Pursuing Precision Horticulture with the Internet and a Spreadsheet

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SUMMARY. Agriculture is changing. State-of-the-art computer systems that use GPS (global positioning systems) data, GIS (geographic information systems) software, remotely sensed images, automated sampling, and information analysis systems are transforming growers' ability to produce their crops. Currently, the farm service and agricultural sales industry, rather than the grower direct most information technology applications. Precision agriculture must become an information-driven and grower-driven process. Data evaluation has to be made simpler, less time consuming, and inexpensive. The purpose of this paper is to outline potential strategies and demonstrate how information can be processed and evaluated with readily available and inexpensive analytical tools.

Most precision agriculture tools are not new. Many remote-sensing software routines, recordkeeping software packages, and positioning systems have been in place for some time. The change is they have become more complete, powerful, available, and less expensive.

Farm-management information systems are an essential part of precision agriculture. Evolving technologies should be viewed as a way to organize and analyze vast amounts of information rather than a limited approach that leads to variable rate applications. Linking on-farm research plots with chemical application and harvest equipment that has mapping and precision application capabilities will become a powerful tool.

A shortage of trained people on the farm, among crop services providers, and in the public research environment who are familiar with these often intimidating technologies limit the industry's ability to take advantage of newly emerging opportunities.

Academic and service industry representatives regularly present precision agriculture examples to grower audiences. What is often left unsaid is that data evaluation commonly requires thousands of dollars of software and many hours of preparation time. Expensive systems also make on-campus academic training programs difficult to develop and all but eliminate distance education opportunities.

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Land grant institutions should initiate development and training programs for simple and inexpensive data analysis systems.

This manuscript is not intended to be a review of precision agricultural practices or geospatial analytical procedures. Reviews on precision agriculture practices (Atherton et al., 1999; National Research Council, 1997; Robert et al., 1996) and geospatial statistics (Mulla and Bhatti, 1997; Wollenhaupt et al., 1997) are available elsewhere.

The purpose of this paper is to outline potential strategies and demonstrate how information can be processed and evaluated using simple analytical tools. The proposed method uses a raster-based GIS system that requires nothing more than an inexpensive (or free) shape file viewer (a type of software for viewing spatial files presented in a shape file format) and Excel, a spreadsheet program available from Microsoft Corporation (Redmond, Wash.). The shape file (*.SHP) format is broadly used in many GIS applications. The data associated with geographic features are easier to handle and may be accessed by many different types of software when stored using this method.

Developing a strategy

At the heart of farm management information systems is yield mapping. Yield monitor data or imagery derived productivity assessments can be linked with other information to help identify rate-limiting factors. Systems that measure grain flow in combines are the most well known yield monitors. GPS-linked harvest equipment that continually records both yield and position is commercially available for grain crops.

Conveyor monitoring systems for potatoes (*Solanum tuberosum* L.) (Campbell et al., 1994; Rawlins et al., 1995) and other row crops are also commercially available. Other prototype systems for a wide variety of crops are under development (Thomas et al., 1999; Whitney et al., 1999). For example a system that records cumulative weight as nuts are swept from the orchard floor into storage bins has been used for Oregon hazelnuts (*Corylus avellana* L.). Similar approaches also work for caneberries (*Rubus* L.) and blueberries (*Vaccinium* L.). A barcode bin system has also

been used for Oregon pears (*Pyrus communis* L.).

Yield monitor data or imagery-derived productivity assessments can be linked with other information to help identify rate-limiting factors. GPS-defined areas can be evaluated to determine if characteristics within specific areas are associated with high or low yields. There is not necessarily a direct cause and effect relationship between factors associated with yield or growth differences. However, this is a logical first step in determining whether variable rate applications are appropriate.

