Farmer	Farmer records

### Assembling the Project Data

In our example, we will use data from an approximately 24 acre field at the Southwest Research and Outreach Center of the University of Minnesota, located near Lamberton, MN in Redwood County. Corn was grown in 1998 and 2000 and soybeans were grown in 1999 and 2001. Crops were harvested using a yield monitor coupled with a GPS receiver. The data collected are listed in **Table 2**.

Table 2. Data collected for analysis of yield data from the Lamberton, MN field.

Layer	Name	Format
Field boundary	Boundary	Shapefile
1998 corn grain yield map (cleaned)	1998CleanedCrn	Shapefile
1999 soybean yield map (cleaned)	1999CleanedSoy	Shapefile
2000 corn grain yield map (cleaned)	2000CleanedCrn	Shapefile
2001 soybean yield map (cleaned)	2001CleanedSoy	Shapefile
Whole-field yield goals	Scientist records	Text file
1998 whole-field total costs of production <sup>1</sup>	SW_MN_FBMA_1998	pdf file
1999 whole-field total costs of production <sup>2</sup>	SW_MN_FBMA_1999	pdf file
2000 whole-field total costs of production <sup>3</sup>	SW_MN_FBMA_2000	pdf file
2001 whole-field total costs of production <sup>4</sup>	SW_MN_FBMA_2001	pdf file
Minnesota historical corn prices (1998-2001) <sup>5</sup>	cmdty144	CSV file
Minnesota historical soybean prices (1998-2001) <sup>5</sup>	cmdty146	CSV file

<sup>1</sup>Southwestern Minnesota Farm Business Management Association, 1999

<sup>2</sup>Southwestern Minnesota Farm Business Management Association, 2000

<sup>3</sup>Southwestern Minnesota Farm Business Management Association, 2001

<sup>4</sup>Southwestern Minnesota Farm Business Management Association, 2002

<sup>5</sup>USDA-NASS, 2003

### Field boundary

The field boundary layer was obtained from an ATV equipped with a GPS receiver and mapping software. The ATV was driven around the field and the geo-referenced path recorded.

### Yield maps

Yield data were collected from a yield monitor installed on a harvester. Coupled to the monitor was a GPS receiver.

### Whole-field yield goals

No within-field yield goals existed for this field. The whole-field yield goals were obtained from the scientists working on the experimental area.

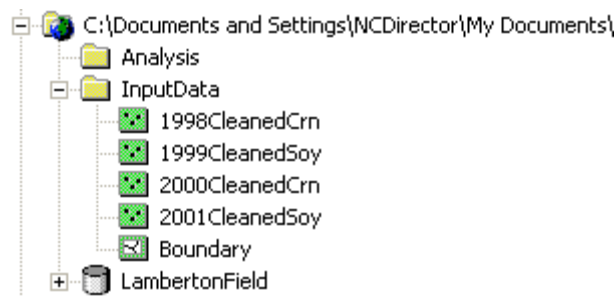
### Whole-field total costs of production

Whole-field costs of production were not recorded for the field. Consequently, surveyed average costs of production were used for corn and soybeans grown on owned land in southwest Minnesota. The surveys were published by the Southwestern Minnesota Farm Business Management Association.

### Commodity prices

Actual prices received by the experiment station for corn and soybeans grown on this field were not recorded. Consequently, we used historical average prices received by Minnesota farmers, as recorded by the National Agricultural Statistics Service (USDA-NASS, 2003).

Spatial data was organized using ArcCatalog and a new Personal Geodatabase created (named LambertonField), shown below:



The whole-field yield goals, total costs, and prices received were extracted from the state and regional data sets (text, pdf, and CSV files) and assembled into **Table 3**.

Table 3. Whole-field data collected from state and regional datasets.

Year	Commodity	Yield goal	Total costs	Price
		(bu/acre)	(\$/acre)	(\$/bu)
1998	Corn	140	272.13	1.71
1999	Soybeans	45	194.71	4.42
2000	Corn	140	252.91	1.71
2001	Soybeans	45	184.69	4.32

## ANALYZING THE DATA

### Calculating Whole-Field Average Yields

The data in Table 3 provided nearly all of the information needed to answer our production questions at the whole-field scale. The only pieces missing were the average crop yields for each year. Historically, farmers calculate field-average yield by dividing the total bushels of grain harvested from the field by the field area. This method of calculating average yield is very reliable, assuming that weights and grain moisture are accurately measured. In our example, we did not have access to these data. We did, however, have the yield map shapefiles from which we extracted this information.

Yield monitors record yield at thousands of places within the field, creating a population of geo-referenced yields for the field. We were interested in finding the mean of this population of yields.

The screenshot shows the ArcMap - ArcView application window. The title bar reads "YieldAnalysis98\_01 - ArcMap - ArcView". The menu bar includes "File", "Edit", "View", "Insert", "Selection", "Tools", "Window", and "Help". The toolbar contains icons for file operations (New, Open, Save, Print), editing (Cut, Paste, Copy, Undo, Redo), and navigation (Zoom In, Zoom Out, Full Extent, Measure, Help). The "Layers" panel on the left shows a list of layers: "2001CleanedSoy", "2000CleanedCrn", "1999CleanedSoy", "1998CleanedCrn" (selected), and "Boundary". The map area displays a field with a boundary and a hatched pattern. The status bar at the bottom shows the coordinates "316160.49 4901796.90 Meters".

**Attributes of 1998CleanedCrn**

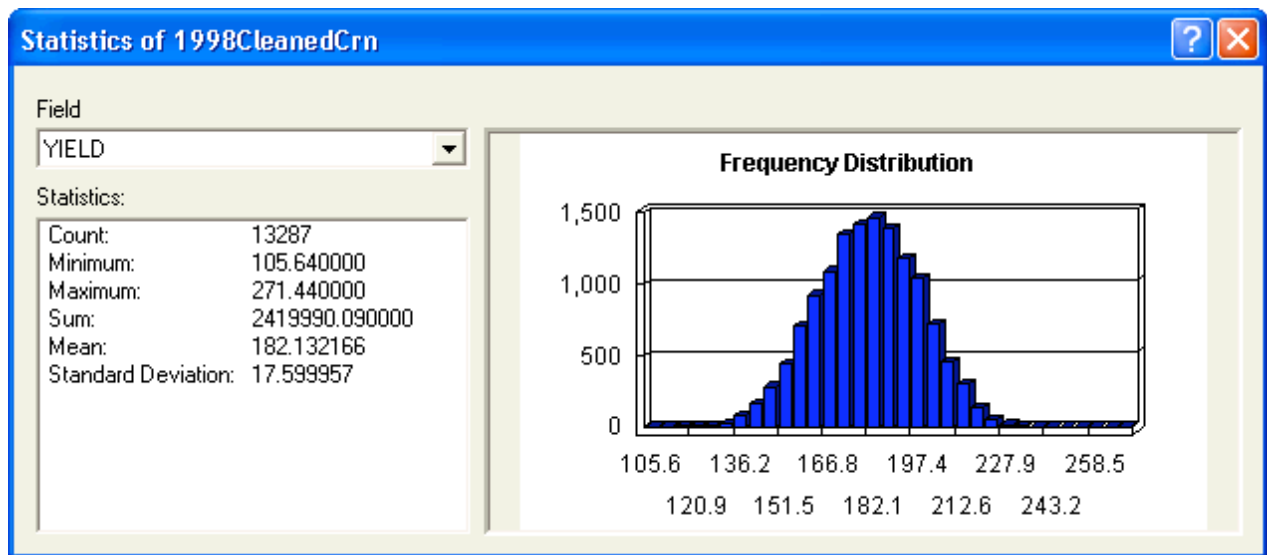
	FIELD	LOAD	GRAIN	YIELD	MOIST	EL
	F1: pragsoybean	L1:	Corn			
	F1: pragsoybean	L1:	Corn			
	F1: pragsoybean	L1:	Corn			
	F1: pragsoybean	L1:	Corn			
	F1: pragsoybean	L1:	Corn			
	F1: pragsoybean	L1:	Corn			

Record: 0 Show: All Selected Records

Context Menu (over YIELD column):

- Sort Ascending
- Sort Descending
- Summarize...
- Calculate Values...
- Statistics...**
- Freeze/Unfreeze Column
- Delete Field

This opened the Statistics window where a few descriptive statistics and a frequency distribution were displayed. The mean yield for the 1998 corn grain data was 182 bu/acre.



This procedure was performed for each yield layer. These field-average yields were added to the data in Table 3 to create **Table 4**. This table contained all the information we needed to answer production questions at the field-scale.

Table 4. Whole-field data for the Lamberton, MN field.

Year	Commodity	Yield goal	Average yield	Total costs	Price
		(bu/acre)	(bu/acre)	(\$/acre)	(\$/bu)
1998	Corn	140	182	272.13	1.71
1999	Soybeans	45	43	194.71	4.42
2000	Corn	140	157	252.91	1.71
2001	Soybeans	45	42	184.69	4.32

### Answering Questions Based upon Whole Field Average Yields

(Refer to outline in IDENTIFYING PROJECT OBJECTIVES)

#### Yield Data for One Crop

**I.A.1. On Average, was the field a profitable enterprise this year?** Answering this question required average yield, total costs, and crop price:

$$[1] \quad \text{Average net return} = (\text{Average yield})(\text{Price}) - \text{Total costs}$$

For instance, in 1998, the average corn yield for the field was 182 bu/A, crop price was \$1.71/bu, and total costs were \$272.13/acre. Therefore, average net return was:

$$\text{Average net return} = (182 \text{ bu/acre})(\$1.71/\text{bu}) - \$272.13/\text{acre} = \$39.09/\text{acre}$$

In 1998, the field was a profitable enterprise with a positive average net return of \$39.09/acre.

**I.A.2. On average, did the field meet production goals?** To answer this question, we needed only the average yield and the yield goal. There were two ways to compare average yield to yield goal: 1) subtracting yield goal from average yield and 2) dividing average yield by the yield goal and multiplying the result by 100 to convert to a percentage (relative yield).

By subtraction, the 1998 average yield exceeded the 1998 yield goal by 42 bu/acre. Therefore, the 1998 average yield was 130% of the yield goal for that year, calculated as follows:

$$\begin{aligned}
 [2] \quad \text{Relative yield} &= (\text{Average yield} / \text{Yield goal}) \times 100 \\
 &= [(182 \text{ bu/acre}) / (140 \text{ bu/acre})] \times 100 \\
 &= 130\%
 \end{aligned}$$

In 1998, corn grain yield not only met but exceeded the production goal.

**I.A.3. On average, what were the per-unit production costs for the field?** Per-unit costs are one measure of production efficiency – the lower the costs, the more efficient the operation. Knowing per-unit costs provides the farmer with insight into how profitable the field can be under different commodity market conditions. Calculating per-unit costs required average yield and total costs:

$$[3] \quad \text{Per-unit cost} = \text{Total cost} / \text{average yield}$$

For the 1998 corn yield data:

$$\begin{aligned}
 \text{Per-unit cost} &= (\$272.13/\text{acre}) / (182 \text{ bu/acre}) \\
 &= \$1.50/\text{bu}
 \end{aligned}$$

For this field in 1998, corn was produced for \$1.50/bu. As long as commodity market prices stayed above this level, the field remained profitable.

### Yield Data for Several Crops

**II.A.1. On average, what is the profitability of the field?** To answer this question, we determined the average net return for each crop, using equation [1] above and the data in Table 4. The results of these calculations are shown in **Table 5**.

Table 5. Average net returns for each crop.

Year	Commodity	Average yield	Total costs	Price	Average net return
		(bu/acre)	(\$/acre)	(\$/bu)	(\$/acre)
1998	Corn	182	272.13	1.71	39.09
1999	Soybeans	43	194.71	4.42	(4.65)
2000	Corn	157	252.91	1.71	15.56
2001	Soybeans	42	184.69	4.32	(3.25)

Averaged over the 4-yr. period, the average profitability was:

$$\begin{aligned}
 4\text{-yr average net return} &= (39.09 - 4.65 + 15.56 - 3.25) / 4 \\
 &= \$11.69/\text{acre}
 \end{aligned}$$

The average profitability of the corn crop was:

$$\begin{aligned} 2\text{-yr average corn net return} &= (39.09 + 15.56) / 2 \\ &= \$27.33/\text{acre} \end{aligned}$$

The average profitability of the soybean crop was:

$$\begin{aligned} 2\text{-yr average soybean net return} &= (-4.65 - 3.25) / 2 \\ &= (\$3.95)/\text{acre} \end{aligned}$$

Corn has been a profitable crop, averaging \$27.33/acre over the last two seasons it was grown. Soybeans have not been profitable, averaging (\$3.95)/acre in the last seasons they were grown.

**II.A.2. Has the field been a consistently profitable enterprise?** To answer this question, we looked at the average net returns during the 1998-2001 period. A new column was added to Table 5 containing an indicator variable (1 = positive net return, 0 = net return equal to or less than 0) (**Table 6**).

Table 6. Average net returns with a bivariate (yes/no) indicator of profitability.

Year	Commodity	Average yield	Total costs	Price	Average net return	Profitable? (1 = yes, 0 = no)
		(bu/acre)	(\$/acre)	(\$/bu)	(\$/acre)	
1998	Corn	182	272.13	1.71	39.09	1
1999	Soybeans	43	194.71	4.42	(4.65)	0
2000	Corn	157	252.91	1.71	15.56	1
2001	Soybeans	42	184.69	4.32	(3.25)	0

To address the question of consistency in profit, we examined how many of the last 4 years had positive net returns. To do this, we simply summed all of the numbers in the last column:

$$\begin{aligned} \text{Number of years with profit} &= 1 + 0 + 1 + 0 \\ &= 2 \text{ of the last 4 years.} \end{aligned}$$

Corn was a consistently profitable crop, with positive net returns in 2 of the last 2 years. Soybeans were a consistently unprofitable crop, with no positive net returns in 2 of the last 2 years.

**II.A.3. On average, what is the production level of the field?** This question was answered for each crop grown on the field. The only data needed were the average yields for each season. Corn yield over the past 2 corn-growing seasons was  $(182 + 157) / 2 = 170$  bu/acre. Average soybean yield was 43 bu/acre.

**II.A.4. On average, how have yields compared to yield goals?** Addressing this question required we first perform the calculation in equation [2] on all crop yields, shown in **Table 7**.



Table 7. Relative yields (percent of annual yield goal) for each crop year.

Year	Commodity	Yield goal	Average yield	Relative yield
		(bu/acre)	(bu/acre)	(% of yield goal)
1998	Corn	140	182	130
1999	Soybeans	45	43	96
2000	Corn	140	157	112
2001	Soybeans	45	42	93

Next the relative yields were averaged for each crop. The average relative yield of corn was  $(130 + 112) / 2 = 121\%$  of the annual yield goals. The average relative yield of soybeans was 95%. Therefore, corn has been exceeding the yield goals and soybeans have been falling just short.

**II.A.5. Has the field consistently met or exceeded production goals?** Answering this question required the addition of a column to Table 7 for an indicator variable (1 = yield goals met or exceeded, 0 = yield goals not attained) (**Table 8**).

Table 8. Relative yields with a bivariate (yes/no) indicator of meeting yield goals.

Year	Commodity	Yield goal	Average yield	Relative yield	Yield goals met? (1 = yes, 0 = no)
		(bu/acre)	(bu/acre)	(% of yield goal)	
1998	Corn	140	182	130	1
1999	Soybeans	45	43	96	0
2000	Corn	140	157	112	1
2001	Soybeans	45	42	93	0

To address the question of consistency in meeting or exceeding yield goals, we examined how many of the last 4 years had relative yields at or above 100%. To do this, we simply summed all of the numbers in the last column:

$$\begin{aligned} \text{Number of years when yield goals met or exceeded} &= 1 + 0 + 1 + 0 \\ &= 2 \text{ of the last 4 years.} \end{aligned}$$

The corn crop consistently exceeded yield goals in 2 of the last 2 years. Soybeans came close to their yield goal, but consistently fell short.

