

Topic 8

Generating Prescription Maps

8.1 Technical Issues

The precision agriculture process can be viewed as four steps: *data logging*, *point sampling*, *data analysis* and *spatial modeling* as outlined in figure 8-1. **Data logging** continuously monitors measurements, such as crop yield, as a tractor moves through a field. **Point sampling**, on the other hand, uses a set of dispersed samples to characterize field conditions, such as phosphorous, potassium, and nitrogen levels. The nature of the data derived by the two approaches are radically different—a "direct census" of yield consisting of thousands of on-the-fly samples versus a "statistical estimate" of the geographic distribution of soil nutrients based on a handful of soil samples.

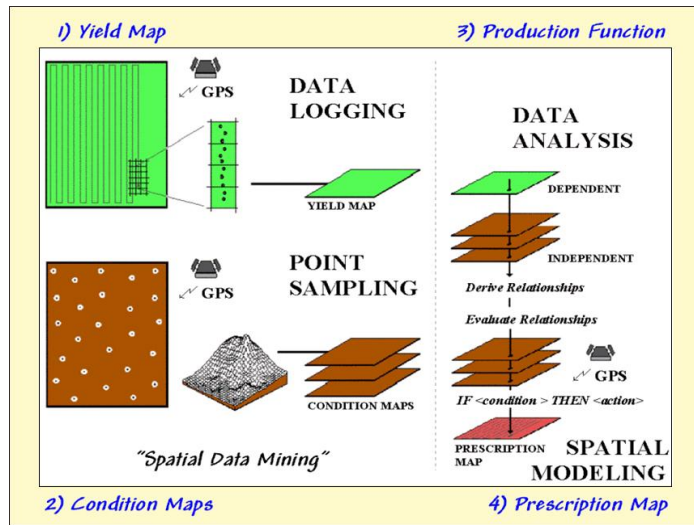


Figure 8-1. Processing steps in precision agriculture.

In data logging, issues of accurate measurement, such as GPS positioning and material flow adjustments, are major concerns. Most systems query the GPS and yield monitor every second, which at 4 mph translates into about 6 feet. With differential positioning the coordinates are accurate to about three feet. However the paired yield measurement is for a location well behind the harvester, as it takes several seconds for material to pass from the point of harvest to the yield monitor.

To complicate matters, the mass flow and speed of the harvester are constantly changing when different terrain and crop conditions are encountered. The precise placement of GPS/Yield records are not reflected as much in the accuracy of the GPS receiver as in "smart"

yield mapping software that adjusts for the lag in mass flow through the harvester. Without it yield measurements can be off tens of feet—for example, an uncorrected 15sec lag * 6 ft/sec = 90 foot displacement error.

In point sampling, issues of surface modeling (estimating between sample points) are of concern, such as sampling frequency/pattern and interpolation

technique. The cost of soil lab analysis dictates "smart sampling" techniques based on terrain and previous data be used to balance spatial variability with a farmer's budget. In addition, techniques for evaluating alternative interpolation techniques and selecting the "best" map using residual analysis are available in some of the soil mapping systems.

In both data logging and point sampling, the resolution of the analysis grid used to geographically summarize the data is a critical concern. Like a stockbroker's analysis of financial markets, the fluctuations of individual trades must be "smoothed" to produce useful trends. If the analysis grid is too coarse, information is lost in the aggregation over large grid spaces; if too small, spurious measurement and positioning errors dominate the information.

The technical issues surrounding mapped *data analysis* involve the validity of applying statistical techniques to spatial data. For example, regression analysis of field plot data has been used for years to derive crop production functions, such as corn yield (dependent variable) versus potassium levels (independent variable). In a GIS, you can use regression to derive a production function relating

mapped variables, such as the links among a map of corn yield and maps of soil nutrients—like analyzing thousands of sample plots. However, technical concerns previously described, such as variable independence and spatial autocorrelation, have yet to be thoroughly investigated. Statistical measures assessing results of the analysis, such as a spatially responsive correlation coefficient, await full discovery and acceptance by the statistical community, let alone the farm community.

