Spatial Technologies in Agriculture and Natural Resources

Proceedings of a Regional Workshop

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Proceedings of a Regional Workshop

Edited by

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Sponsored by
Southern Natural Resource Economics Committee (SERA-IEG-30)
Southern Rural Development Center
Farm Foundation

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AGENDA
SPATIAL TECHNOLOGIES IN AGRICULTURE AND NATURAL RESOURCES
SRIEG-10 Conference

Global Hydrology and Climate Center
977 Explorer Blvd.
Huntsville, Alabama
May 20, 1999

Thursday, May 20

8:00 Registration

8:30 Introduction - Spatial Technology: Potential Applications in Agriculture with Emphasis on Natural Resource Impacts
Upton Hatch, Auburn University, Moderator

Overview of Remote Sensors: Opportunities and Limitations
Doug Rickman, GHCC/NASA

Value of Improved Information in Agriculture: Weather and Climate Forecasts
Jim Mjelde, Texas A&M

10:00 Break

10:30 Practical Applications of Spatial Technologies: Emerging Technologies and Impact on Agricultural Resource Use
John Bergstrom, University of Georgia, Moderator

Agricultural Water Data Systems
Larry Treadaway, University of Florida

The Effects of Yield Response and Spatial Variability on Use of Variable Rate Nitrogen Technology
Roland Roberts, University of Tennessee

Spatial Analysis of Techniques and Water Quality Monitoring
Nancy White, NC State

12:00 Lunch

1:30 Applications of Remote Sensing in Agriculture and Natural Resources
Ron Ritschard, University of Alabama/Huntsville, Moderator

Changing Land Cover in the Urban-Rural Fringe
Dale Quattrochi, GHCC/NASA

Mapping Multi-temporal Agricultural Land Use in the Mississippi Alluvial Valley of Arkansas
Bruce Gorham, University of Arkansas, Center for Advanced Spatial Technologies

Challenges in the Use of Coarse Resolution Soil Moisture Data in Agricultural and Environmental Applications
Chip Laymon, GHCC/NASA

3:00 Break

3:30 Spatial Analysis Applications in Agriculture and Natural Resources: What can the Scientific Community Provide? What can the Clientele Use Successfully? (Panel)

Paul Mask, Auburn University, Moderator
Jim Cruise, University of Alabama/Huntsville - Hydrology
Jeff Luvall, GHCC/NASA - Ecology
David Laughlin, Mississippi State University - Agricultural Economics

4:30 Adjourn

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Spatial Analysis in Agriculture: An Overview of Precision Agriculture

By

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Spatial Analysis in Agriculture: An Overview of Precision Agriculture

Precision agriculture is spatial information technology applied to agriculture. Also known as site-specific farming, it encompasses collecting and analyzing data for different locations within a field in a way that allows management decisions to vary in those diverse locations (Thirkawala, 1999).

Spatial information technologies include global positioning systems (GPS), geographical information systems (GIS), variable-rate technologies (VRT), and remote sensing (RS) (Lowenberg-DeBoer, 1998). Global positioning systems utilize a group of satellites regulated by the United States Department of Defense. They are used for accurately locating ground position (Strickland, 1998). Geographical information systems encompass computer hardware and software with procedures for compiling, storing, retrieving, analyzing, and displaying spatial data. They are designed to assist with planning and decision-making. Variable-rate technology is used for applying soil amendments at variable-rates within a field. Remote sensing involves the detection of energy reflected or emitted from an object with a sensor that is not in direct contact with the object. In sum, precision farming combines these technologies to help with decision-making by providing information needed for crop and soil management in specific field locations (Strickland, 1998).

Precision Farming Overview

Precision farming, also known as site-specific crop management, encompasses several types of technology including geographical positioning systems, remote sensing, geographic information systems, and variable-rate application. There are several factors to consider before adopting precision farming techniques. These include the amount of soil and crop variability, the ability of the farmer to understand and use the technology, and the suitability and cost of the technology.

Global Positioning Systems

Global positioning systems (GPS) use 24 satellite signals to define positions on the earth. The satellites circle the earth twice a day in six orbital paths. GPS can be used to georeference soil samples, tillage, planting, spraying, scouting, and harvesting. For example, GPS is used to georeference soil sampling and for tractor navigation. The hardware required for GPS includes a GPS receiver and antenna, a differential correction signal receiver and antenna, and an interface.