**II.A.6. On average, what are the per-unit costs of production?** We used the data in Table 4 along with equation [3] to calculate per-unit production costs for each crop season (**Table 9**).

Table 9. Per-unit production costs for each cropping season.

Year	Commodity	Average yield	Total costs	Per-unit production cost
		(bu/acre)	(\$/acre)	(\$/bu)
1998	Corn	182	272.13	1.50
1999	Soybeans	43	194.71	4.53
2000	Corn	157	252.91	1.61
2001	Soybeans	42	184.69	4.40

The average per-unit costs of corn production were  $(1.50 + 1.61) / 2 = \$1.56/\text{bu}$ . Average per-unit costs of soybean production were \$4.47/bu.

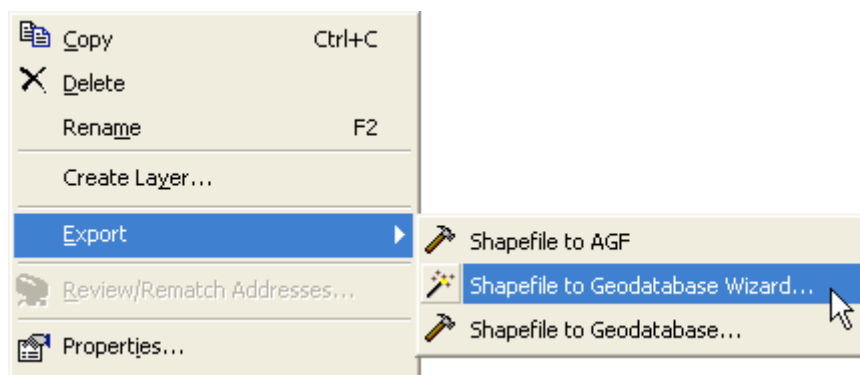
### Answering Questions Based upon Site-Specific Yields (Refer to outline in IDENTIFYING PROJECT OBJECTIVES)

In the previous section, we created a new map file named YieldAnalysis98\_01.mxd, added our field boundary and yield shapefiles, and then used ArcMap to calculate whole-field yield averages. These data were then assembled with our other information to create Table 4. This table contained whole-field yield goals, average yields, total costs, and commodity prices. This core data set was then used to answer all of the field-scale production questions we asked.

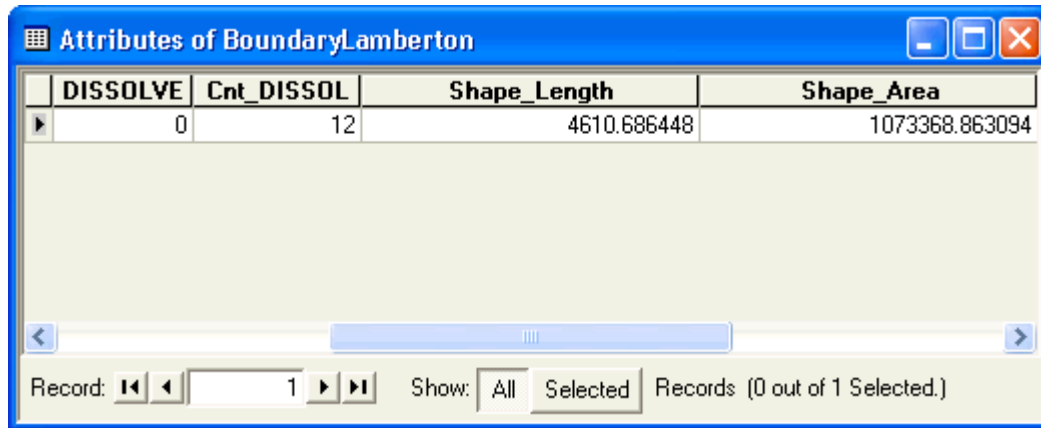
In this section, our core data set was a series of rasters that we created in ArcMap, using Spatial Analyst. Each raster corresponded to one entry in Table 4. We then input equations [1] through [3] into the Raster Calculator to create new rasters that answered our site-specific production questions.

### Creating Rasters of Entries in Table 4

Our original boundary shapefile did not contain any information about the extent of its area. To rectify this, we used ArcCatalog to export the shapefile to the personal geodatabase we created earlier named LamberttonField. In ArcCatalog, we right-clicked on the Boundary shapefile and used the Geodatabase Wizard to guide us through the export procedure.



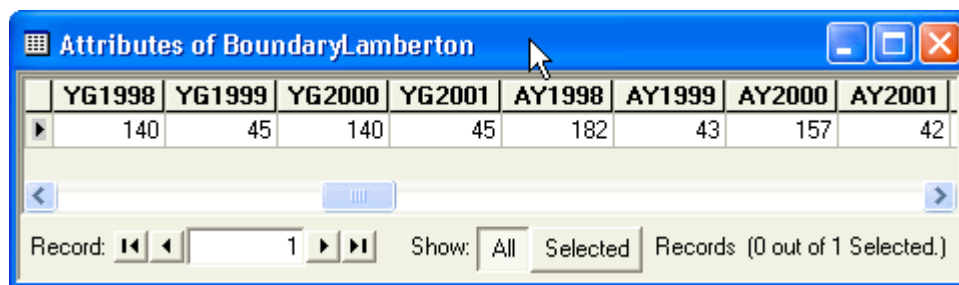
This new boundary layer was named BoundaryLamberton and contained 2 new columns labeled Shape\_Length (ft.) and Shape\_Area (ft<sup>2</sup>). The 1073368.863094 ft<sup>2</sup> calculated for the newly created BoundaryLamberton feature class corresponds to 24.6 acres.



DISSOLVE	Cnt DISSOL	Shape_Length	Shape_Area
0	12	4610.686448	1073368.863094

Because the BoundaryLamberton layer contained more complete information than the original Boundary shapefile, the Boundary shapefile was deleted from the YieldAnalysis98\_01 map file and the BoundaryLamberton layer added in its place.

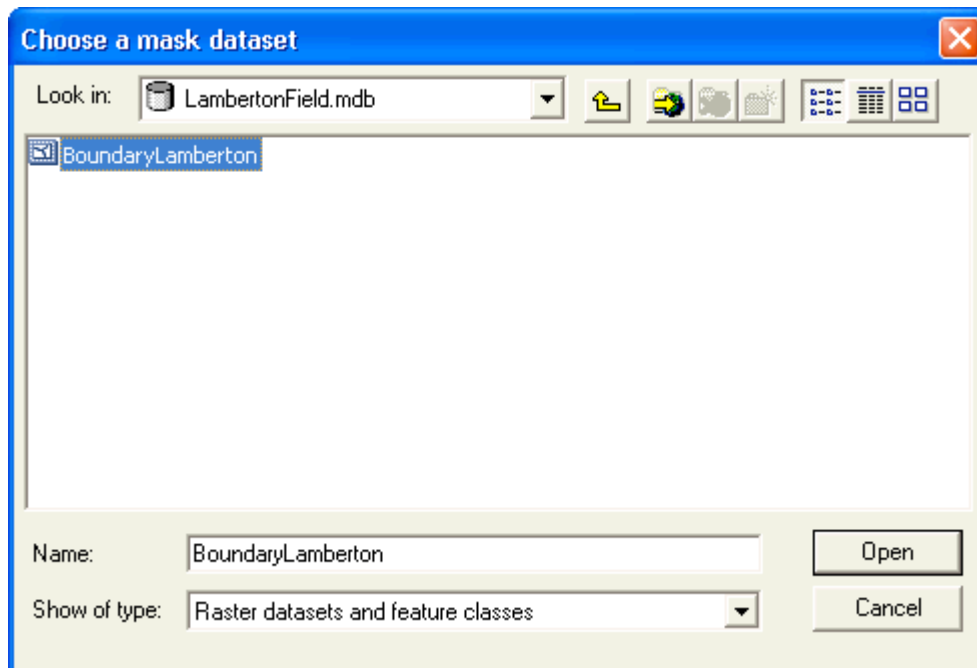
Next, we opened the attribute table for BoundaryLamberton, then click Options | Add Field... to create a new column of data. The first field we created was a column to hold a reminder of the grid area we wanted to use as a standard. We wanted a grid that was 30 ft. on each side (900 ft<sup>2</sup>). The new column was labeled Grid\_Size\_SqFt and 900 was typed in as the entry. The next field was labeled YG1998 and the 1998 yield goal from Table 4 was entered. We repeated this process of adding new fields and entering data until all of the data from Table 4 had been entered. We used the naming convention XYYYYY for the column headings, where XX = YG, AY, TC, and PR for yield goal, average yield, total costs, and price, respectively. YYYY was the year.



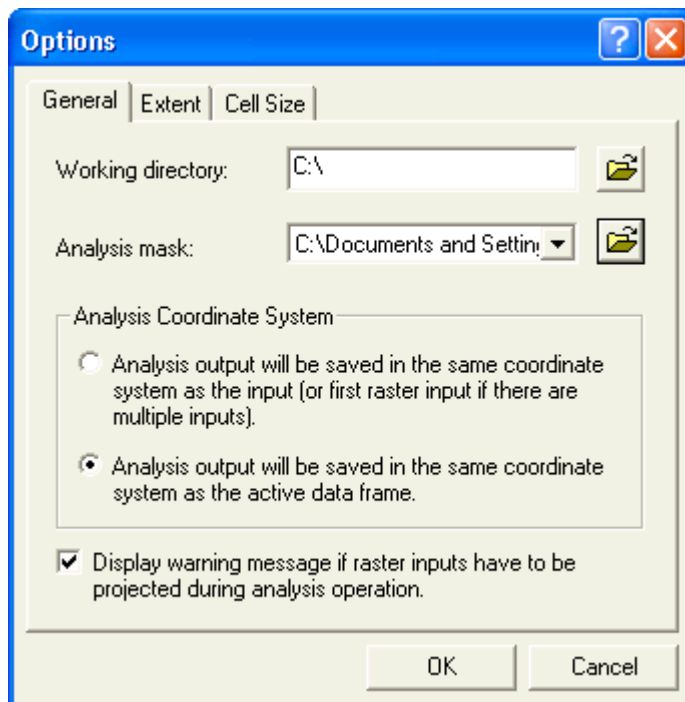
YG1998	YG1999	YG2000	YG2001	AY1998	AY1999	AY2000	AY2001
140	45	140	45	182	43	157	42

Next, Spatial Analyst was used to create rasters of all of these new fields in the BoundaryLamberton attribute table (Spatial Analyst | Convert | Features to Raster...).

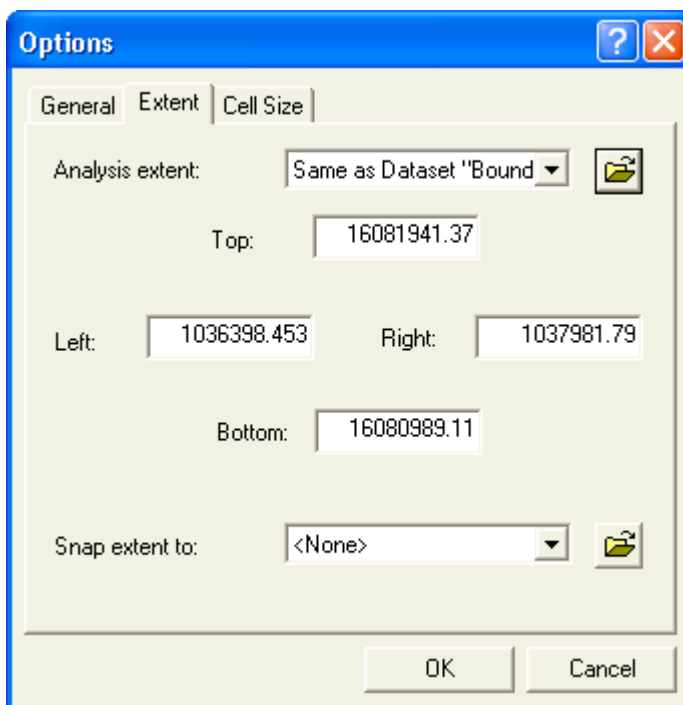
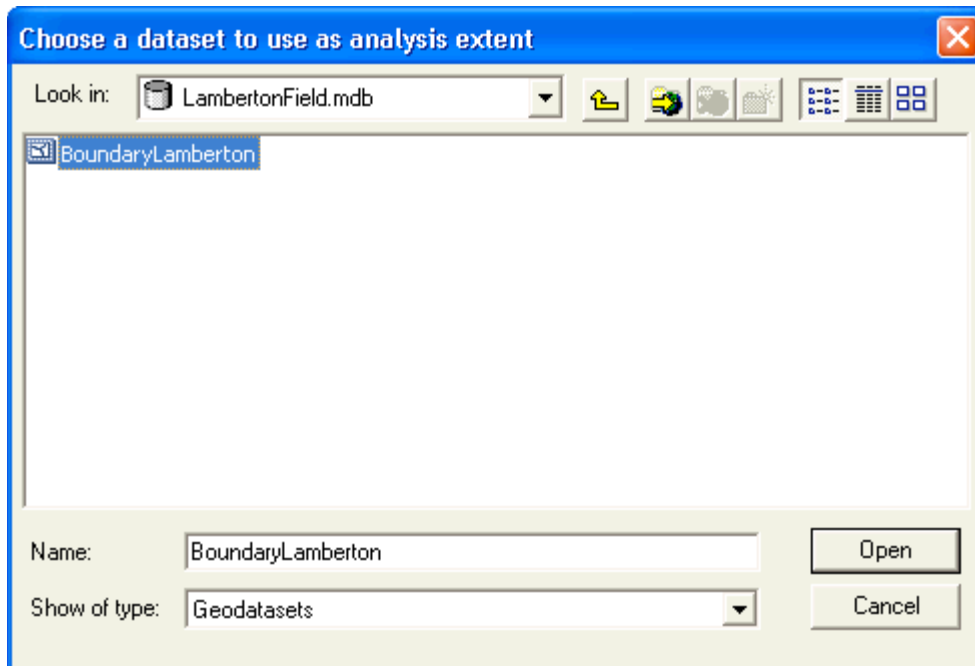
First, options were configured in Spatial Analyst (Spatial Analyst | Options). On the General tab in the Options dialog box, we selected the BoundaryLamberton feature class in the LamberttonField personal geodatabase as the Analysis mask.



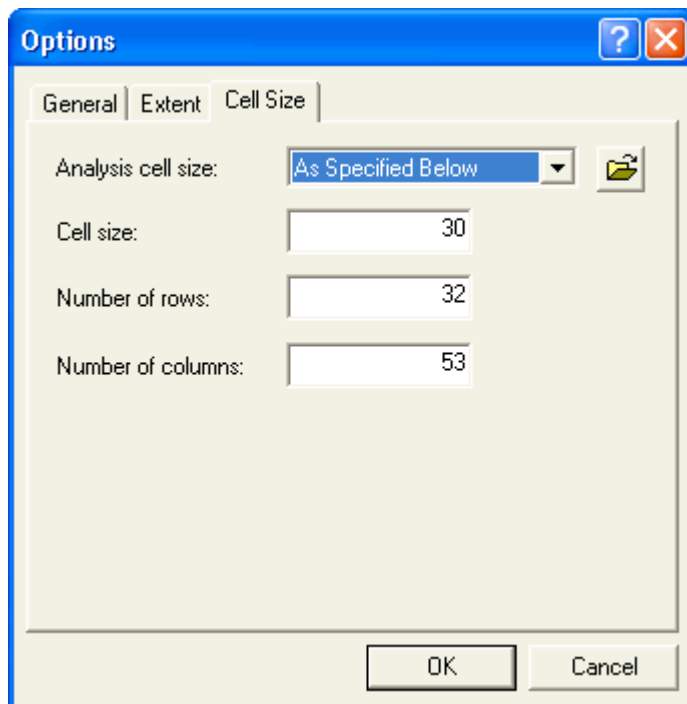
Next, we selected "Analysis output will be saved in the same coordinate system as the active data frame", which was feet.