In theory, *spatial modeling* moves the derived relationships in space or time to determine the "optimal" actions, such as the blend of phosphorous, potassium and nitrogen to be applied at each location in the field. For the most part, these translations are based on existing science and experience without a direct link to data analysis of on-farm data. For example, a prescription map for fertilization is constructed by noting the existing nutrient levels (condition) then assigning a blend of additional nutrients (action) tailored to each location forming an "if (condition) then (action)" set of rules. The issues surrounding spatial modeling are similar to data analysis and involve the validity of using traditional "goal seeking" techniques, such as linear programming or genetic modeling, to calculate maps of the

optimal actions.

Figure 8-2 illustrates applying the spatial technologies and processing steps for variable-rate fertilization. The prescription map in the middle contains application values that are interpreted on-the-fly and used to vary the application rate as the equipment moves through the field.

Step 4 in the figure is the discovery phase that relates yield variability to field conditions and inputs. The earlier discussions

in this book introduced some of the data analysis considerations and procedure used in this phase. The next couple of sections discuss how a prescription map (step 5) can be generated based on the spatial relationships that are uncovered.

The Precision Ag Process (Fertility example)

As a combine moves through a field 1) it uses GPS to check its location then 2) checks the yield at that location to 3) create a continuous map of the yield variation every few feet. This map 4) is combined with soil, terrain and other maps to derive a 5) "Prescription Map" that is used to 6) adjust fertilization levels every few feet in the field.

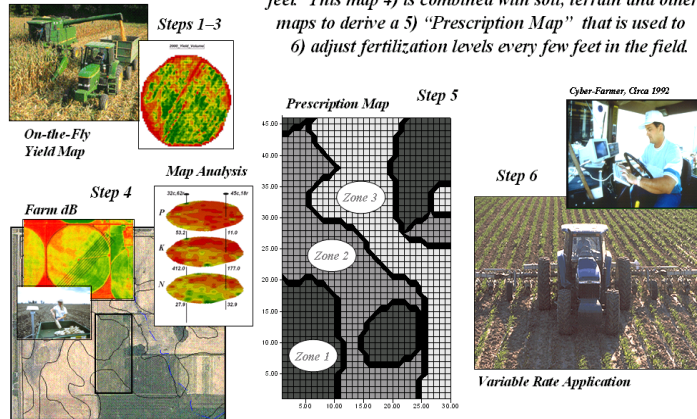


Figure 8-2. Sequence of steps in generating a variable-rate application of fertilizer.

8.2 Applying Decision Rules

The simplest procedure for generating a prescription map involves implementing a rule set. For example, the amount of additional phosphorous (P) and potassium (K) for each location in a field can be determined by comparing the current amount to desired levels. The following calculations are simplified to

demonstrate the concept and are designed for irrigated corn on the case study data set.

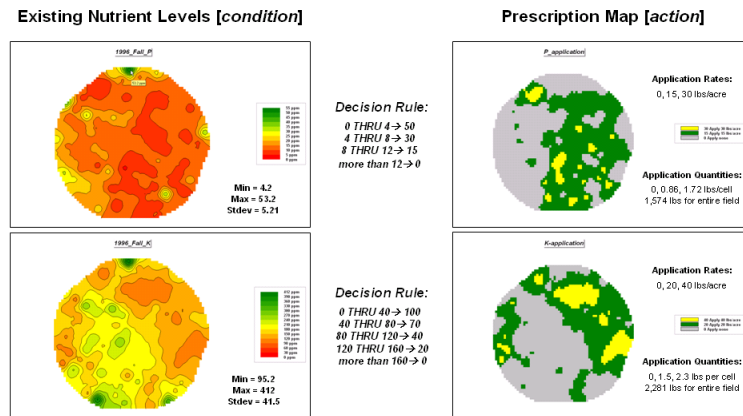


Figure 8-3. Prescription maps of P and K based on decision rules.

The P-level recommendation uses **decision rules** to reclassify current phosphorous levels throughout the field. The general rule can be stated as “If [condition] Then [action]” and specifically stated as:

- If [0<P<4ppm] Then [apply 50 lbs P₂O₅/acre]
- If [4<P<8ppm] Then [apply 30 lbs P₂O₅/acre]
- If [8<P<12ppm] Then [apply 15 lbs P₂O₅/acre]
- If [P>12ppm] Then [apply 0 lbs P₂O₅/acre]

The recommended P-applications are for Colorado conditions with relatively high pH levels. The top-right inset in figure 8-3 shows the existing map of phosphorous levels that was reclassified to derive the prescription map (top-left).