Geographic Information Systems

Geographic information systems (GIS) are used to input, store, retrieve, analyze, and display geographic data. The hardware needed for GIS includes a computer, high-resolution display monitor, digitizer/scanner, plotter/color printer, and a floppy disk drive. The software consists of a user interface, data input, data storage, data output, and data transformation.

Variable-rate Application

Variable-rate application (VRA) requires controllers, which change the application rate on the go, and actuators, which respond to the controller to regulate application. Variable-rate applications include applications of fertilizer, pesticides, and seed. The two methods of VRA are map-based and sensor-based. Map-based VRA requires GPS, GIS, and software for producing the maps.

Remote Sensing

Remote sensing measures energy reflected and emitted from objects without actually coming in contact with the objects. Four properties of remote sensing data that should be considered when using remote sensing systems include spatial resolution, spectral response, spectral resolution, and frequency of coverage. Spatial resolution refers to the size of the smallest grid cell of the imagery. Spectral response is the sensing system's ability to collect and respond to radiation in a spectral band. Spectral resolution is the ability of a sensing system to distinguish between different wavelength's electromagnetic radiation. Frequency of coverage, also known as temporal resolution, refers to how often a sensing system is available for data collection at a particular ground site.

The two main remote sensing platforms are aircraft-based and satellite-based. Aircraft-based systems provide images with higher spatial and spectral resolution than data from satellite-based systems. They are also easier to maintain and have the ability to provide images with a higher resolution. They can sense areas when conditions are optimal. In contrast, satellite-based platforms are in fixed orbits. Cost varies according to image type, image size, and level of processing.

Yield Monitoring

Site-specific crop management is often begun by spatial monitoring of yield. Crop yield data, when combined with soil maps, topographic maps, images, etc., can be used to develop a precision crop management system. For many years, farmers have used the collect-and-weigh method to determine yields for whole farms as well as individual fields. However, in the past few years, farmers have begun adopting a more technologically advanced way of measuring yield using a electronic yield monitors. A yield monitor measures and records yield as the crop is being harvested. The items that are found in most yield monitoring systems include a grain flow sensor, a grain moisture sensor, a ground speed sensor, a header position switch, and a display console. A yield map can be produced by using the data provided by the yield monitor and combining it with a location for each data point.

Variable Rate Technology

Several studies have evaluated the potential of variable-rate technology in agriculture. Cook and Bramley (1998) summarized the principles, practices, and possible benefits of precision agriculture focusing on Australian systems. They conducted a case study in the Western Australian wheat belt to show the potential benefits of site-specific fertilizer application. They examined the variable effect of urea in an 80 ha wheat (*Triticum aestivum*) field. They selected the maximum response over a grid of sample points as the optimal rate of application, and then used that response to estimate the whole field gains from VRA. Their results demonstrated that the benefits of VRA could be significant and sufficient enough to cover the costs of field mapping and equipment costs.

English, et al. (1999) explored the economics of spatial variation in yield potential. In their analysis, they determined the spatial break-even variability and then applied it to a hypothetical 30-acre corn (*Zea mays L.*) field. The field consisted of two land qualities and the break-even variability was determined for an array of nitrogen and corn prices for the different land production potentials. The analysis sought to assess the effect of variable-rate technology on net returns, taking into account the yield potential variability of the soil, the changing input and output prices, and the response of the crop to inputs. The net returns for both uniform and variable-rate technology were compared and the spatial break-even variability proportions for the field were determined. Results showed that additional returns from the adoption of variable-rate technology were more than adequate to cover the additional costs when the field is between 30% to 85% poor land.

Lowenberg-DeBoer (1999) evaluated precision farming's potential in managing production risk of agronomic crops. Lowenberg-DeBoer presented a theoretical model suggesting that precision agriculture, under certain circumstances, could reduce temporal yield variability. The model was site-specific and used a quadratic crop production function with two inputs, one, an aggregate input, controlled by the producer, and the other a stochastic weather index.