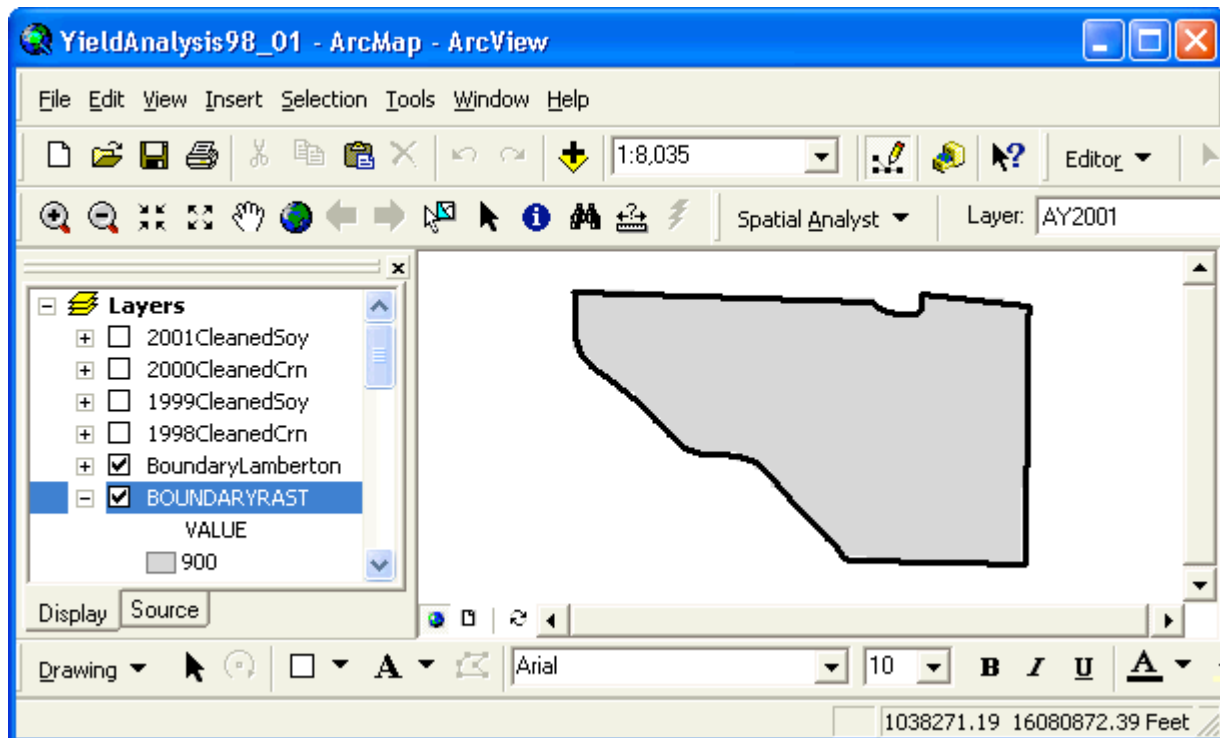
On the Extent tab, we selected again the BoundaryLamberton feature class in the LamberttonField personal geodatabase as the Analysis extent.



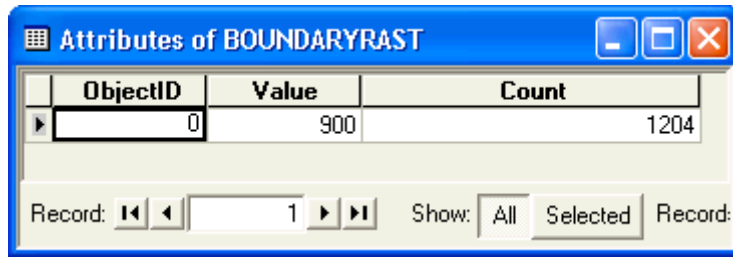
On the Cell Size tab, we specified a Cell size of 30 (ft).



Once the options had been specified, we began creating rasters. The first raster created was that of the Grid\_Size\_SqFt field, and was named BOUNDARYRAST. It was used to test how we were using the raster creation process.



After a visual inspection of the raster and its relationship to the BoundaryLamberton layer, a verification of the area covered by the raster was performed. The attribute table was opened to determine the number of entries (number of cells included in the raster), which was 1204.



ObjectID	Value	Count
0	900	1204

Record: 1 Show: All

Since each cell had an area of 900ft<sup>2</sup>, the total area covered by the raster was calculated as

$$1204 \text{ cells} \times 900 \text{ ft}^2/\text{cell} = 1083600 \text{ ft}^2,$$

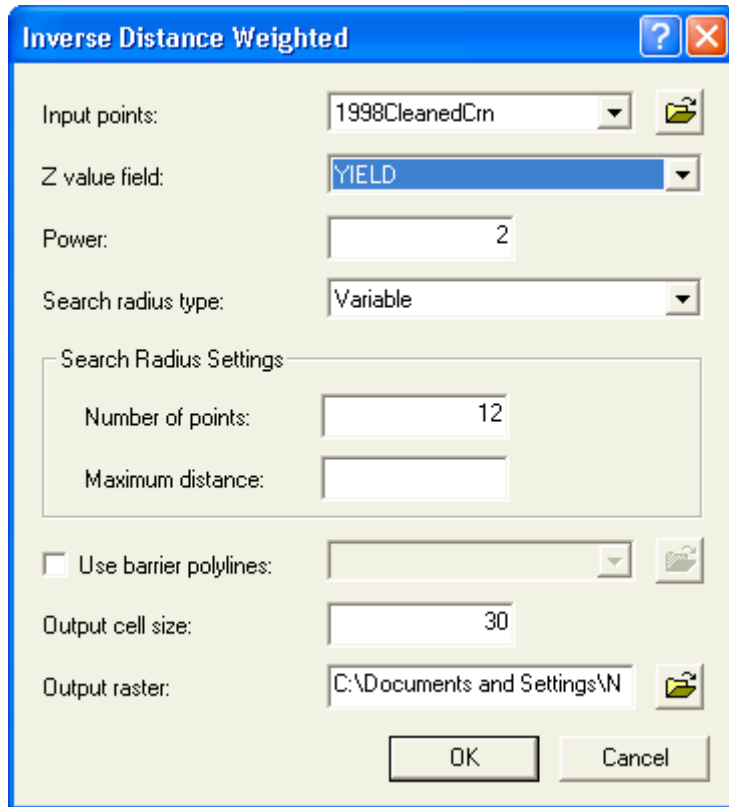
which is 24.9 acres, within 1% of the 24.6 acres calculated for the BoundaryLamberton layer during the export to the personal geodatabase.

Rasters were made of the remaining columns added to the BoundaryLamberton attribute table. The result was 17 new rasters in the Table of Contents of the map file, corresponding to the BOUNDARYRAST raster and the rasters corresponding to the 16 entries in the last 4 columns of Table 4.

- ☒ BoundaryLamberton
- ☐ BOUNDARYRAST
- ☐ PR2001
- ☐ PR2000
- ☐ PR1999
- ☐ PR1998
- ☐ TC2001
- ☐ TC2000
- ☐ TC1999
- ☐ TC1998
- ☐ AY2001
- ☐ AY2000
- ☐ AY1999
- ☐ AY1998
- ☐ YG2001
- ☐ YG2000
- ☐ YG1999
- ☐ YG1998

## Creating Rasters of Yield Maps

For yield maps, we used Spatial Analyst to create interpolation rasters. The interpolation method selected was inverse distance weighting with a Power of 2 (Spatial Analyst | Interpolate to Raster | Inverse Distance Weighted...). Yield was selected as the Z value field.



These new rasters were added to the Table of Contents in the map file.

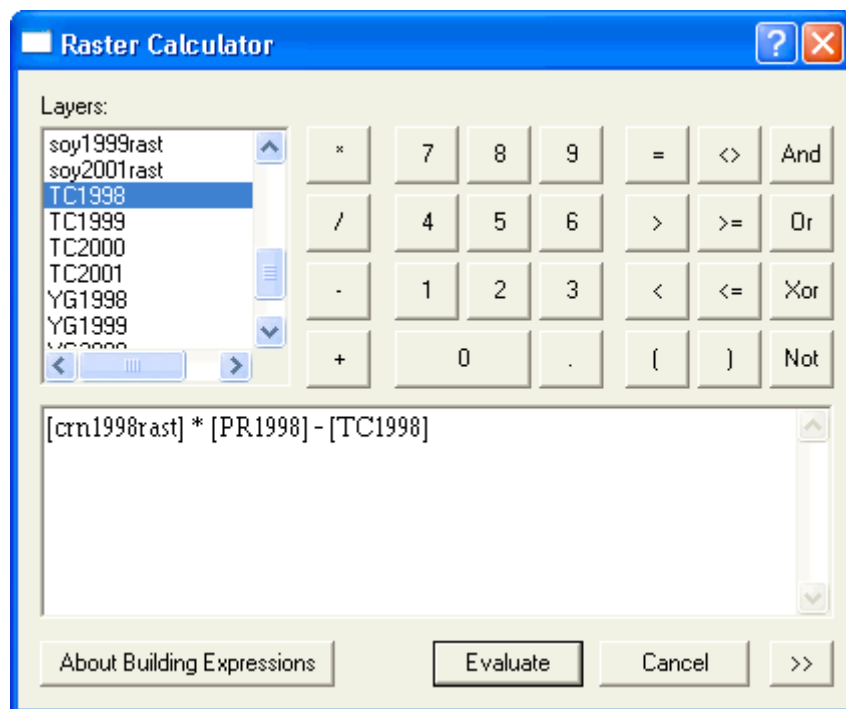
- ☐ soy2001rast
- ☐ crn2000rast
- ☐ soy1999rast
- ☐ crn1998rast

Once all of these rasters had been created we began answering site-specific production questions using the Raster Calculator in Spatial Analyst (Spatial Analyst | Raster Calculator).

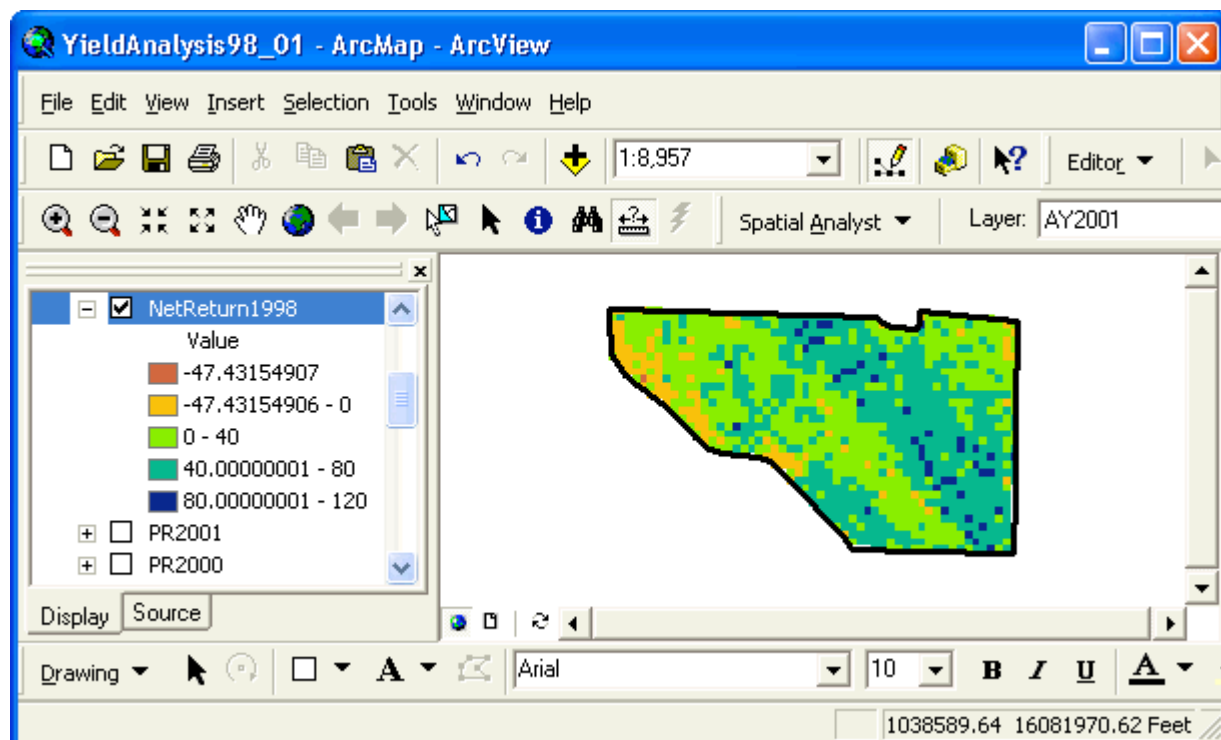
### Yield Data for One Crop

**I.B.1. What areas of the field were profitable this year?** To answer this question, we entered equation [1] (substituting site-specific yield for average yield) into the Raster Calculator, using the rasters for interpolated yield, crop price, and total costs. For the 1998 corn data, the rasters used were crn1998rast, PR1998, and TC1998.