The prescription map identifies the application rate in pounds per acre. To convert the rate maps to quantity maps a conversion factor must be applied. Each grid cell is 50x50ft representing a 2,500sq-ft area. Since an acre contains 43,560sq-ft, each cell is 2500/43560= .0574 or about 6 percent of an acre. The factor can be applied to the per acre rates on the prescription map to calculate 0, 0.86, and 1.72lbs/cell application levels. The total pounds of phosphorous applied to the entire field is calculated by summing all of the individual cell quantities (total of 1,574lbs for the entire field).

The same procedure is repeated for the “If, Then” potassium decision rules—

- If [0<K<40] Then [apply 100 lbs K₂O/acre]
- If [40<K<80] Then [apply 70 lbs K₂O/acre]
- If [80<K<120] Then [apply 40 lbs K₂O/acre]
- If [120<K<160] Then [apply 20 lbs K₂O/acre]
- If [K>160] Then [apply 0 lbs K₂O/acre]

The right side of the lower inset in figure 8-3 shows the spatial distribution of current potassium levels. The left side shows the prescription map for the field, and reports its per-cell application quantities (0, 1.5 and 2.3lbs/cell) and total pounds of potassium for the entire field (2,281lbs).

8.3 Applying Decision Equations

The nitrogen application utilizes an equation that considers the yield goal, percent organic matter, residual nitrogen and irrigation input, to determine the amount of nitrogen needed at each location:

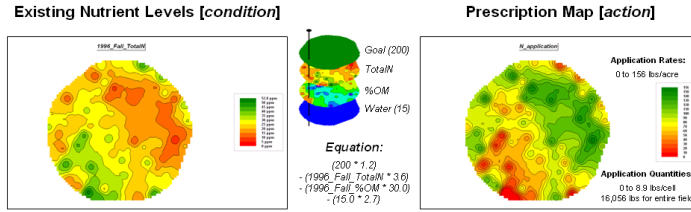


Figure 8-4. Prescription map for nitrogen.

$$N_application = (yield\ goal \times 1.2\ N/bu_Corn) \\ \text{minus } (residual\ N \times 3.6\ lbs/acre) \\ \text{minus } (\% \text{ organic matter} \times 30.0) \\ \text{minus } (15\ acre\text{-feet_irrigation_water} \times 2.7)$$

The continuous function is evaluated using the Compute command—

$$Compute\ (200 * 1.2) \\ - (1996_Fall_TotalN * 3.6) \\ - (1996_Fall_ \%OM * 30.0) \\ - (15.0 * 2.7)\ FOR\ N_application$$

—that assumes a yield goal of 200 bushels and application of 15 acre-feet of water.

The right side of figure 8-4 shows the spatial distribution of current nitrogen levels (residual nitrogen) and the percent organic map that serve as input variables in the equation. A yield goal of 200bu/ac and 15acre-feet irrigation are assumed.

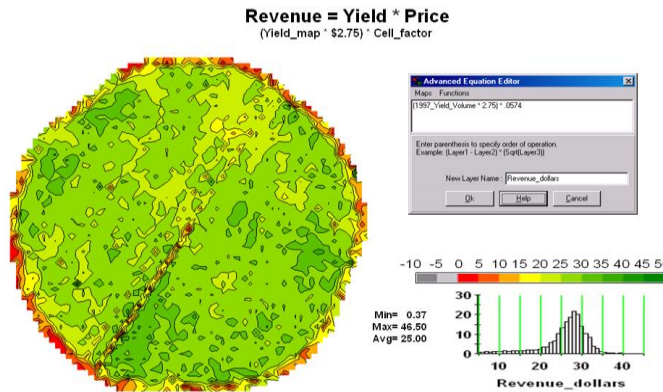


Figure 8-5. A revenue map is calculated by multiplying yield by price, adjusting from per acre to per cell value.