Even after careful evaluation the cause of low yield may not be apparent. In many cases we have found low yield areas are associated with high soil nutrient levels. This may occur if growth is limited by something other than soil fertility. Years of relatively high fertilizer applications on areas with poor growth may lead to high soil test values. Where soil fertility is not a major limiting factor, precision agriculture approaches should focus on other management options.

If a limiting factor is either unidentifiable or not economically alterable, management adjustments can still be made. Although several years of yield data collection will often be required to delineate chronically low yielding areas adequately, a grower can eventually avoid putting expensive inputs on areas of a field that are unprofitable and unlikely to respond.

Sorting out the best approach

Clearly, affordable computers and data-processing software have simplified the process of making site-specific prescriptions. However, there is still considerable debate about which approach is most likely associated with increased profit. Some of the more commonly used sampling strategies for precision agriculture are the regular spaced grid with individual samples representing 2.5-acre (1.0-ha) units (Mulla, 1991). Targeted or directed sampling (Pocknee et al., 1996) based on soil map units (Carr et al., 1991; Clay et al., 1999), soil organic matter content (Francis and Schepers, 1997), topography and terrain attributes (Franzen et al., 1996; Jones et al., 1989; Yang et al., 1998), remotely sensed images (Mulla and Bhatti, 1997; Franzen et al., 1999), noninvasive sen-

sors (Morgan and Ess, 1996), or yield maps (Ferguson et al., 1997; Mullah and Bhatti, 1997) have been proposed as an alternative to regular grid soil sampling. In addition to map-based application systems, on-the-go sensor systems that are linked to variable rate application equipment have been proposed (Addsett et al., 1999; Giles and Slaughter, 1997).

Most disagreements focus on whether using grid sampling or zone management to diagnose crop requirements is more useful. Others feel that adjusting inputs to match yield potential is the most appropriate use of evolving technology. It is likely that a combination of approaches will be most profitable. The best approach will likely be dependent on the profit margin of the crop.

Many of these questions could be answered from on-farm research on growers' fields. These trials can easily be conducted on portions of a field (using on-farm equipment-sized test plots and yield monitors) before making a commitment to use any given procedure on a wide scale. Growers can determine if constant rate, variable rate, or zonal management applications are more profitable for their specific land and management system. It will also be possible to determine if a variable rate approach based on soil testing, zonal management, yield potential or combinations of these methods are most appropriate. Once established, georeferenced test plots can be easily evaluated for many years.

Automated evaluations of large on-farm test plots have several advantages. It facilitates easy application of treatments using farm-sized equipment, and simplifies the logistics when harvesting multiple plots. Spatial variability can be incorporated into statistical analyses. The layout and design of future trials can also be enhanced when extensive spatial data are available. One can use a smaller boundary well within the plot border for data analysis. This will help alleviate border effects and yield monitor lag time.

As more growers take advantage of these technologies, it becomes increasingly important that they have access to trained experts who can help them correctly use the equipment and interpret the results. Service industry representatives with the newest and most advanced hardware may still lack the expertise to make the best deci-

sions. As the agriculture management industry becomes more information and grower driven, knowledge and evaluation skills will become much more important than hardware or software availability.

The following simple guidelines are proposed for growers interested in using information technologies:

- Focus first on managing information rather than any particular precision agriculture solution. Variable rate applications are not always appropriate. Automated systems can be useful, but less complicated simple management changes can be a better economic and environmental choice.
- Use yield monitor systems, aerial imagery, soil maps and field data to identify possible management zones, determine how problem areas are distributed, and what factors limit yield.
- If a limiting factor can be economically altered, consider site-specific treatments to improve the limitation.
- If a limiting factor is unknown or not easily changed, manage inputs accordingly. Site-specific management of inputs based on profit potential may be appropriate.
- Consider economic and environmental impacts when making management decisions.
- Set up test plots that can be automatically evaluated with yield monitoring systems. Insist that test plots be incorporated into any commercial variable rate application.