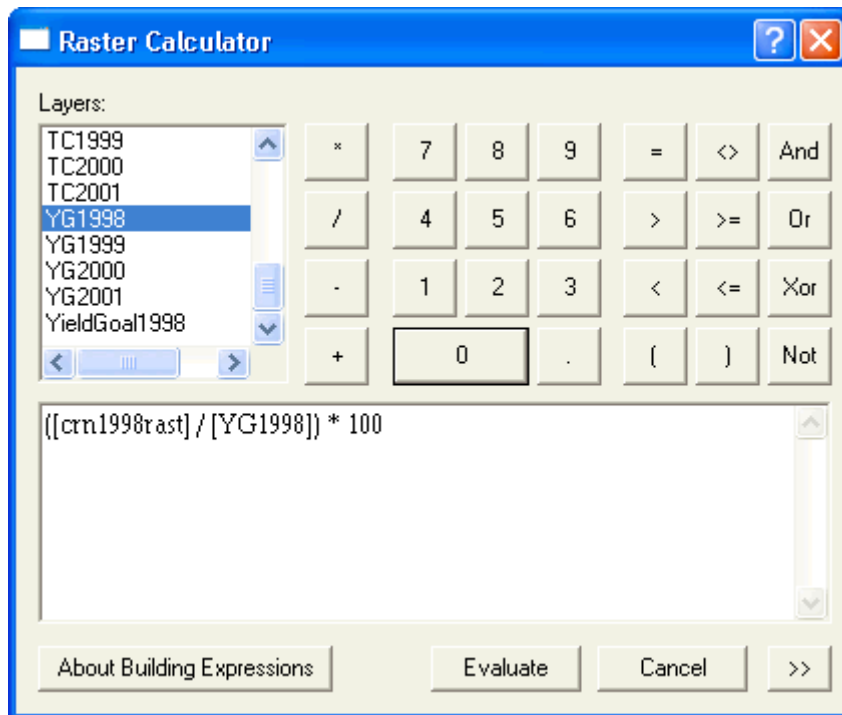


This created the following map of net returns:

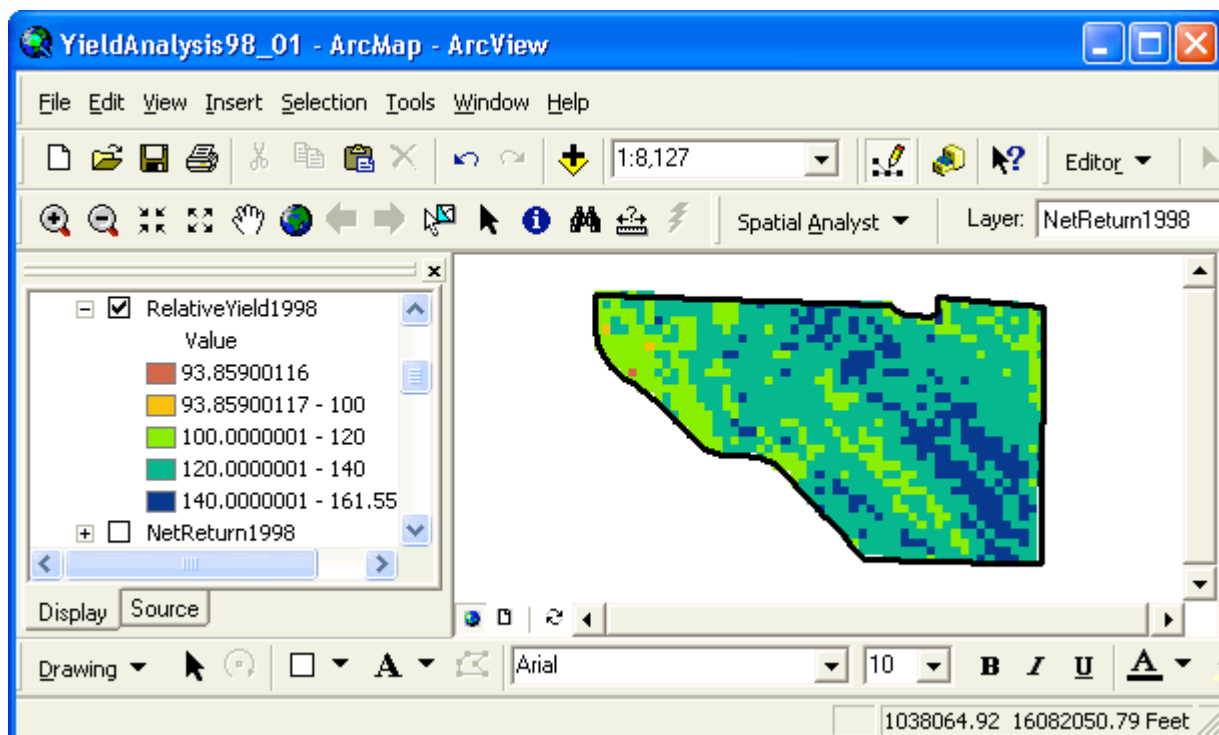


The highest profit area in the field in 1998 was in a zone extending from the north central border of the field to the southeast corner. The lowest profit area was along the northwest border of the field.

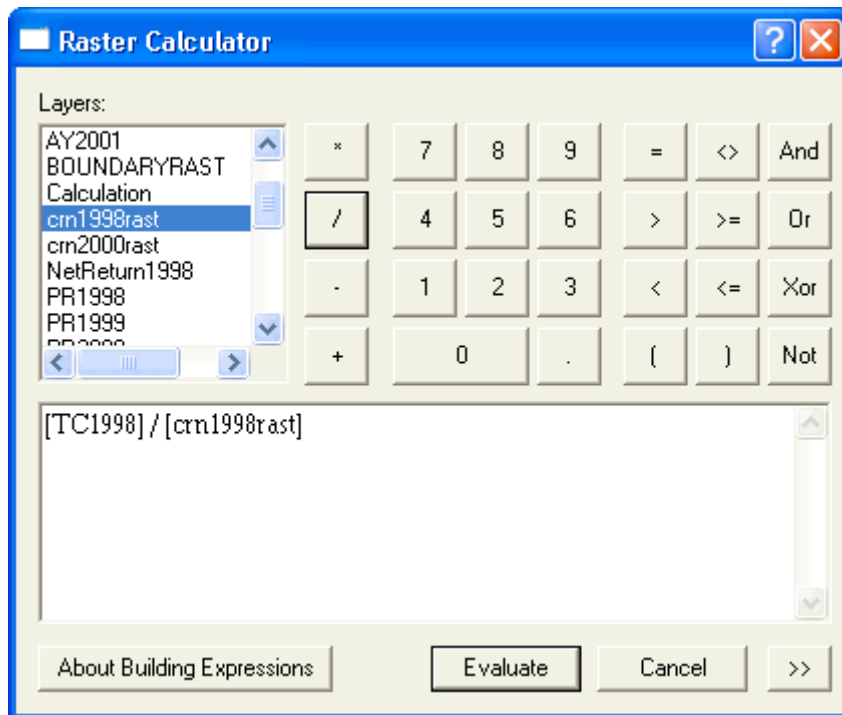
**I.B.2. What areas of the field met or exceeded production goals?** To answer this question for the 1998 corn yield data, we divided the interpolated corn yield raster (crn1998rast) by the whole-field yield goal raster (YG1998) then multiplied by 100 to convert to a percentage, akin to equation [2].



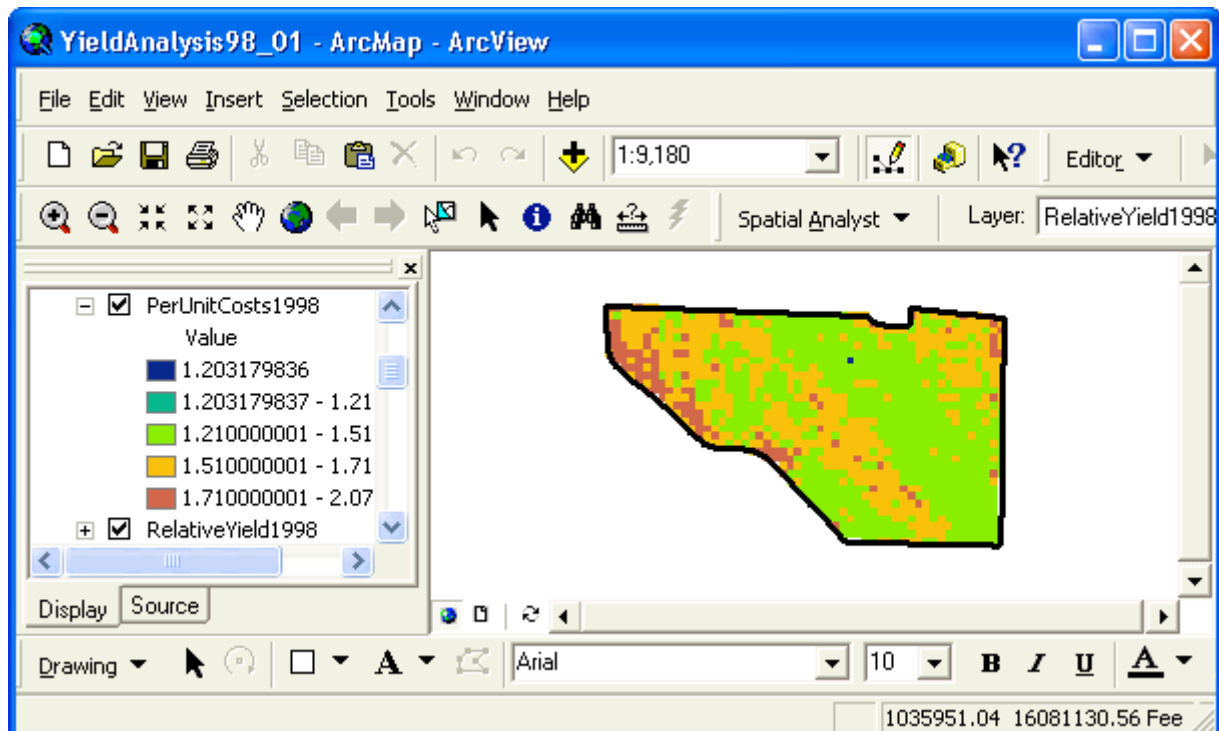
The resulting map showed that corn yield in practically all of the field exceeded the 1998 yield goal.



**I.B.3. How did per-unit production costs vary within the field?** Per-unit costs were calculated in a manner analogous to equation [3]. For the 1998 corn yield data, total costs (TC1998) were divided by the corn yield interpolated raster (crn1998ras).



The resulting map showed that the profitable regions identified above had per-unit production expenses ranging from \$1.21/bu to \$1.51/bu, which was about 20 – 50 cents per bushel below the \$1.71/bu market price in 1998.



## Yield Data for Several Crops

**II.B.1. What is the average profitability of areas within the field?** This question was answered by examining the average profitability of each crop. We calculated net return for each year, added the annual net returns together, then divided by 2 to obtain average net returns for the 2-yr period. The calculation for the 1998 and 2000 corn years are shown below. Average soybean net returns were calculated similarly.

**Raster Calculator**

Layers:

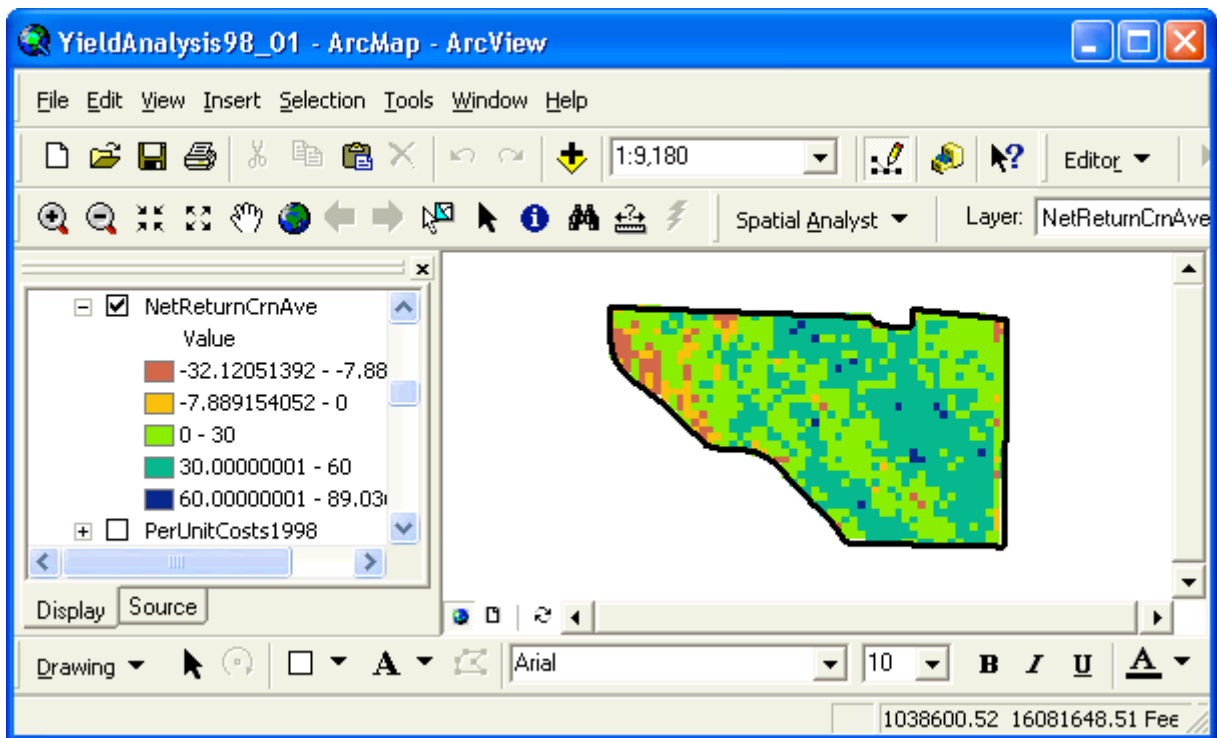
- PR2001
- RelativeYield1998
- soy1999rast
- soy2001rast
- TC1998
- TC1999
- TC2000**
- TC2001
- TC1998

Expression:

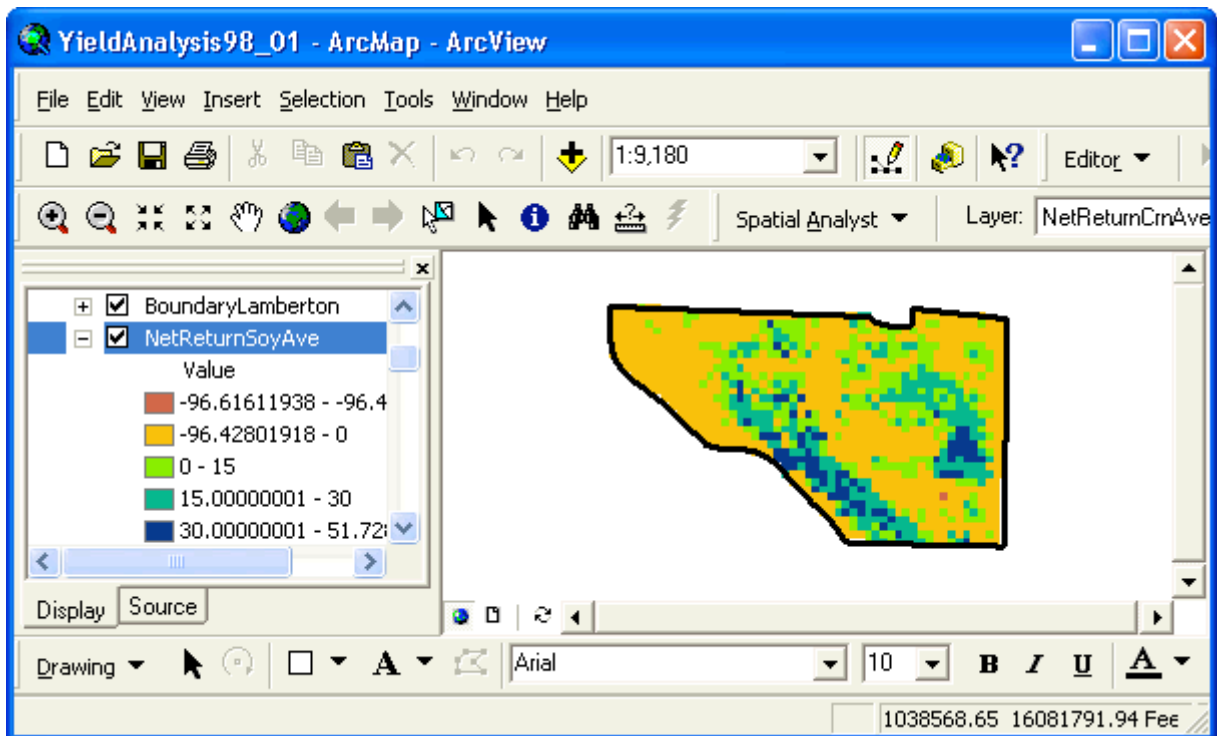
$$(((\text{[crn1998rast]} * \text{[PR1998]} - \text{[TC1998]}) + (\text{[crn2000rast]} * \text{[PR2000]} - \text{[TC2000]})) / 2$$

Buttons: About Building Expressions, Evaluate, Cancel, >>

The 2-yr. average net returns for corn are shown below.