The left side of the figure shows the prescription map for the field. The nitrogen application calls for a rate of 0 to 156lbs/ac with most of the field in the 50 to 120 range. Note the per-cell application quantities (0 to 8.9) and total pounds of nitrogen for the entire

field (16,056) that are needed during the growing season. The nitrogen recommendations can be divided between pre-plant, planting, cultivation, and irrigation activities. Typically, a maximum of 40 lbs per acre is the maximum applied for a single dose.

The difference between using an equation verses a set of discrete decision rules to generate a prescription map is important. Decision rules lump a single application rate for relatively large ranges of residual nutrient levels. For example, a location with 40ppm of potassium gets the same application rate (70lbs/ac) as a location with 79ppm—a 40ppm difference in “condition” but assigned identical “action.”

If an equation was used P and K the solution would respond with a continuous gradient of recommendations that better matches the input needed for each field location. In a sense, successful site-specific agriculture reflects a continuum of management actions as much as it reflects a site-specific response.

8.4 Economic Maps

Conversion of maps from physical units into economic terms provides additional insight for decision-making.

For example, assuming a corn price of \$2.75 per bushel and using the .0574 per cell conversion factor, the yield map can be converted into a revenue surface as shown in the upper-left portion of figure 8-5. Each cell identifies the contribution it makes to the revenue generated by the field. Note the pattern of very low contribution by the field edge and along the access road.

Also note that the maximum revenue for a location is \$46.50 with a whole-field average of \$25.00 per cell. The total revenue for the field is calculated by adding up revenue for the individual cells—\$82,180.

If variable rate technology is used for applying fertilizer, costs per cell can be derived. For example, phosphorous, potassium and nitrogen inputs can be translated into their costs per pound—

Superphosphate (0-46-0) fertilizer costing \$280 per ton...
 2000lbs fertilizer * .46= 920 lbs of P₂O₅ per ton fertilizer
 920/2.29= 402 lbs of P per ton fertilizer
 \$280/402= \$.697 cost for one pound of P

Potash (0-0-60) fertilizer costing \$158 per ton...
 2000 * .60= 1200 lbs of K₂O per ton
 1200/1.21= 992 lbs of K per ton
 \$152/992= \$.153 cost for one pound of K

Urea (45-0-0) fertilizer costing \$300 per ton...
 2000 * .45= 900lbs of CO(NH₂)
 \$300/900= \$.333 cost for one pound of N

The costs per pound are multiplied by their respective “per cell” prescription maps derived in the previous section. The result are individual cost surfaces for P, K and N (left side of figure 8-6). The three maps are added together to identify a map of total variable cost that in turn is added to fixed costs of \$100 per ac (right side of the figure). Note that the highest costs are concentrated in the northeastern portion of the field. Summing the individual costs for each location calculates the total costs for the entire field (\$25,671).

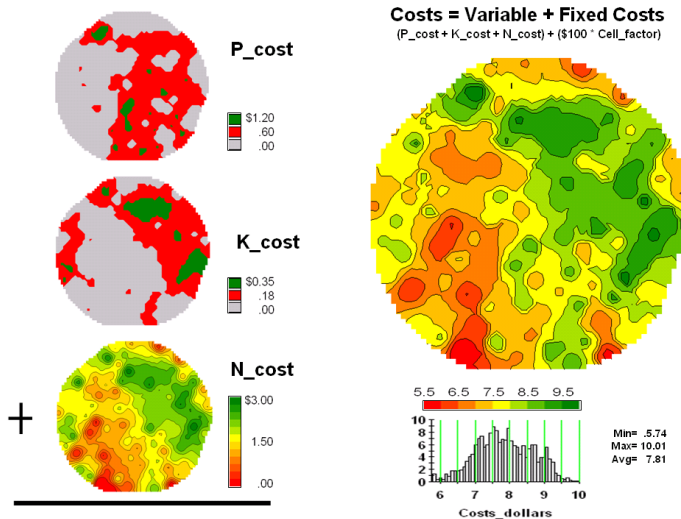


Figure 8-6. A total costs map is derived by summing the variable and fixed cost maps.

A profit map is generated by subtracting the total cost map from the revenue map as depicted in figure 8-7. Note the very poor performance of the area in the northeast portion of the field, as well as the field edge and access road locations.

Nearly four percent of the field actually has a negative profit (-

\$7.49 to 0 identified as gray). The sum of the profit for all of the cells identifies the field’s overall performance (\$56,508).