Internet-based information and service

As the Internet becomes an increasing source of information, World Wide Web-based agricultural information services will become commonplace. An Internet based information system was selected for our data examples. However the approach described can be applied to data from any source. The *mPower*³ program (*mPower*³ Inc., Greeley, Colo.) cooperatively developed with several land grant universities provides Internet-based delivery of farm information. Including regional weather and forecasts, imagery products, site-specific weather data, pest models, disease models, weather alerts, historical management information, and detailed spatial information on individual fields.

All information is stored in a secure environment, and is disseminated via the Internet. The universal access, constant file format, and standard data structure of the Internet-based data delivery and archival system facilitate data use and interpretation. Although information can be entered into the system in several forms, archived data is generally downloaded in standard formats.

The *mPower*³ program currently uses registered geotif files (*.TIF) for images. For a more in depth look at image formats, see Avery and Berlin (1992), an introductory textbook. ESRI (Environmental Systems Research Institute Inc., Redlands, Calif.) shape files for vector information and DBASE or comma delimited text files for tabular data. Spatial data can be downloaded in either geographic (decimal latitude and longitude) or UTM (universal transverse mercator) coordinate systems. The UTM coordinate system identifies location by using the distance in meters east of (easting) and north of (northing) a given reference point. The following analysis examples are for data archived in *mPower*³ formats, with UTM coordinates, using techniques that have universal application.

Overview of data organization and simple analysis system

Data analysis software must be easy to use and inexpensive, but still powerful. One approach is to create a data processing web page that allows a user to pick data analysis methods that are suited to their data and needs. Information would be uploaded, processed using the desired utility, and then converted to the desired output format. This will help reduce the required software investment and the need to learn several different computer programs. Geostatistical processes (nearest neighbor, kriging, cokriging, etc.) and complicated file conversions that deal with map projections or datum conversion can be done on a Web page. Users can upload raw data and download the processed files.

A prototype data analysis system is described below. A set of software utilities we have created converts spatial information into a form that allows easy extraction of information of interest. One can then visualize and query

information with a simple shape file viewer and Microsoft Excel. The key to our package is to convert all spatial information (data associated with polygons, kriged soil and yield data, geographic information, image information, etc.) into a system of regularly spaced grids. This conversion becomes a much easier process when using the UTM coordinate system. Some of the important data conversion utilities are as follows.

UTILITY 1. A program that takes ASCII (text) files consisting of spatial coordinates and other associated information and converts them to a shape file. The shape file contains the original data, a positioncode field (x.y or easting.northing), and empty fields for future analysis for each point.

UTILITY 2. A program that takes any shape file polygon(s) and creates another shape file that consists of a set of points that fall within the boundary of the polygon(s) for any desired grid spacing. The data originally assigned to the polygon(s) is preserved for each point and additional database fields are created. One of the additional database fields is a field called positioncode (x.y or easting.northing).

UTILITY 3. A program that takes any georeferenced TIFF image file (UTM coordinates) and creates a shape file that consists of a set of points for any desired grid spacing. The RGB image (red image band, green image band, Blue image band) digital values for each point, some additional calculated file fields, easting, northing, and positioncode are preserved for each point in the shape file database.

UTILITY 4. A program that takes ASCII (text) files of spatial information (grid soil samples, yield monitor data, etc.) krigs the appropriate values and places the output into a shape file. The shape file contains point coordinates, the processed data, a positioncode field (x.y or easting.northing), and empty database fields that can be used if one wishes to add more information later. Once again, the grid interval for the output shape file can be set to any spacing. This utility also has an option that creates gridded shape files that are calculated from point density rather than a kriging routine.

Once data are processed information can be visualized, extracted, combined and queried in many ways. Although statisticians may be concerned

when summarizing and relating kriged values against other kriged data or otherwise manipulated values, this approach allows easy visualization and analysis of several components in large data sets. Some currently used precision agriculture software packages (SST Development Corp. Stillwater, Okla.; Agris Corp. Roswell, Ga.) that enable

the user to summarize multiple layers of precision agriculture information are using this approach.