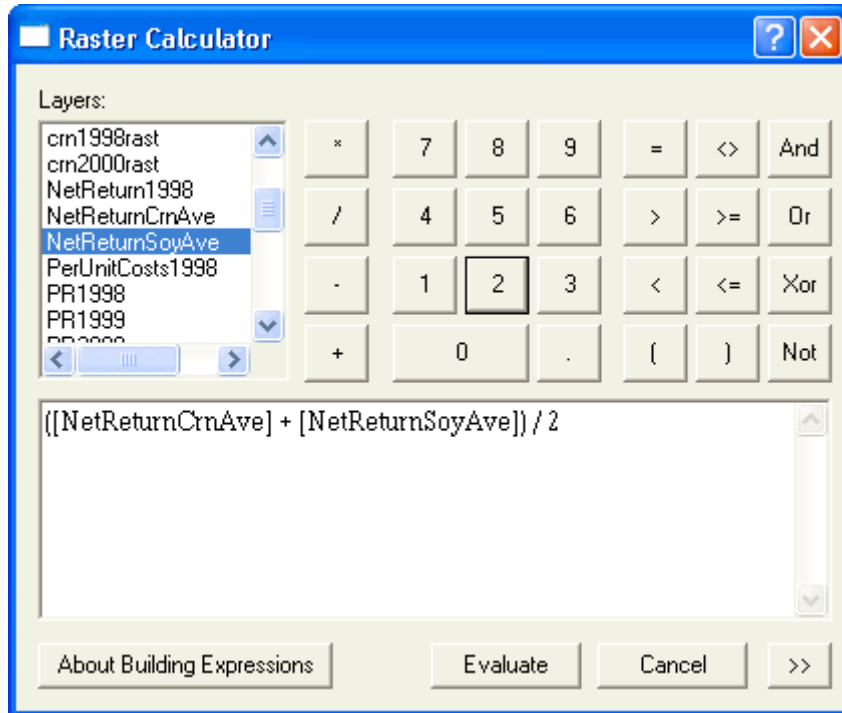


The 2-yr. average soybean net returns are shown below.

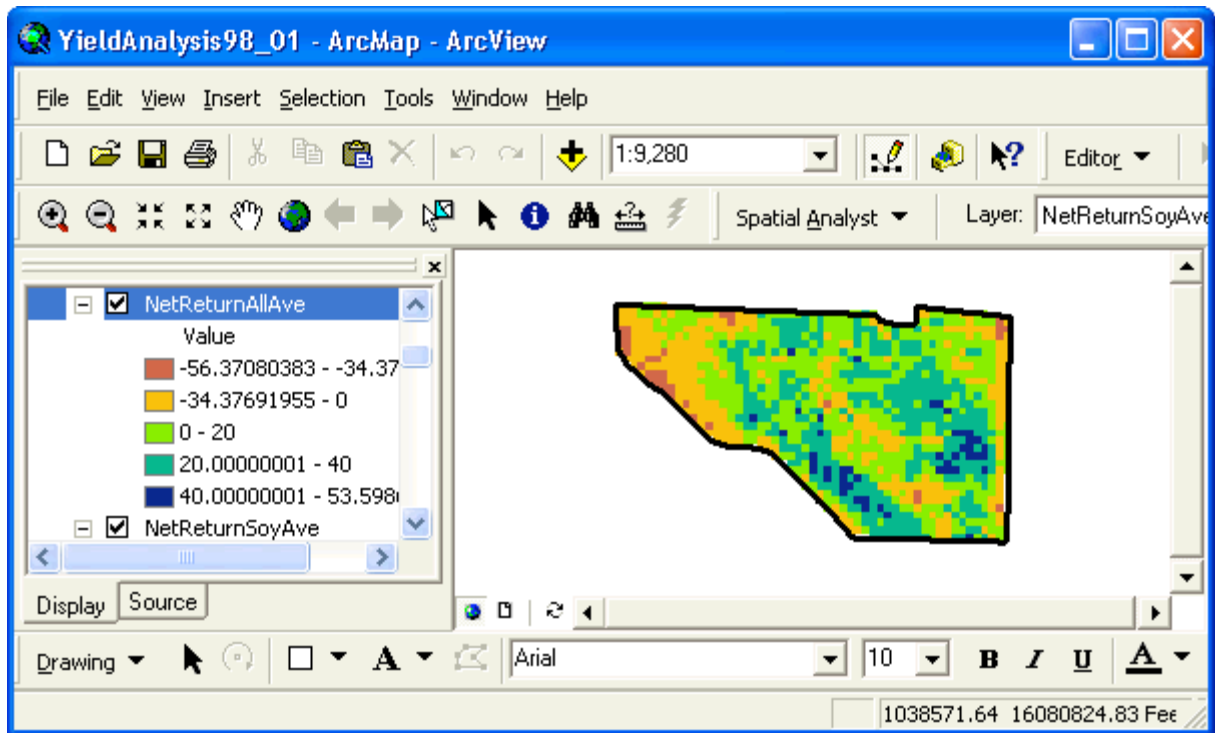


Averaged over 2 seasons, corn was profitable in most of the field. The extent of average soybean profitability was much more reduced. Generally, areas of higher average corn profitability corresponded to profitable soybean production as well.

The 4-yr. average profitability across all crops was calculated by averaging the 2-yr. average corn net return raster (NetReturnCrnAve) with the 2-yr. average soybean net return raster (NetReturnSoyAve):



The resulting map demonstrates the average profitability of the two parallel areas running northwest to southeast across the field.



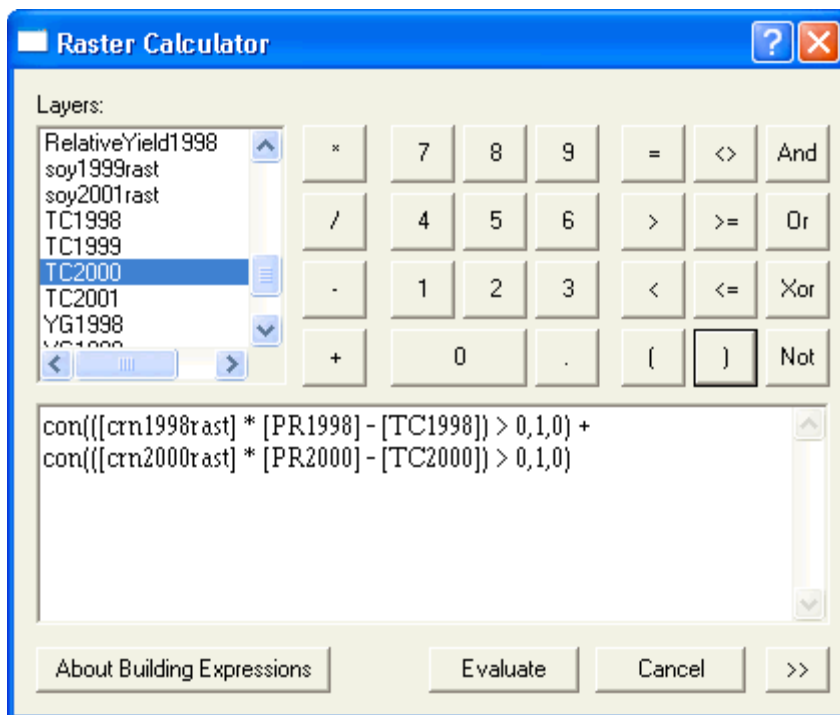
**II.B.2. What areas in the field have been consistently profitable?** This question, like the preceding one, required examining consistency in profit within crops first. We used the con function in the Raster Calculator to create a binary indicator raster (1 = profitable, 0 = unprofitable) for each crop, then we added these binary rasters together. The general form of the con function is:

con(condition, expression to use if true, expression to use if false)

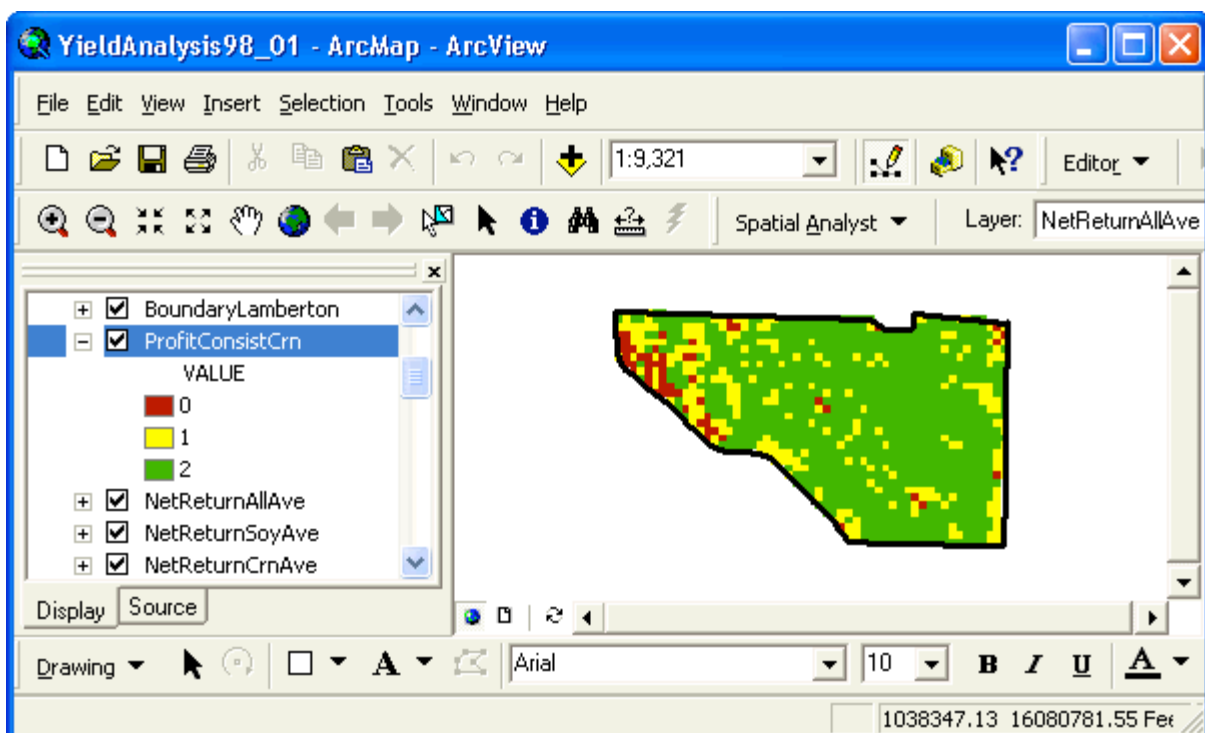
In our case, the general form of the con function is:

con(net return > 0, 1, 0)

For the 1998 and 2000 corn yield data, we wrote con functions for the net returns for each year, then added the functions together:

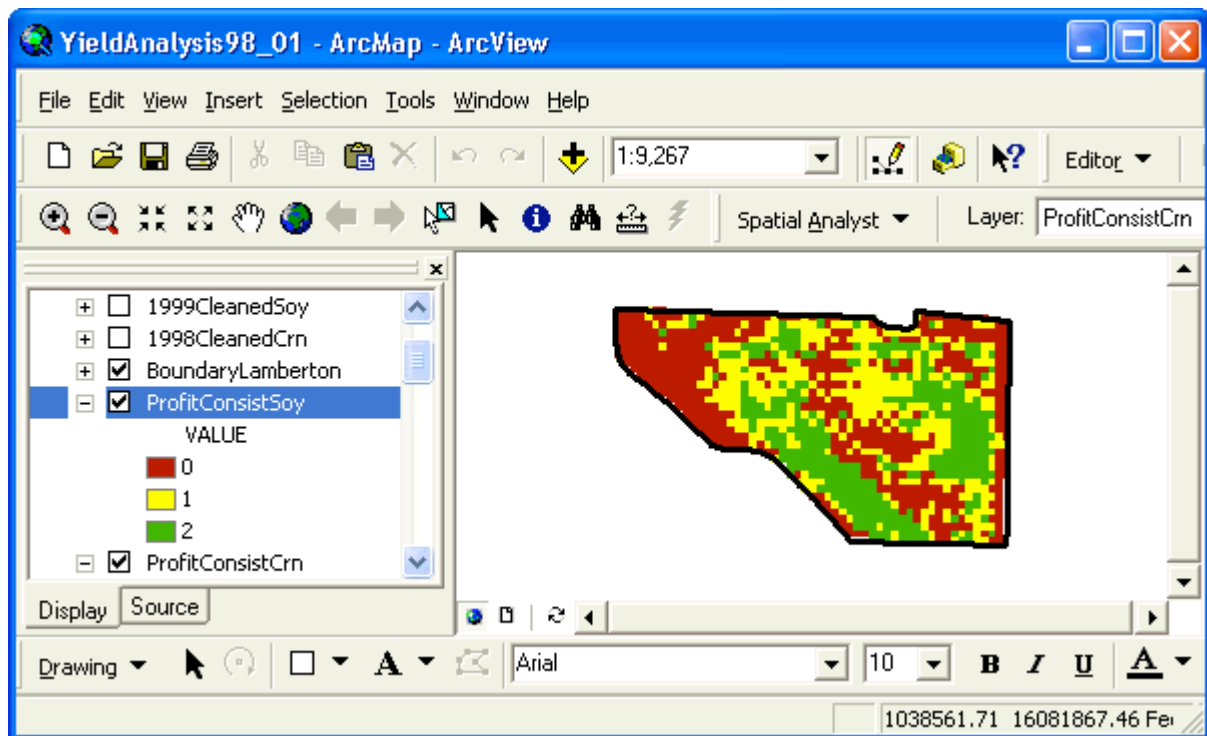


The resulting raster had three possible values: 0, 1, and 2, indicating how many of the last 2 yr. had been profitable in various areas of the field when corn was grown.