In many respects the economic analysis is like a spatial spreadsheet. Once the analysis is structured

various scenarios can be investigated. For example, if corn prices fell to \$2.50 which portions of the field would become unprofitable? Or if nitrogen fertilizer fell to \$250 per ton, how much would overall profit increase? Or what is the cost and productivity differences between whole-field and site-specific fertilization programs?

8.5 On-Farm Testing

In a similar fashion, spatial data analysis readily supports on-farm studies. For example, consider the investigation outlined in figure 8-8.

Strip trials for two seed hybrids are planted using GPS positioning. One hybrid is nematode tolerant but its effectiveness is dependent on several soil and terrain factors. While the resistant hybrid proved valuable in a controlled research field, it is not known for sure how effective it will be on the unique conditions of fields hundreds of miles away.

A whole-field test involves masking the yield map by the strip partitions (light and dark green) and exporting the two data sets to Excel. A t-Test is completed to determine if one hybrid significantly outperformed the other over entire field (whole-field analysis).

Another approach interpolates soil samples tested for nematode levels similar to generating maps of soil nutrient concentrations (see Topic 4). Areas of high nematode concentrations are isolated by

identifying locations that are more than one standard deviation above the mean. The yield for the strip trial partitions falling within these areas are masked and exported to Excel to assess if a significant difference exists between the two hybrids within areas of high

nematode concentrations (*discrete zone analysis*).

Yet another approach uses the complete yield and nematode map surfaces. A regression model and accompanying AVOVA analysis is developed for all locations in the field. The process investigates the spatial relationship

among yield levels and nematode concentrations within the two hybrid types (*continuous surface analysis*).

This final approach uses all of the information about the continuous numeric and spatial distributions in the field-

collected data. The analysis can be extended by considering other factors, such as soil type or percent organic material. On-farm testing of spatially consistent data has two major advantages over traditional agricultural testing—it utilizes distributions of actual farm

conditions and provides a wealth of analytical capabilities for investigating spatial relationships.

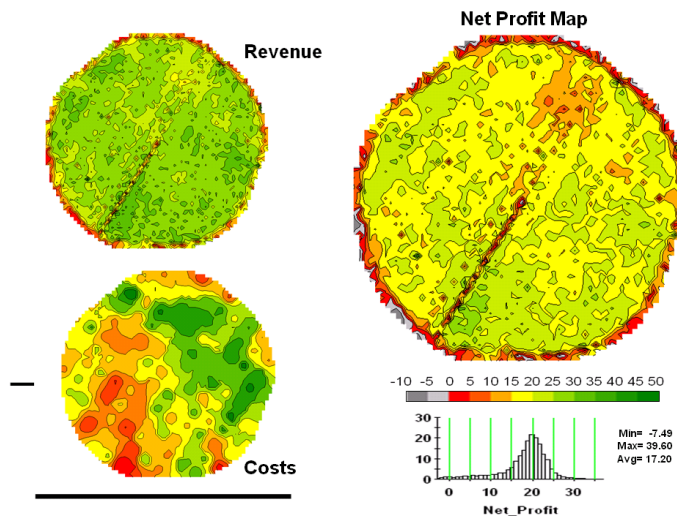


Figure 8-7. Subtracting the costs map from the revenue map generates a profit map identifying relative economic performance of each location in the field.

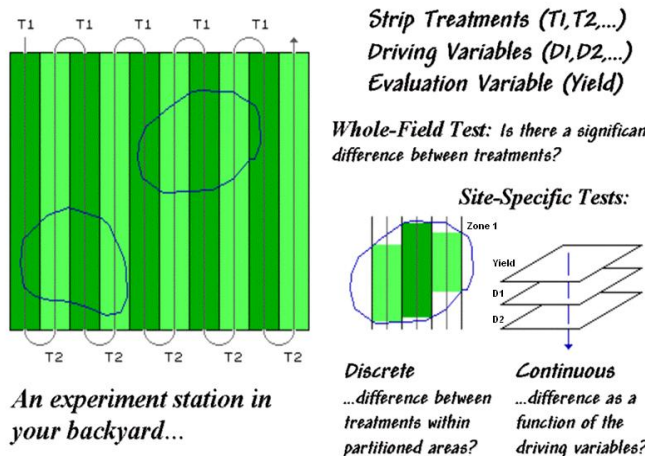


Figure 8-8. On-farm studies, such as seed hybrid performance, can be conducted using actual farm conditions.