Lowenberg-DeBoer showed that empirical evidence from an on-farm trial in the Eastern Corn belt indicated that precision farming can reduce risk. The treatments were whole field management (soil testing and fertilizer application on a whole field), grid (the same done on a three acre grid system), and soil mapping (the same done again according to soil mapping). Rotations used by farmers were either a corn-soybean or a corn-soybean-wheat rotation. Results showed that the use of precision farming technology has modest risk reduction benefits in crop production. The benefits of this risk reduction lead to higher profits in the long run.

Bongiovanni and Lowenberg-DeBoer (1998) evaluated the profitability of variable-rate application of lime. The research was done using data for farms in Indiana in a corn-soybean (*Glycine max*) rotation system. It involved a spreadsheet simulation model for corn and soybean pH response functions estimated with experimental data. Three approaches were considered including two site-specific strategies and one intermediate approach. The first site-specific approach involved grid sampling the field and applying lime to the individual grids using agronomic recommendations. The second site-specific approach was similarly done, but used the economic rule to determine the recommended rate of lime. The intermediate approach involved applying a uniform rate of lime to bring the grid cell with the lowest pH up to full production. These were compared to whole field management with recommendations using a composite soil test and a single rate of lime application.

Results showed that the site-specific management with economic recommendations was the most profitable option, and the site-specific management with agronomic recommendations was the second most profitable alternative. The site-specific strategies tended to decrease variability in the yields, on average.

Watkins, et al. (1999) examined the profitability and environmental consequences of using variable-rate nitrogen and irrigation in seed potato (*Solanum tuberosum*) production. Their study simulated seed potato yields and nitrogen losses for four different areas of a 63 ha field. Optimal levels of nitrogen were found for each area.

They evaluated the average nitrogen losses and economic returns for both uniform and variable-rate nitrogen and water applications. Results showed that by varying the water application rather than the nitrogen application across a field, greater economic as well as environmental benefits may be achieved. These studies showed that for the most part, variable-rate technology has potential for increasing profit while lowering the environmental impacts.

Geographic Positioning Systems (GPS)

Other studies have been carried out on the value of using GPS in variable-rate application. Sunil Thirkawala, et al. (1999) conducted a study assessing the economic feasibility of using variable-rate technology for applying nitrogen fertilizer to corn. The three different application systems used were constant rate (application given over the whole field based on the average fertility for the entire field), three-rate (the farmer selects from three rates while manually operating a three-way switch in the tractor), and multiple-rate (four or more rates are coupled with GPS). The three application systems were examined under varying probability distributions for field fertility.

Net returns calculated for all three-application methods were positive. However, the constant rate was generally more profitable. As the application area increased, multiple-rate net returns became larger than those for constant rate because fixed costs could be spread over the larger area. The soil fertility distribution characteristics determined the application area at which the profitability between the constant rate and multiple-rate changed.

Buick explored the goal of maximizing crop production while lowering environmental impacts. He conducted a trial on a 1,000-acre farm in New Zealand comparing three guidance techniques for application procedures in the field. Buick sought to minimize the occurrence of overlaps and skips to maximize the overall swathing efficiency for field treatments. The three guidance techniques included a traditional foam marker system and two GPS-based guidance systems, one interfacing a light bar to a sub-meter accuracy Differential GPS receiver and the other interfacing the light bar to a centimeter accuracy RTK (Real Time Kinematic) GPS receiver. Application overlaps and skips were calculated by using an RTK GPS receiver to track the actual path of the spray equipment. A percentage swath area was computed for each pair of the adjacent swaths and for the whole field application. Results from this trial showed that the sub-meter GPS guidance was at least as effective as the foam marker in swathing efficiency, and that centimeter GPS guidance has a higher swathing efficiency than the other two techniques.

Remote Sensed Imagery

Remote data are collected by using sensors on airplanes or satellites to detect electromagnetic radiation emitted or reflected from objects on the ground. More formally defined, remote sensing involves obtaining physical data about an object without being in contact with the object. By using the data acquired through remote sensing, farmers are able to obtain detailed spatial information about features in their fields to assist management decisions.