When data are derived from sources with detailed spatial components (images and yield monitor data, hundreds of points of information per acre), little is lost if the information is purposely degraded to a consistent

grid spacing (in fact this may act as a smoothing technique). The choice of interpolation technique is far less critical for spatially dense data sets.

For soil grid data or other sparsely sampled information (acres per information point), it is not recommended to statistically evaluate kriged components. Although the kriged data are still useful for visualization, mapping and management applications, an analytical approach that uses only the original point data is proposed.

For example when evaluating soil information, samples are taken in a 10- to 15-m (32.8- to 49.2-ft) radius of a given sample point. This eventually allows soil data to be correlated with image or yield monitor information stored on a 10-m grid. The original GPS-derived UTM coordinates of soil sample data points are relocated to the nearest designated 10-m grid node. Moving the center of the sampling area several meters has little practical consequence, since sample spacing is at least an order of magnitude greater than the small position error we may introduce. A similar approach could be applied to any spatial data collected in this manner that are associated with specific areas. In this case, soil or other spatial data assigned to a GPS-derived polygon are eventually associated with a set of points within a given polygon at the selected grid spacing.

Spatial data evaluations

In the views presented in Fig. 1a and b. Processed hazelnut data for yield and vigor are presented using an inexpensive shape file viewer. In this example, emergePro viewer (*mPower*³ Inc.) was used. Other inexpensive or free shape file viewers could also be used.

In Fig. 1a, the 10-m gridded shape file for yield is presented in emergePro superimposed over a false color near infrared (NIR) photo of the same scene. The kriging utility (utility 4) was used to create the gridded shape file from weight based yield monitor data. The yield information is presented in varying shades of gray, high yield areas appear darker than low yield areas.

In Fig. 1b, a 10-m gridded shape file for vigor in the hazelnut orchard is presented in emergePro. This information is superimposed over the original NIR photo. Of interest to us is the portion of the image within the hazelnut orchard field boundary. The area

Fig. 1. Views in emergePro (a shape file and image viewer) are presented. Visual representations of the data in gridded databases for yield (top, a) and tree vigor (bottom, b) for a hazelnut (*Corylus* sp.) orchard are shown. For yield and tree vigor colors darken as yields or vigor respectively increase. All data presentations are superimposed over a digital false color, near infrared (NIR) aerial photograph of the same scene.

of interest (the orchard) was defined by extracting only the points that could be linked to the shape file database presented in Fig. 1a. Utility 3 was used to convert the image to a shape file.

Two of the three bands in the original NIR image [green band (g), red band (r), and near infrared band (ir)] were used to calculate a vigor estimate. The normalized difference vegetation index (NDVI) $\{((r - ir)/(r + ir)) + 1\} \times 128$ was automatically calculated (utility 3) as one of the shape file fields. The NDVI is a standard index often used in remote sensing applications to approximate plant biomass or plant vigor based on in-season imagery (Tucker, 1979; Tucker et al., 1981). For a more in depth look at remote sensing see Avery and Berlin (1992). Different vigor categories were defined based on NDVI values. Darker areas in Fig. 1b are more vigorous than lighter areas. Portions of the original NIR image can be seen in Figs. 2d and 3a.

In the following example (Fig. 2a and b) the databases (yield, vigor, soil type, and trunk cross sectional area files) associated with the shape files created by our data conversion utilities are stored in a 10-m grid format and linked to each other by positioncode. All data are from the hazelnut orchard previously described. The data are linked by using the Microsoft Query capability of Excel (included in the custom installation features), as shown in Fig. 2a.

Points in the four databases have common position codes and are therefore joined together. It is also possible to link databases using both of the X and Y coordinates. However, linking with a single field (positioncode) makes the query process much quicker. Similar approaches can be used to link, join, or extract many types of information.