8.6 Conclusion

The *Spatial Statistics* and *Spatial Analysis* operations introduced in this book identify an important compartment in precision agriculture’s toolkit. Understanding the spatial, as well as the numerical distribution of field data provides considerable insight into relationships and interactions on a site-specific basis. While broad, whole-field averages give us a general feel for the data, they are often woefully inadequate for managing farm inputs and actions in an economically and environmentally effective manner—“a little more over here, a little less over there.”

Agriculture is at a threshold akin to the mechanization era of the 1930s and the green revolution of the 1960s. The computer and computer maps form the cornerstone of an entirely new perspective on how we analyze data and formulate management actions. The vital ingredient needed is innovation by researchers and producers who understand precision agriculture data and can “*think with maps.*”

The application of this new perspective within production agriculture has been rapid. Since its inception in the early 90s, precision farming has moved from a fledgling idea to an operational reality on millions of acres.

The infrastructure for precision agriculture is coming online. Most manufacturers offer precision farming options with their farm vehicles and implements. A growing number of service providers offer advice to farmers in their adoption of the new technology. At present, however, a full implementation of precision agriculture is still in the hands of the developers, researchers and innovative producers.

Advancements in the data analysis and spatial modeling phases await contributions from a new generation of producers. The considerable knowledge and methodologies of current and future agricultural science and field management need to be reviewed for their spatial inferences and insight.


The Analyzing Precision Ag Data discussion and hands-on experience in this book are intended to fuel this revolution. The procedures introduced are just the tip of the spatial analysis and data mining iceberg that is rapidly moving

whole-field management to a more holistic approach.

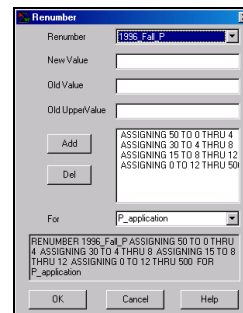
8.7 Exercises

Access MapCalc using the *Agdata.rgs* data set by selecting **Start** → **Programs** → **MapCalc Learner** → **MapCalc Learner** → **Open existing map set** → **PA_AgData.rgs**. The following set of exercises utilizes this database.

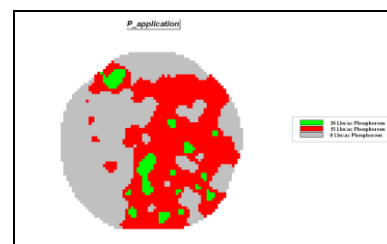
8.7.1 Deriving a Prescription Map

 Press the **Map Analysis** button to access the analytical operations, select **Reclassify** → **Renumber** then complete the dialog box as shown below to implement the following decision rule for phosphorous recommendations.

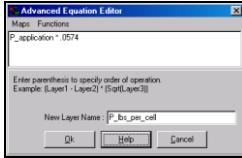
If $[0 < P < 4ppm]$ Then $[apply\ 50\ lbs\ P_2O_5/acre]$
 If $[4 < P < 8ppm]$ Then $[apply\ 30\ lbs\ P_2O_5/acre]$
 If $[8 < P < 12ppm]$ Then $[apply\ 15\ lbs\ P_2O_5/acre]$
 If $[P > 12ppm]$ Then $[apply\ 0\ lbs\ P_2O_5/acre]$



*RENUMBER 1996_Fall_P
 ASSIGNING 50 TO 0 THRU 4 ASSIGNING 30 TO 4 THRU 8
 ASSIGNING 15 TO 8 THRU 12 ASSIGNING 0 TO 12 THRU 500
 FOR P_application*

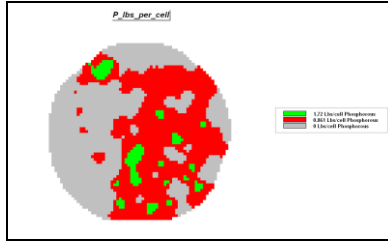


To convert the rate map recommendations (pounds per acre) to per cell amounts select **Overlay** → **Calculate** and complete the dialog box below using a conversion factor of .0574 (50x50=2500sq-ft per cell / 43,560sq-ft per acre = .0574).