Remote sensing can be used to measure soil and crop characteristics. In particular, images produced from remote sensing can help farmers with planting, fertilizing, irrigating, as well as other management decisions in the field. For example, Filella, et al. (1995) explored using remote sensing to inexpensively estimate and monitor N status in crops. Their objective was to see if leaf chlorophyll in wheat could provide a quick estimation of nitrogen using remote sensing. In their study, they measured both the visible (VIS) and near infrared (NIR) reflectance of a wheat crop which had been treated with five different rates of nitrogen fertilizer. Remote sensing data improved the nitrogen classification, allowing for the clear distinction between wheat plots with a nitrogen deficiency and those plots that were well fertilized. Results showed nitrogen status in wheat could be assessed using semi empirical pigment reflectance indices based on absorption bands.

Carlson, et al. (1991) evaluated the possibility of using remote sensing to monitor the crop water stress in dense vegetation before any major damage occurs. They focused their study on presenting additional evidence of transient water stress, showing the effects that the evapotranspiration (ET) plateau had on canopy radiometric temperature, and reporting the components responsible for the onslaught of the transpiration plateau. They also looked at the point in which transient stress could be detected using remote measurements of surface temperatures. It included the effects of cloud cover and bare soil and how they might disguise the stress signal.

Carlson, et al. found that a decrease in soil moisture led to an earlier formation and longer duration of the ET plateau. This indicated that the ET plateau could develop in moist soil with high atmospheric and solar demands. They also found that it might be possible to remotely sense the onset of harsh crop water stress using radiometric surface temperatures.

Campanella (2000) explored using remote sensing and precision farming technology to help cotton (*Gossypium hirsutum L.*) producers reduce production costs and increase yield. The eventual goal of his research was to combine the successful approaches into a Decision Support System for cotton production. His intention in conducting the research was to test the Decision Support System elements for cotton in certain field trials that imitate actual farming conditions. Research focused on testing variable-rate seeding, spatially variable insecticide, and variable-rate plant-growth regulator.

The first test involved variable-rate seeding. It showed that a lower seeding rate tends to produce more lint yield and minimize seeding costs. The test also showed that, when integrated with remotely sensed data, certain patterns emerge between seeding rates and yield. However, the emergence of these patterns was not enough to validate the need for imagery-based variable-rate seeding prescriptions.

The second test showed that remote-sensing based spatially variable insecticide prescriptions could be processed from multi-spectral imagery, which detected areas of fast-growing, healthy cotton. Since tarnished plant bugs are attracted to fast growing cotton, sprays could be selectively made in these areas. However, the imagery costs must be figured into the cost-benefit analysis to determine profitability.

The third and final test used image analysis to identify the most robust cotton plants. In cotton, the most robust plants tend to yield less. Therefore, applying the plant-growth regulator only to the most vigorous plants as identified in the imagery could meet the goal of minimizing plant-growth regulator application while increasing yield. Campanella concluded that a Decision Support System for cotton production, using precision technology with remote sensing as the key data source, might reduce the costs for farmers while maximizing yield.

Servilla explored the effectiveness of passive sensor digital imagery in his study conducted on a center-pivot cornfield in Nebraska. He took three images of the field using an airborne sensor about a month before harvest. The sensor measured the reflected blue, green, red (VIS), and NIR energy in the cornfield. One image combined the blue, green, and red energy measurements to form a true color composite. The true color image showed minor amounts of visible stress, except for a small amount of yellowing in the west side of the field.

The second image was a false color composite image produced using the green, red, and NIR energy measurements. Results from this image showed that the yellowing remained, and there was a rather distinct difference in vegetation where a narrow strip in the field had been missed when planting the corn.

For the final image, the red and NIR energy measurements were used within a mathematical normalization technique to produce an image providing a Normalized Difference Vegetation Index. This image resulted in delineating two areas of stressed vegetation: a poor drainage area and an area of sloped ground, both of which affected the corn health. The digital imagery also showed areas of stress induced by herbicide and pesticide damage, as well as poor irrigation, insect damage, and others.

Maas and Dunlap (1989) conducted research to show the effects of leaf pigments on light reflectance, transmittance and absorbance in corn. The role of leaf pigments has been one of particular interest because conditions such as nutrient deficiency, stress, and pollution damage may be detected using remote sensing. In their study, Maas and Dunlap examined leaf reflectance, transmittance, and absorptance spectra for corn seedlings. They used seeds with various pigmentations, namely normal, albino, and etiolated seeds, to show the effects of pigments versus the effects of cell structure and water content.