In Fig. 2b, both tabular and graphical representations of the linked data were requested. These Excel pivot tables show average yield for the hazelnuts categorized by vigor (NDVI) and soil type. A pivot table is a term created by Microsoft to describe Excel's feature to dynamically summarize data. It creates frequency distributions and cross-tabulations of several different data dimensions and the bar charts linked to them.

This is an interesting analysis that has management implications. Maximum vigor only occurs in the most productive soil unit (coded 25.1). However, maximum vigor is not associated with maximum nut production. An in-

termediate vigor is associated with maximum yield. On the right are the counts for each vigor-soil type category. Since all data are on a 10-m grid, the count data can be converted to areas for each category.

To see the data that were used to calculate each cell in the pivot table or save these data for statistical evaluations, simply click on the desired cell. It is not necessary to categorize in two directions, as it is presented in this example (yield by vigor and CSA (trunk cross sectional area)). For example, it is possible to see average yield plotted individually for each vigor, CSA or soil type category. Many data visualizations are possible.

Linked data can also be queried using Microsoft Query. Any image or a screen capture from the shape file viewer

can be used as the background for an Excel scatterplot. By defining the x and y axes appropriately, and using the image as a scatterplot background, geographic information maps can be effectively visualized in Excel. In Fig. 2c, a query was initiated to identify all points that have high vigor and are also present in the selected soil type. Results (scatterplot) of this query are superimposed over an image captured from emergePro. In this view the scatterplot background was derived from the 10-m gridded shape file for soil type that was superimposed over an NIR photo of the same scene. The gridded soil type shape file was created using the polygon to point shape file utility (utility 2). Many other images or maps could also be used as scatterplot backgrounds.

The scene in Fig. 3a shows the

hazelnut orchard with GPS boundaries of test plots. The grower also has a yield file for this orchard with all data spaced on an even 10-m grid. Treatment plot numbers and replication numbers are assigned to the four polygons that make up the test-plot-boundary shape file. In this example, the top boundary defines treatment plot 1, replicate 1. Although test plots for tree crops are often set up to follow the tree and row structure of an orchard, this is not necessary. Any test plot shape or location can be evaluated. It is also possible to have information arranged with a grid spacing that associates information with the location of individual trees.

In Fig. 3b, the conversion utility (utility 2) that converts a shape file boundary into a new shape file that consists of a series of points within the original boundary on a regularly spaced grid has been applied. Since the yield data file and the gridded test boundary file now are spaced on the same 10-m interval all the positions codes (easting,northing) match up as can be seen in Fig. 3b. The smaller points (test plot points) overlap the larger points (yield points). Therefore yield and test plot databases can be linked in Excel to make an evaluation.

Once the yield and test plot databases are linked, a pivot table can easily

evaluate the data (Fig. 3c). Although this example demonstrates the evaluation of yield monitor data, the same technique can be used to determine if test plots differ in characteristics derived from images. For example, by simply using a gridded shape file for vigor in place of the yield file, a similar analysis could be made for NDVI (or any other RGB transformation) in the test plots of interest.

In the example shown, error bars represent the variability associated within each test plot shape file boundary. If experimental designs are kept simple, statistical evaluations (paired *t* test, simple analysis of variance, simple regression) can also be conducted in Excel.

Linking on-farm and off-farm data

The information displayed in Fig. 4 is from a pear production operation in Oregon that sells both standard grades of fruit and high-quality gift boxes. In Fig. 4 a) yield has been