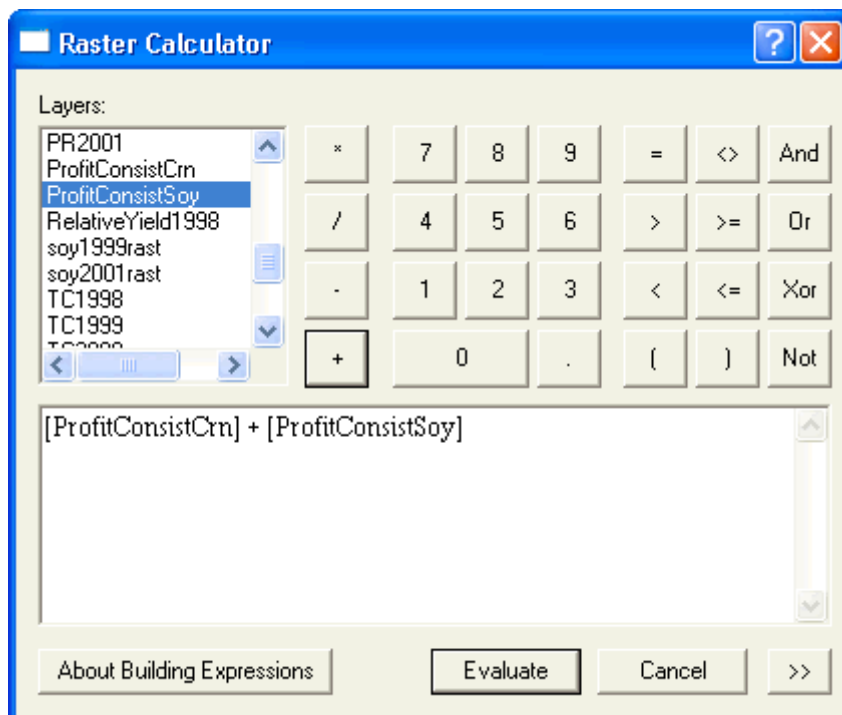




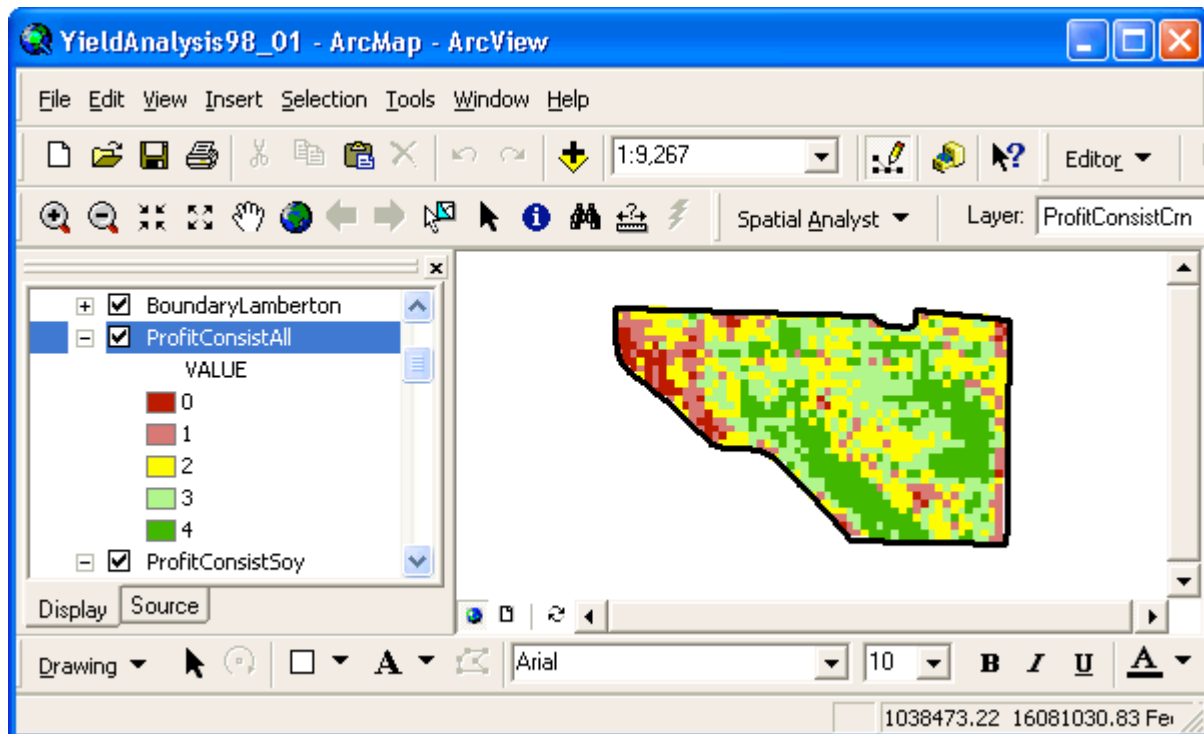
Similar calculations were made for soybean net returns. The resulting raster is shown below.



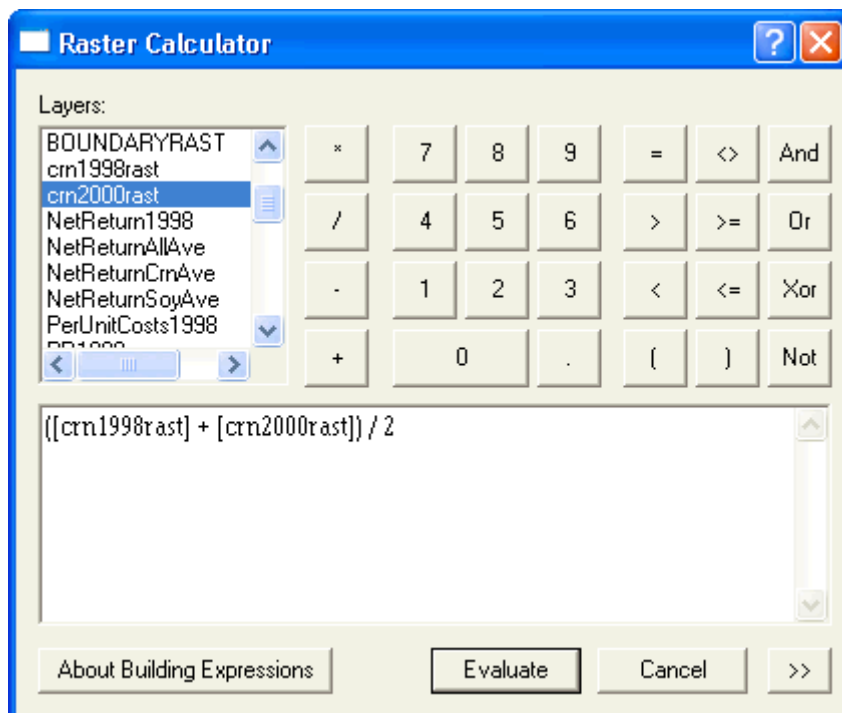
To examine consistency in profit across all 4 yr. of production, we added the profit consistency map for corn (ProfitConsistCrn) to the one for soybeans (ProfitConsistSoy).



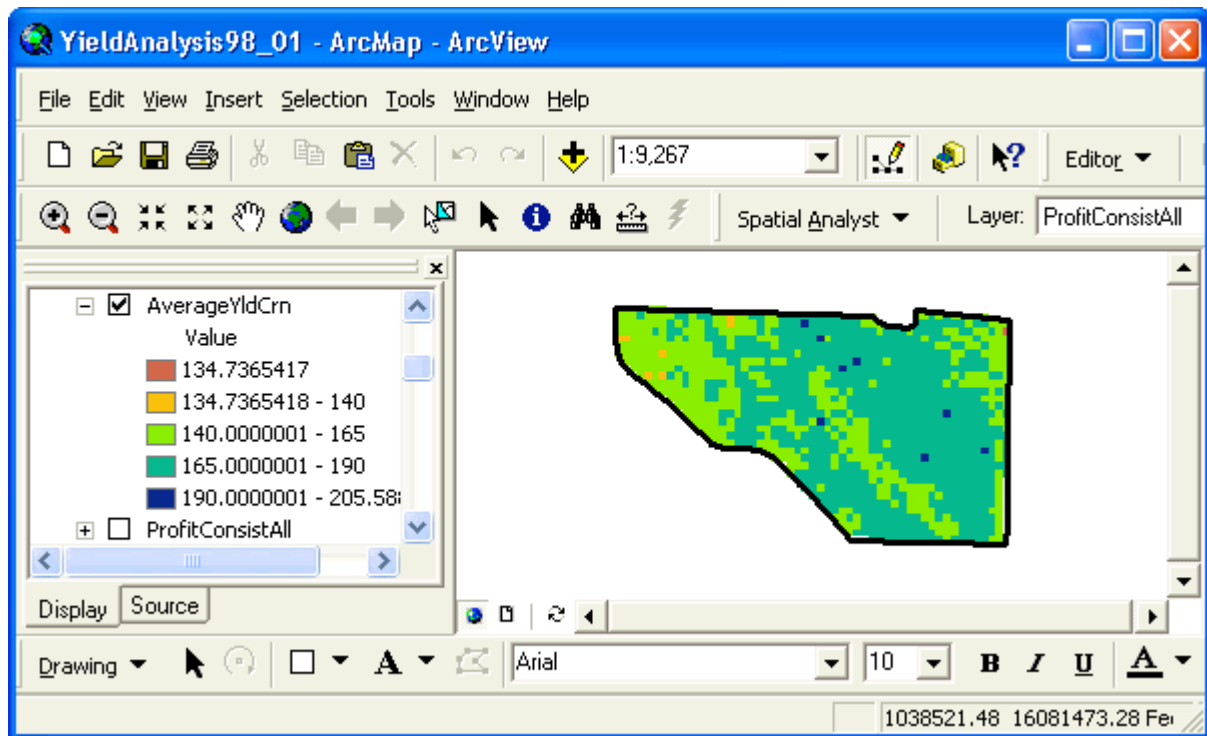
There were 5 possible values: 0, 1, 2, 3, and 4, corresponding to how many of the last 4 yr. had been profitable. Again small, parallel field areas running diagonally in the field exhibited greater consistency in profit across all crops.



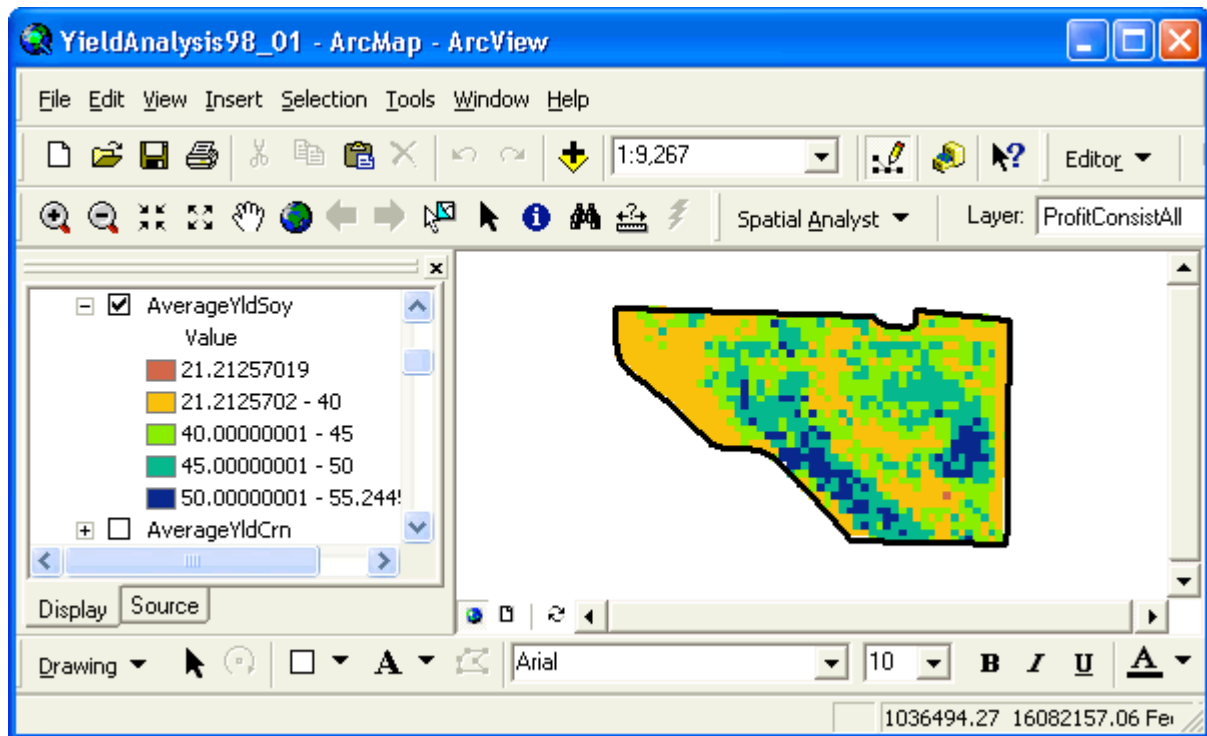
**II.B.3. What is the average production level of areas within the field?** We determined this from the interpolated yield raster files for each crop. We averaged the corn and soybean yield data separately. The calculation for corn was entered as:



The resulting raster showed average corn yield for the past 2 corn-growing seasons. Most of the field was in the 140-190 bu/acre production range.

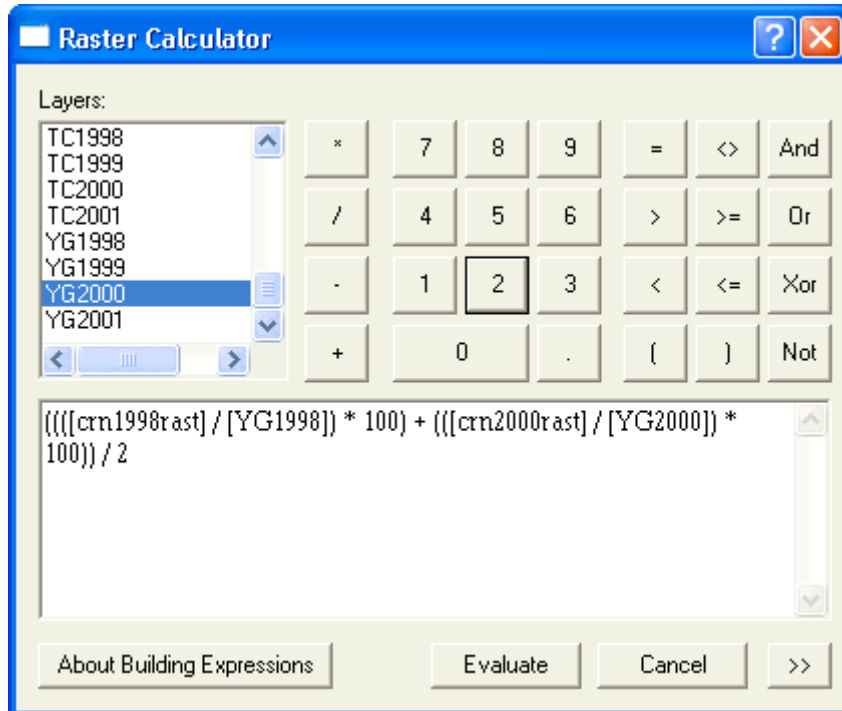


A similar raster was created for average soybean yield. Large areas of the field were in the 21-40 bu/acre production range. The higher 40-55 bu/acre yields were located in two parallel, diagonal areas in the middle of the field.

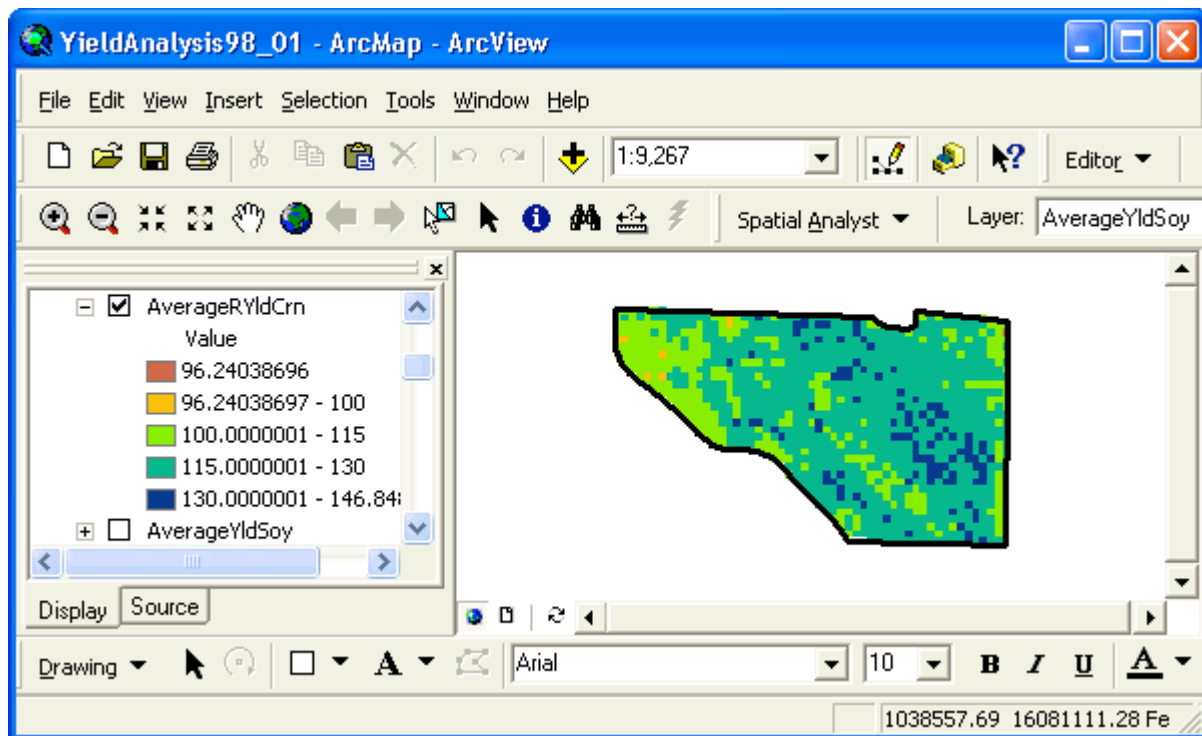


**II.B.4. How have average yields within the field compared to yield goals?** This question was addressed by dividing each interpolated yield raster by the appropriate annual whole-field yield goal raster then multiplying by 100 to convert the ratio to a percentage (relative yield raster). Relative yield rasters were then averaged by crop and across crops.