Results showed that in the NIR (λ=1,000nm) transmittance in the normal leaves were considerably less than that of the etiolated and albino leaves. However, reflectance and absorptance were notably greater for the normal leaves as compared with the albino and etiolated leaves. Differences could have been related to the thickness and water content of the leaves. These results suggest that remote sensing could be used to estimate leaf pigment concentrations in agricultural crops.

Aase and Siddoway explored using remote sensing to aid crop forecasting groups with such information as winter wheat acreage, extent of winterkill, and subsequent reseeding to spring crops. They reported results of research conducted to estimate simulated winterkill using a handheld radiometer imitating four LANDSAT multi-spectral scanner data. LANDSAT data, in some cases, correlated better with yield than vegetation index models, but vegetation index models had better year-to-year resemblances of vegetation conditions.

GIS and Field Maps

Hobbs used maps generated from using GIS to evaluate site-specific farming applications in the Palliser triangle, also known as short grass country. He used

Provincial Survey aerial photographs and GIS spectrographic software to generate maps to delineate management zones according to soil color. Four management zones were created and directly overlaid with topographic maps. He used soil-sampling techniques to collect data on 10 to 15 individual samples from each of the four zones. Results showed that there was 75 to 85 pounds of nitrogen available on hills and mid-slopes, while toeslopes and bottoms contained no nitrogen. Available nitrogen within zones varied as much as twenty pounds.

Gorham (1998) conducted another study using maps reproduced by digitizing procedures. His study dealt with finding accurate agricultural land-use maps so that potential problem areas, such as areas with low fertility and poor drainage, could be identified and predictions could be made about where problems are likely to occur so solutions could be found. Nine out of 27 counties along the Mississippi River in Arkansas were selected for sampling. The nine counties covered 13 million acres of cropland. These nine counties were chosen based on their geographical distribution, crop diversity/specialization, total harvested acres of principal crops, and driving distances between county offices. Farm fields were found on the satellite images and field/crop information was reproduced using digitizing techniques. The raw data were divided into broad categories including urban, water, transportation, agriculture, and forest. These classifications were then subdivided into more specific categories. This second set of categories was then united into 3 final maps. Next, each of these seasonal maps was developed into one image by compounding all the categories for that particular season. Results showed that crop accuracies in this study met or exceeded those of other crop mapping studies.

Soil Sampling

Soil sampling is another important part of site-specific farming. Haneklaus, et al. (1998) suggested that soil properties, such as texture, organic matter content, and landscape geomorphology, have a considerable influence on the productivity of soils. They held that a soil inventory needs only to be taken once for the variation assessment of these time constant properties. This soil inventory can be done properly by soil surveying, which combines GPS with the human sensory capability. In their study, geo-coded soil samples were taken in a field in northern Germany. Results from this study showed that self-surveying is remarkably appropriate for getting the basic soil information needed at a low cost.

While many farmers use manual soil sampling, some have begun to use sensing technologies to obtain soil information. Swinton and Jones (1998) explored using manual soil sampling versus the use of both remote and in field sensing technologies. They use a conceptual model to show that expected profit and profit variance from site-specific input management depend on the accuracy of spatial information. They showed that sensing information, both spatially and temporally, is more accurate than soil sampling information. However, soil sampling gives more precise measurements than sensing. Sensing is more profitable when timeliness matters, in-field micro-variability is great, and when sensor equipment measures attributes fairly accurately. In-field soil sampling has higher payoffs when sensor equipment is not reliable, timeliness is not important, and there is a larger scale of spatial variability.

Lowenberg-DeBoer (2000) looked at the potential value to corn and soybean farmers in the Midwestern US of automated pH sampling. He made the point that there is an economic trade-off between grid soil sampling, lab tests, and soil sensor data. There is a choice between relatively accurate data information from a few points with manual sampling versus less accurate information for many points with the soil sensor data. He questioned whether the lower cost of the sensor data was enough to offset the yield losses due to less accurate pH information. The results from his research showed that, as a general conclusion, the pH soil sensor has potential to be economically beneficial for the farmer. He found that using sensor information had modest cost savings compared to manual sampling.