Fig. 2. Views in an Excel worksheet that demonstrate the linking, summarizing, and querying of spatial data are shown. (far top left, a) A view of an Excel worksheets that illustrates the linking process for gridded databases using the common position code field called POSITIONCO. Since all spatial data is archived in the same regularly spaced grid system unique position codes are used to link different point attributes [trunk cross sectional area (CSA), tree vigor, soil type, and yield (YLD)]. (far bottom left, b) The pivot table results are displayed as both graphical and tabular summaries. Average yield across the categories of vigor [relative normalized difference vegetation index (NDVI)] and soil type (the values 73, 67, 25.2, and 25.1 designate different soil types) are presented. Yield units are lb/acre (1 lb/acre = 1.12 kg·ha⁻¹). NDVI is a unit less measure that is related to vigor. (top right, c) Counts for the number of points associated with each vigor-soil type category are displayed. (bottom right, d) An Excel worksheet that demonstrates the results of a query initiated to identify all locations that have relatively high vigor (upper third) and are also found associated with a specific soil type (73). Query results are superimposed over a classification of soil types overlain on a false color, near infrared (NIR) image. Units on x and y axes are universal transverse mercator (UTM) coordinates.

calculated from bin density (utility 4). Bright green areas have higher yield; dark red areas have low yield. Values range from 0 to 81 bins/acre (0 to 200 bins/ha). The original bin locations are also shown as small white crosses. An ASCII file with the original bin locations was converted to a shape file using utility 1.

If bar-coded bins are also tracked through the packinghouse spatial references to crop quality are possible. Once integrated into an orchard's record keeping system, the GPS-bar-code combination can help producers gain more insight into their orchard and packinghouse operations. Profit is very dependent on gift box production rather than simple yield. Until now, it was difficult to determine profitability of different parts of the orchard. The bar-coded bins can now be linked to a computerized packinghouse.

By scanning storage bins' bar codes, packing house personnel can follow fruit during the 15-min process of being dumped on the packing line to being placed into gift boxes. It is possible to label each gift box with its own serial bar code. Individual gift boxes can be scanned to determine who picked the fruit, when it was packed, where it was stored, the location within an orchard where the pears were produced, and from which bin the pears originated. Bin codes can be linked to field codes providing a chemical applications history for individual gift boxes. Figure 4 b) presents a map of gift boxes [0.5 lb (227 g) per box] per acre. Values vary from less than 4,856 (dark red) to more than 48,560 (light green) gift boxes/acre (12,000 to 120,000 gift boxes/ha).

Spatial management also has crop storage implications. For example, if pears come from a high-risk area in an orchard—a high-nitrogen site (which is associated with low-calcium fruit), a winter-damaged plot, a water-stressed area, or from locations that produced poor quality fruit in the past—a grower may want to pack and immediately market the fruit.

As orchard managers compile records over time, the information can help them think about how they are managing different parts of their orchards. Growers can couple the site-specific data about processed fruit with expense and revenue data to make not only yield maps, but also profit maps of

their orchards. Altered management schemes can also be evaluated in on-farm research trials to determine if new practices are more profitable (produce more gift boxes per acre).

The power of a spreadsheet

Since data DBASE (*.DBF) files can be manipulated in a spreadsheet environment, data evaluation and conversion are relatively straightforward. Standard Excel formulas can be used to manipulate image, yield, or other

spatial data. Variable rate application files can be created from yield data, imagery, soil type, soil test data, or other spatial information. The information in any portion of a database can be extracted, deleted, or manipulated. Spatial identity is retained and portions of a database that have been modified can be reinserted into the original file.

Although procedures are still complex, a spreadsheet environment has many advantages. Microsoft's Excel is inexpensive and already installed on

many computers. Furthermore, the advanced spreadsheet skills that one acquires while learning to process spatial information have broad applications to other farm management issues. Excel's pivot table features are designed to allow easy analysis of very large external databases and provide easy and secure access to network or Internet data storage systems.

Agricultural chemical and fertilizer application data that were formerly associated with a polygon can be linked to a set of points. Field records stored in a point format have the ad-

vantage of being independent of field boundary changes. All data are associated with each point. Spot applications can easily be assigned to the appropriate portion of a field. The polygon to point utility (utility 2) and an Excel pivot table can always be used to extract information for any polygon to be evaluated in the future.