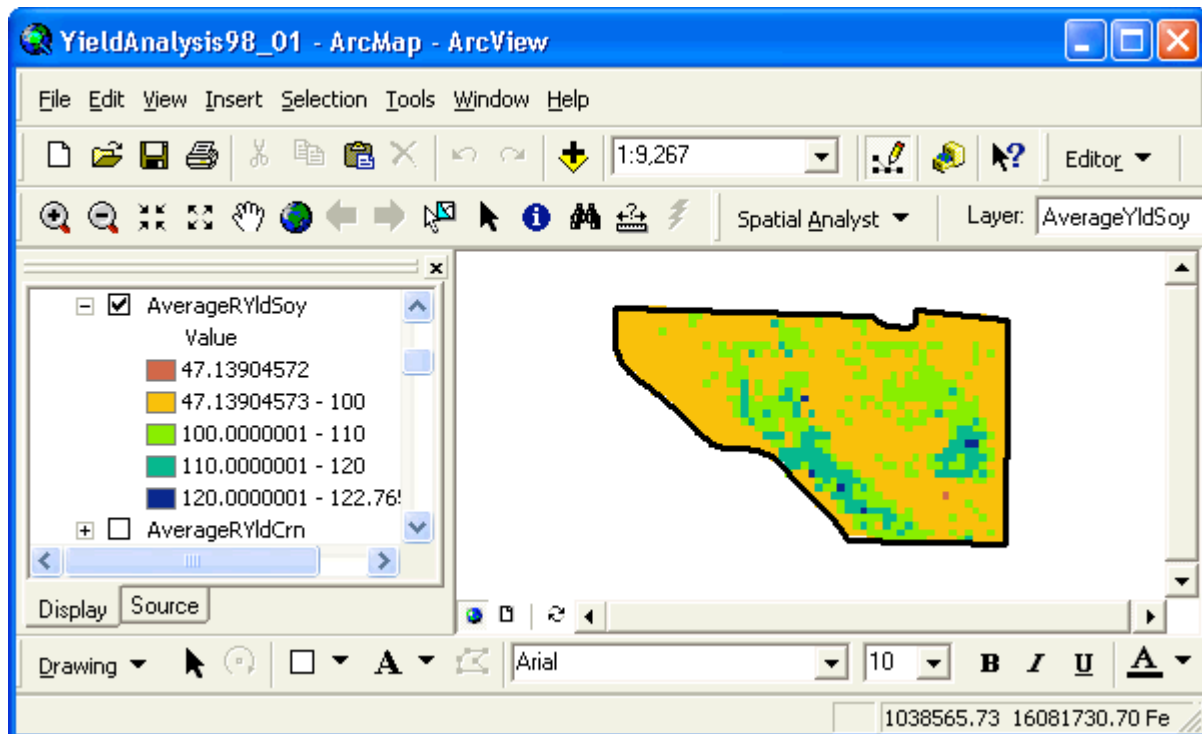
Average corn relative yields were calculated using the following expression:



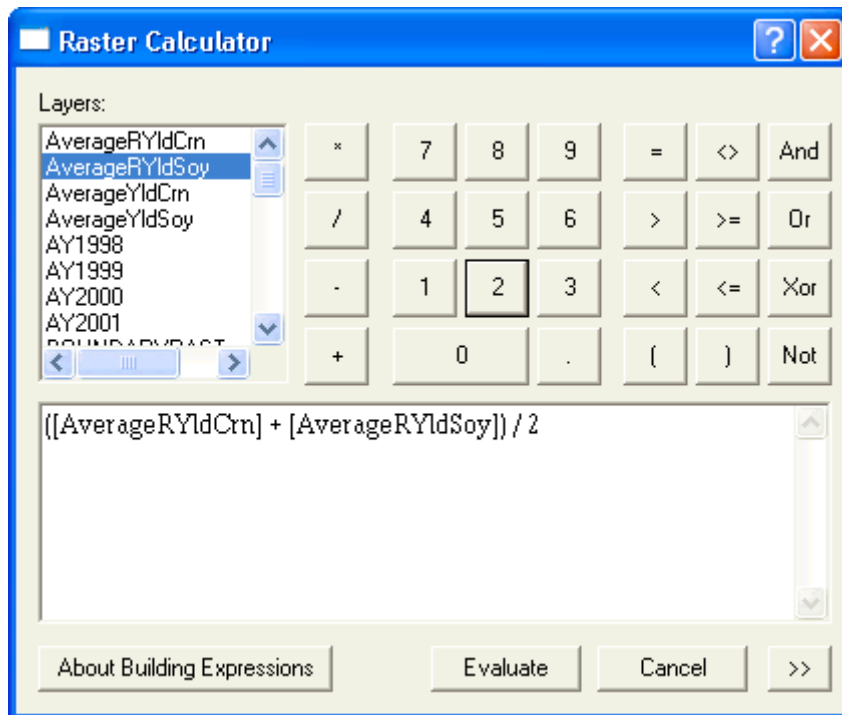
The resulting average relative yield raster for corn showed that most of the field yielded 115-130% of the yield goals set each year.



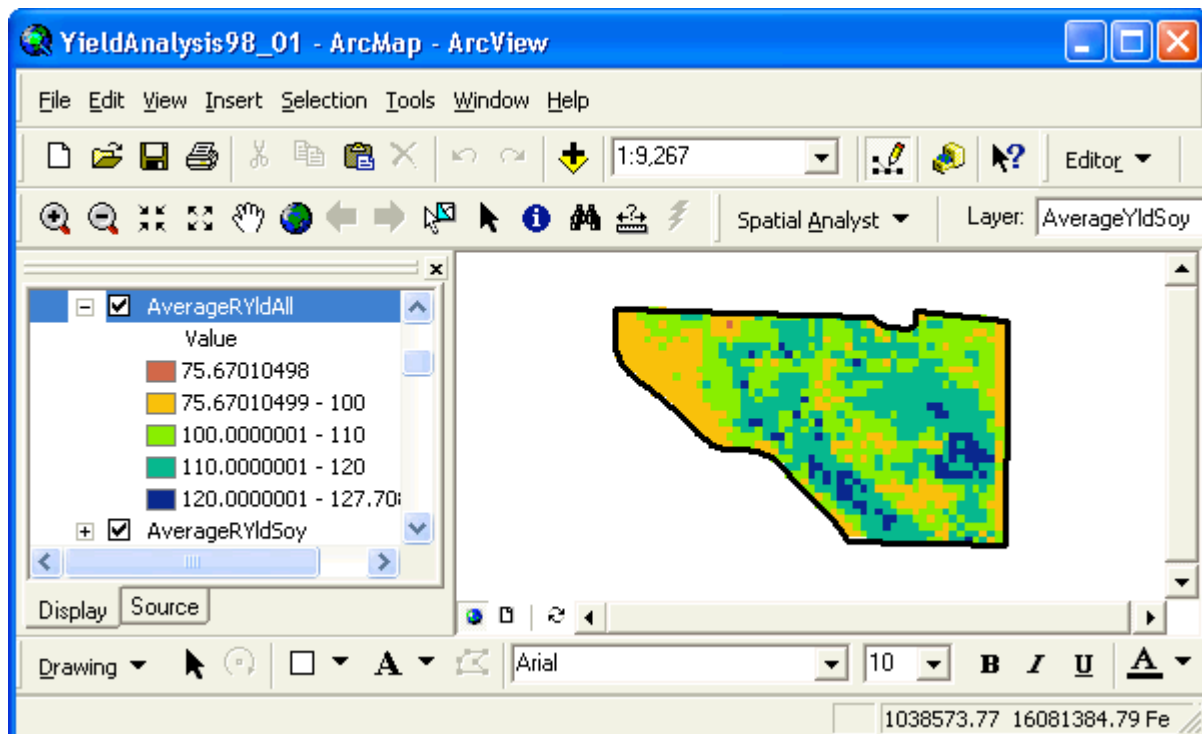
The average relative yield raster for soybeans showed that most of the field fell below yield goals set each year. Two parallel, diagonal production areas were in the range of 100-120% of the production goals established.



To calculate average relative yields across all crops, we averaged together the average relative corn yield raster (AverageRYldCm) and the average relative soybean yield raster (AverageRYldSoy):



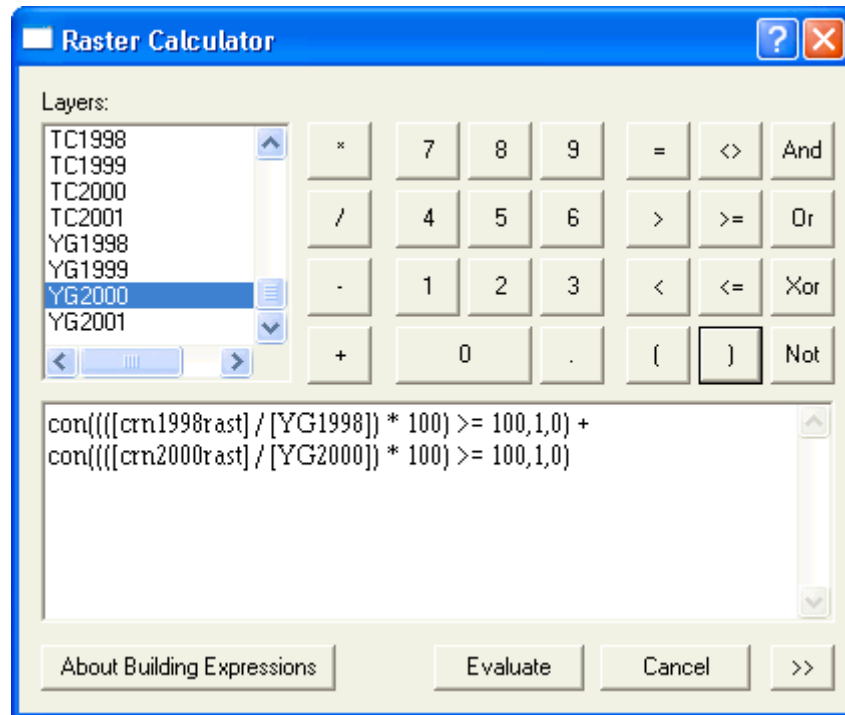
The resulting raster showed relative yield averaged across all crops. The now familiar parallel, diagonal areas in the field were clearly yielding, on average, higher than current production goals.



Answering this question again involved use of the `con` function to create indicator variable maps. Our generalized expression was:

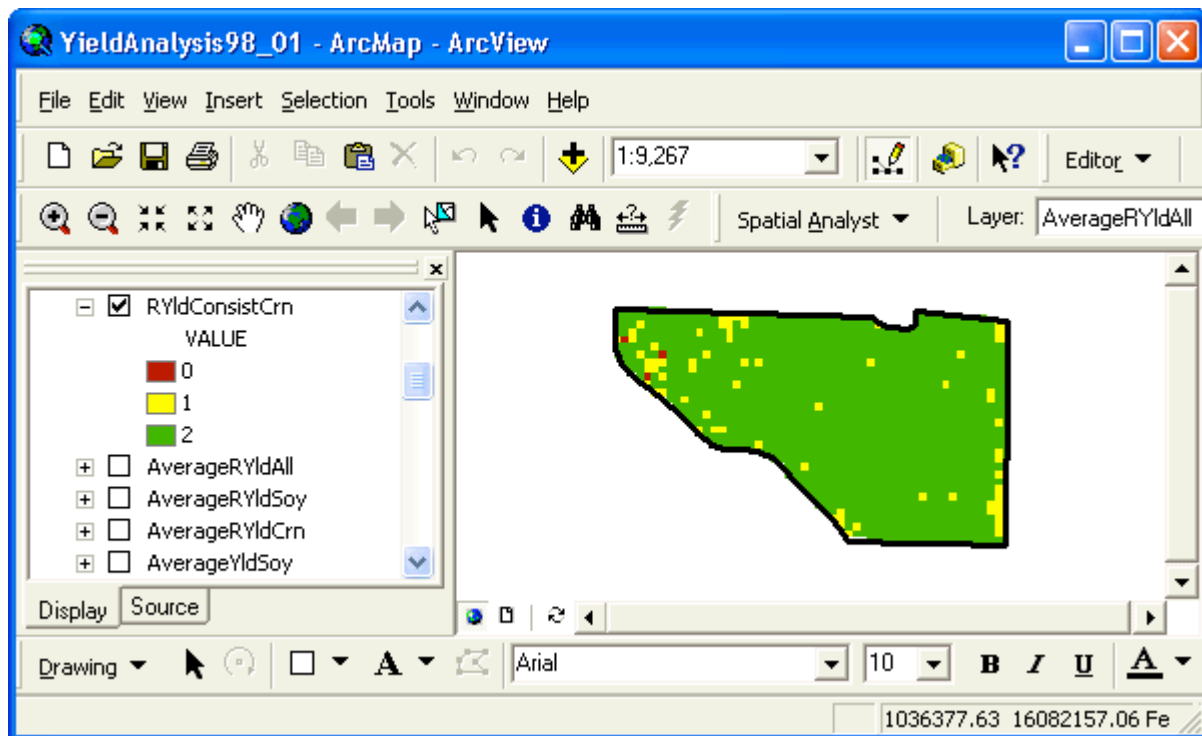
```
con(relative yield  $\geq$  100, 1, 0)
```

Thus, areas meeting or exceeding production goals were marked with a "1" and all other areas were marked with a "0". For the 1998 and 2000 corn yield data, we wrote con functions for the relative yields for each year, then added the functions together. A similar function was written for the soybean data:

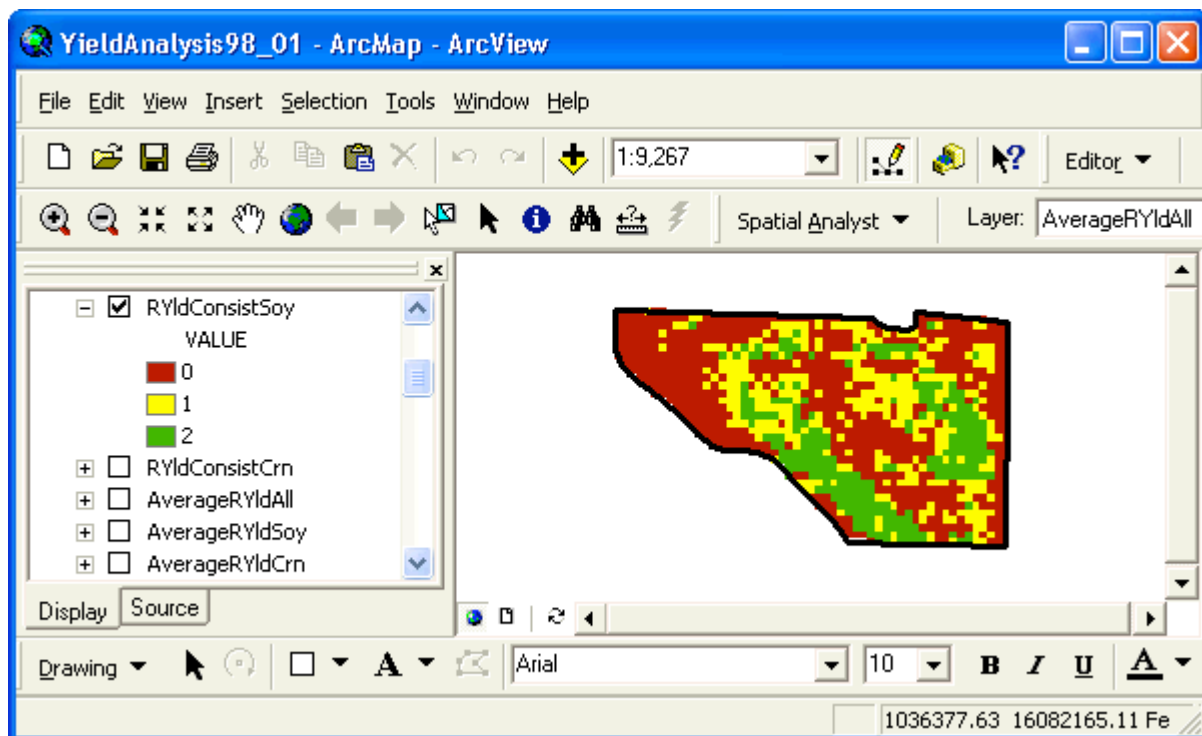




The resulting rasters showed areas that consistently met or exceeded annual production goals in 0, 1, or 2 of the last 2 production years. The raster for corn was:

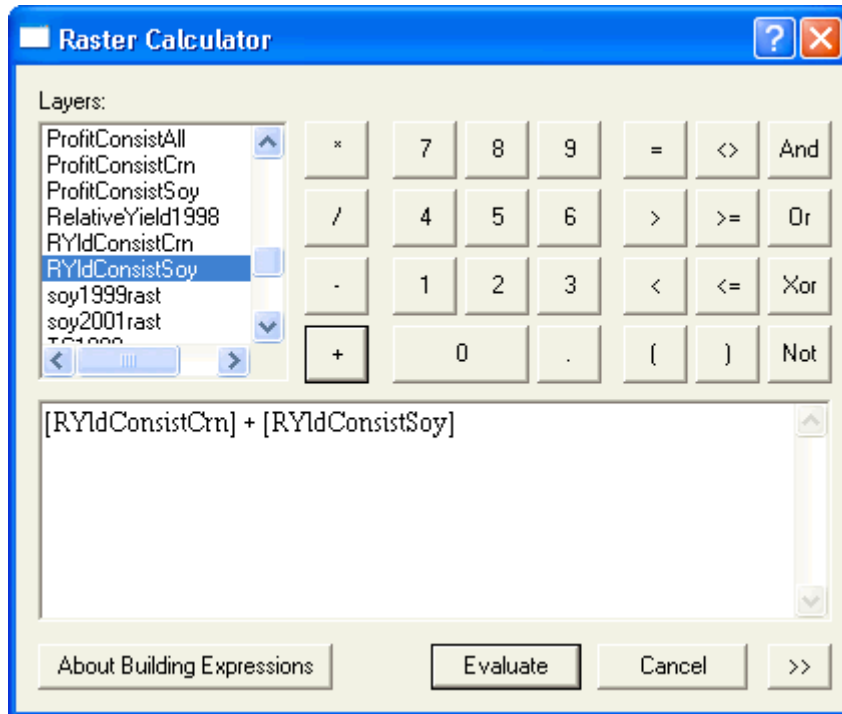


The raster for soybeans was:

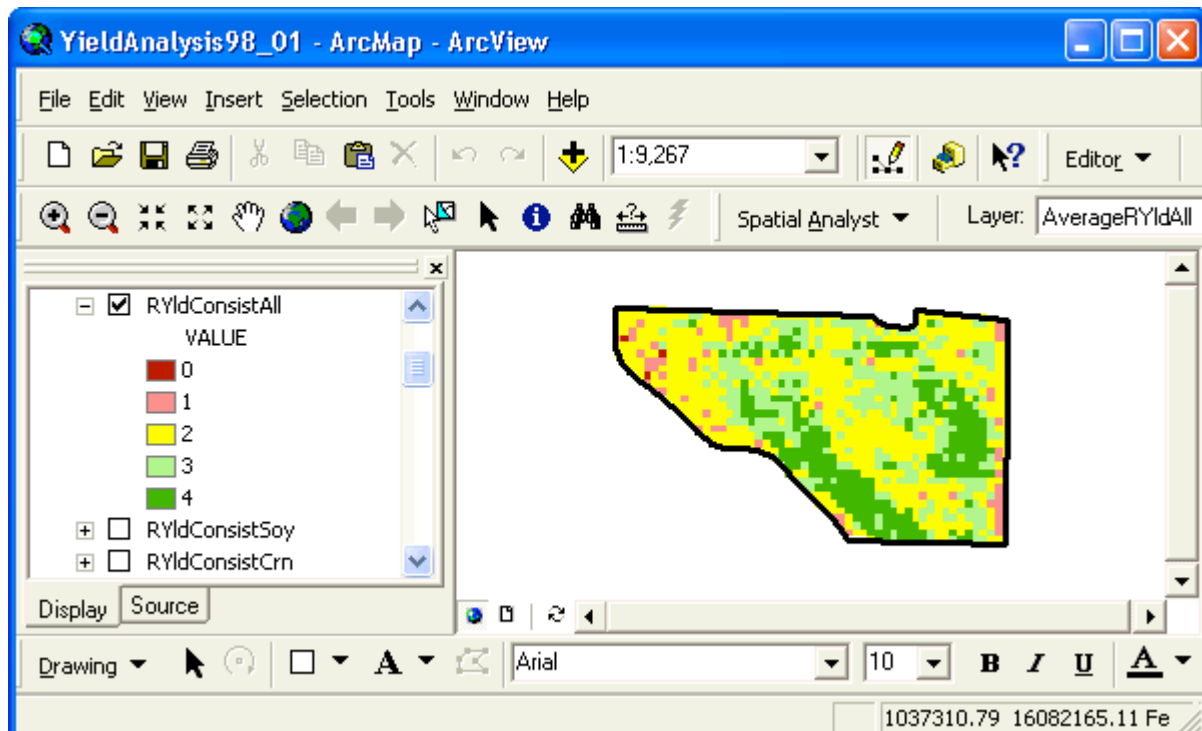


Obviously, corn was much more consistent across the field in meeting or exceeding production goals than was the soybean crop.

To examine relative yield consistency across all crops, we added together the relative yield consistency maps for corn (RYldConsistCrn) and soybeans (RYldConsistSoy):



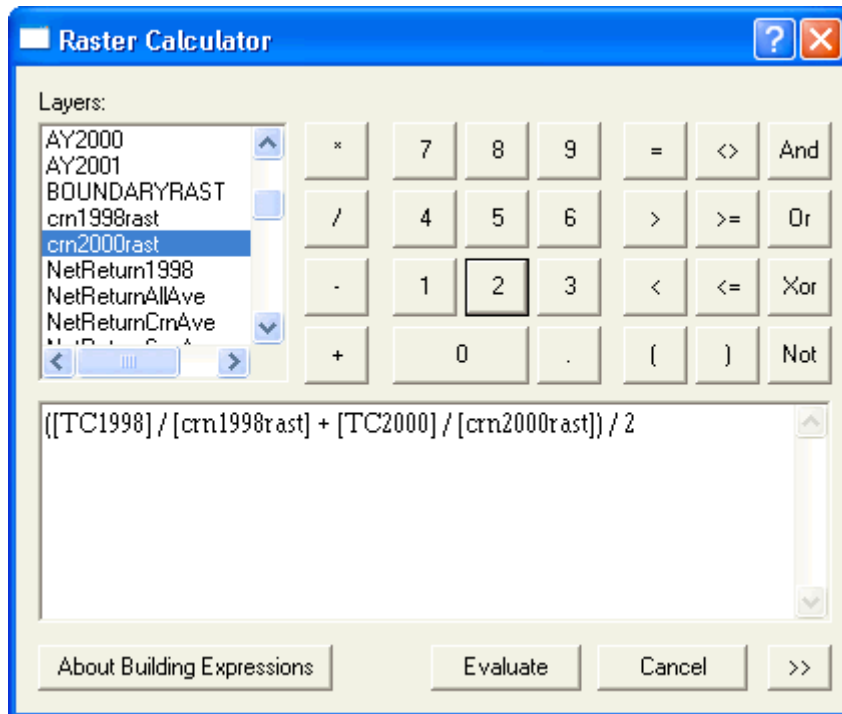
This produced the following raster:



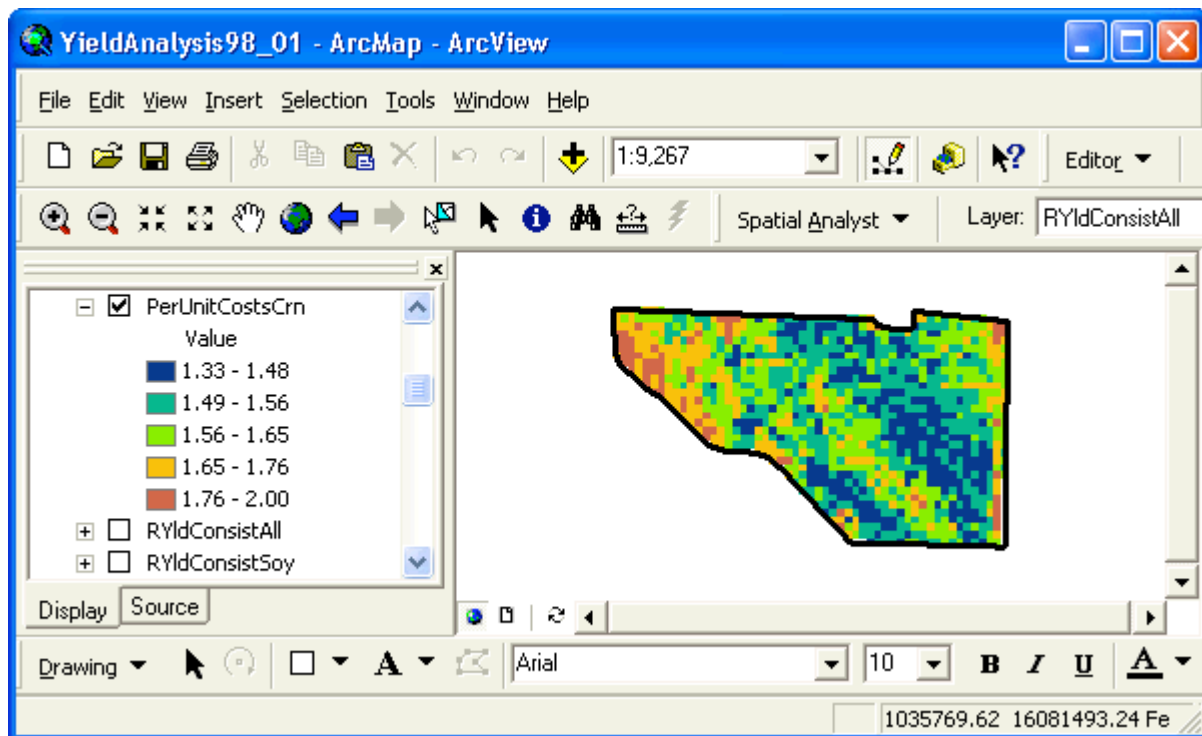
This map shows the impact that the inconsistent soybean production had upon the overall consistency of production in this field.

**II.B.6. What are the average per-unit costs of production of areas within the field?** This was calculated for each crop by averaging annual per-unit cost rasters. These annual per-unit cost rasters were calculated akin to equation [3], only interpolated yield rasters were used in the denominator rather than average yields.

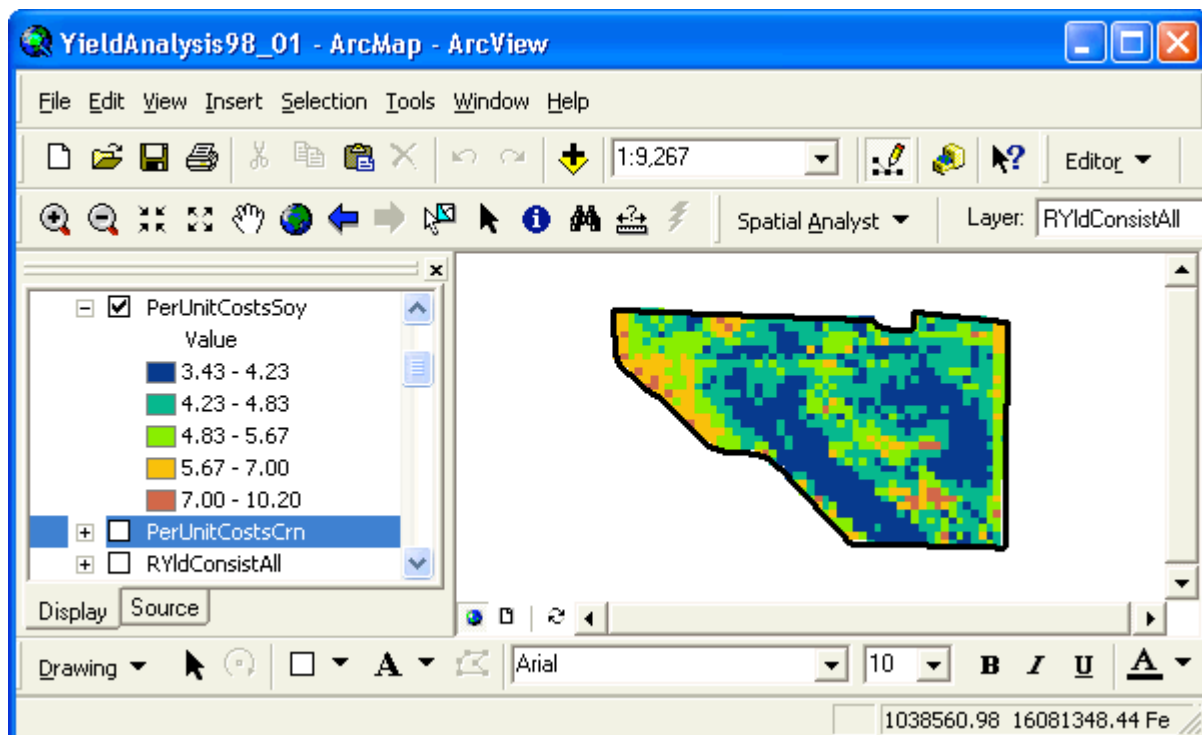
The equation for the average per-unit costs of corn production was entered as:



This produced the following per-unit corn production cost raster (note color ramp has been flipped to indicate that lower production costs are more advantageous):



A similar equation was written for soybeans to produce the following per-unit soybean production cost raster:



These raster were useful for determining which areas of the field were capable of providing positive net returns under a variety of possible commodity price scenarios.

### **IMPLICATIONS OF GIS ANALYSIS ON CURRENT MANAGEMENT APPROACHES**

The GIS project conducted with ArcMap and ArcCatalog has yielded the following points for consideration:

1. Corn is a consistently profitable crop and consistently exceeds annual production goals. A possible change in current management approaches might be to intensify corn production by managing inputs for higher yields. The current yield goal of 140 bu/acre for the entire field appears to be too low.
2. Soybeans are consistently profitable in isolated areas of the field. Soybean yield below annual production goals in significantly large areas of the field. Another crop with higher profit potential may need to be included in the rotation.
3. For both crops, there is enough variability in the field that creating maps of variable production goals may be a good next step. In particular the lower-yielding northwest corner of the field may need to have lower production goals established. Another option might be to put that area of the field into a conservation reserve program offered by the USDA-NRCS.
4. These types of maps can lead to productive and stimulating conversations with farmers. New analyses may be desired to clarify salient points. Discussing the effectiveness and impacts of current management strategies can lead to the consideration of new options not previously considered.

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