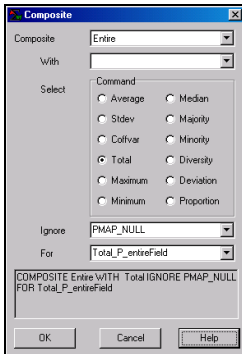


Calculate $P_{application} * .0574$ For $P_{lbs_per_cell}$

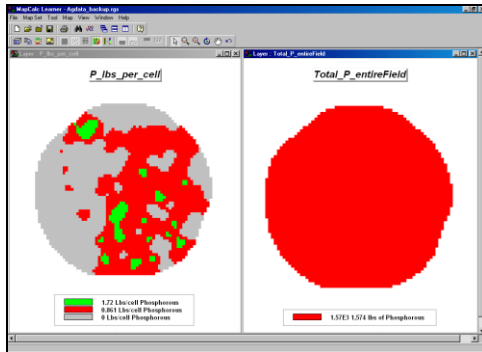
.0574 For $P_{lbs_per_cell}$



To calculate the total pounds of phosphorous for the entire field, select **Overlay** → **Composite** and complete the dialog box below.



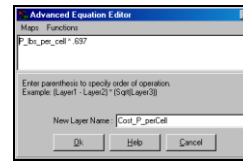
COMPOSITE Entire WITH $P_{lbs_per_cell}$ Total IGNORE PMAP_NULL FOR $Total_P_entireField$



Total amount of phosphorous for the entire field is 1,574 pounds with most of it applied to the eastern portion of the field.

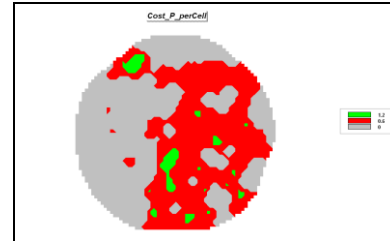
8.7.2 Deriving Economic Maps

Assuming a cost of \$0.697 per pound of phosphorous, derive a map indicating the cost per cell.

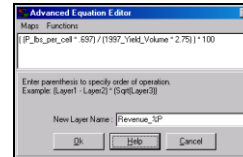


CALCULATE $P_{lbs_per_cell} * .697$

FOR $Cost_P_perCell$



Assuming a corn price of \$2.75 per bushel and \$.697 expense per pound of phosphorous, calculate the percent of revenue for the variable application of phosphorous at each map location. Select **Overlay** → **Calculate** and complete the dialog below.



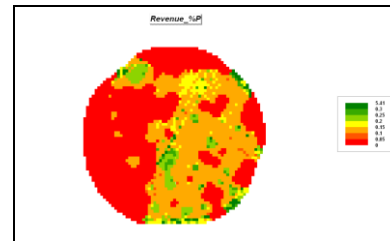
Calculate $((P_{lbs_per_cell} * .697) / (1997_Yield_Volume * 2.75)) * 100$ For $Revenue_SP$

Right-click on the derived map and select the **Shading Manager** option. Complete the display specifications shown below.

Min [>=]	Max [<]	Count	acres	% Girded Area	Color	Lock
0.3	5.41	53	3.04	1.6	Green	On
0.25	0.3	60	3.44	1.8	Off	Off
0.2	0.25	167	9.58	5.1	Off	Off
0.15	0.2	160	9.18	4.9	Off	Off
0.1	0.15	1200	68.9	36	Off	Off
0.05	0.1	16	0.918	0.49	Off	Off
0	0.05	1633	93.7	50	Red	On

User Defined

Ranges, 7 ranges (0-.05, .05-.10, .10-.15, .15-.20, .20-.25, .25-.30, .30-5.41), set the 0-.05 range red, .15-.20 yellow and .30-5.41 green.



You can exit the program by selecting **File** → **Exit** or by clicking on the “X” in the upper-right corner of the MapCalc program window. If you want to save your work, specify a new file name, such as *AgData_Topic8_exercises.rgs*. Each exercise set assumes you will start with the basic *AgData.rgs* data set and this database will become cluttered with exercise maps if you save your results to it each time.