The gridded database spreadsheet approach to analyzing spatial data is essentially a raster-based (information associated with many individual points) GIS system. In the past, slower computer processing capabilities and

smaller capacities made the large data files associated with raster data sets unmanageable to the average individual. This led to the variety of vector based (information associated with polygons and lines) GIS systems currently available today. However, with the ever-increasing capabilities and the reduced costs of modern personal computers, the past limitations are rapidly disappearing.

Most commercially available precision agriculture software packages can import and export different file formats. For example, in some systems, data from many different commercially available yield monitors can be imported. Similarly files can be exported in "ready to go" format for a variety of variable rate controllers.

Compatibility problems still create difficulties. Any alternative data analysis system will have to deal with multiple formats. However, we believe that data formats will likely become more standardized in the future. Shape file (*.SHP), DBASE (*.DBF), and Text (*.txt) file formats are some of the more universal. Furthermore, data conversion utilities can solve many incompatibility problems and would be included on the utilities web page.

Conclusion

Many information technologies discussed have immediate application. Others will be commercially imple-

Fig. 3. Views in emergePro (a shape file and image viewer) and an Excel worksheet that demonstrate the process of summarizing on-farm research trials. (far top left, a) Test plot locations (two treatments, two replications) are displayed in emergePro. (far bottom left, b) Gridded database points for both the test plot boundaries and hazelnut yield are displayed for a portion of the field that also displays the original global positioning system (GPS) derived shape file boundary of the test plots. (top right, c) A pivot table evaluation of test plot yields is displayed. The pivot table results show both graphical and tabular summaries of average yield they display average yield in lb/acre (1 lb/acre = 1.12 kg·ha⁻¹) across both treatment and replication categories. (bottom right, d) Graphical and tabular representations of the pivot table analysis display counts for the number of points associated with each treatment-replication category.

mented in the more distant future. Precision agriculture must become an information-driven and grower-driven process. Evolving technologies should be viewed as a way to organize and analyze vast amounts of information rather than a simplistic approach that leads to variable rate applications. To accomplish this data evaluation has to be made easy, accessible to everyone, less time consuming, and inexpensive.

It is recommended that potential users familiarize themselves with an easy-to-use, GIS package and obtain access to a handheld GPS receiver.

They can also work with researchers to incorporate on farm research plots, and generate maps using automated yield monitoring systems.

The *mPower*³ analysis approach discussed in this paper has been cooperatively developed with several land grant universities. More effort is needed to develop programs that teach, and extend simpler systems. It is our hope that the procedures outlined above can serve as a starting point.

The simple shape file viewer-Excel approach described here can be improved. Interface customization is

relatively easy to do. Excel application programmers can automate routine tasks. There must be hundreds of other useful data application utilities that have been independently developed at other academic institutions. These simple utilities can be integrated into and directly launched from Excel. The value in this approach allows data to be managed at many levels from very easy tasks to extremely complex comparisons. The pivot-table examples shown can be manipulated in a standard Excel spreadsheet. Custom installation of advanced features (Microsoft Query) is not required for an end user if the file structure and linking arrangements are previously defined.

The complex tasks can be completed by more advanced users and saved in an Excel format for others to view.

More complex utilities that require a software interface (e.g., ESRI's MapObjects or Complex Geostatistical Packages) can be housed on a data-processing web page. The academic community should find a way to link past and future programming efforts to a simple analytical system.

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Fig. 4. Views in emergePro that demonstrate the process of mapping total yield and quality (gift boxes per acre) components for pears are displayed. Gift boxes refer to small [0.5 lb (227 g)] ready-to-sell packages containing high quality pears. (top, a) Yield for a pear orchard has been calculated from the density of global positioning system (GPS) referenced bins. Original bin locations are marked with small white crosses. (bottom, b) A map of gift boxes per acre is presented. For yield and gift box presentations colors change from light to dark as yields or gift boxes per acre respectively increase.

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