Yield Monitors

Using a yield monitor to obtain information about crops is often used in precision farming. Zhang et al. (1999) evaluated the usefulness of a new system, which compared yield monitor results with other techniques, called field-level geographical information system (FIS). The goal of field-level geographical information system is to provide analytical functions that are useful for precision farming research and to provide a tool for analyzing and managing various field data. They conducted an experiment on variable-rate fertilizer application of nitrogen in two center-pivot irrigated cornfields in central Kansas. The experiment was based on yield mapping and soil sampling with the goals to optimize the nitrogen input for maximum yield and to minimize contamination of groundwater caused by leaching. In their study, field data were organized in excess of forty digital map layers. These data were collected by field survey, soil sampling and lab tests, crop sampling, yield sensor on a combine, and remote sensing. Results from their research showed that field-level geographical information system tools are flexible in that they provide a series of analytical functions that are not found in common GIS. However, field-level geographical information system is still under development.

Economic Viability

Snyder, et al. (1999) examined the economics of site-specific nitrogen management for irrigated corn in Kansas. Comparisons were made of uniform and variable nitrogen management using both soil sampling and detailed yield maps. Using data from both uniform and variable rate experiments, a quadratic function was estimated for each site and each year.

Results indicated that there is potential for profitable use of precision nitrogen management. Variable rate technology for nitrogen application used less nitrogen than the uniform management. For that reason, it was determined to be more profitable in some years while not in others.

Roberts and English (1999)conducted similar research involving nitrogen applications for cotton. They used a hypothetical cotton field that was initially assumed to have fifty percent of the land as high yield response to nitrogen and the other fifty percent low yield response. The two land qualities were assigned a yield response function reflecting high and low yield responses to nitrogen. Differences in returns above nitrogen costs for both uniform and variable-rate technologies were compared with costs of using additional variable-rate applications rather than uniform application rates. Results showed that nitrogen application using variable-rate technology might improve the efficiency of applied nitrogen and even reduce the amount of nitrogen applied. On the high yield response land, yield increased faster with increases in nitrogen than on the low yield response land. This meant that the marginal physical product of nitrogen was greater for the high yield response land than for the low yield response land. He concluded variable-rate technology has the potential to increase a farmer's profits by helping him make better decisions, increasing his yield averages, and decreasing his nitrogen cost. Increases in nitrogen application using variable-rate, rather than uniform application, may contribute to higher production of cotton and less loss to the environment.

Lowenberg-DeBoer (1998) assessed the profitability potential of variable-rate corn. He used the available information on crop response to plant populations, along with estimates of crop responses by yield potential obtained from Pioneer Hi-Bred agronomists. He developed spreadsheet budget examples using data from a three-year study in Kentucky. This study assumed that the corn areas with high, medium, and low yield potentials were known and that the proper kind of equipment was available to change populations. The seeding rate was the only rate that was site-specifically determined.

Three scenarios were developed for the study: First, 50% high-yield-potential land and 50% low-yield-potential land; second, 50% high and 50% medium-yield-potential land; and finally, 50% low and 50% medium-yield-potential land. Results showed that this method of variable-rate seeding has profit potential mostly for farmers with some low-yield-potential land. When a farmer has a large portion of low-yield-potential land, the largest benefits come from the savings in seed costs. However, for farmers with medium and high potential land, uniform rate seeding appears to be the best method because the cost of variable-rate seeding is greater than the benefits of seed savings.

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Value of Improved Information in Agriculture: Weather and Climate Forecasts

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Value of Improved Information in Agriculture: Weather and Climate Forecasts

Our increased understanding of climatological phenomena has caused a proliferation of studies valuing climate forecasts. The majority of these recent studies have valued climate forecasts associated with the El Niño / Southern Oscillation (ENSO) phenomena. Although most studies are well developed, it is my belief there has been a lack of attention paid to previous literature in valuing information, in general, and the literature specific to valuing climate / weather forecasts. Further, some studies have ignored the physical-based literature. Another source of overlooked information is the related climate change literature. Almost all studies, including studies conducted by myself, are guilty of ignoring this literature. It is impossible to incorporate all aspects of these different lines of literature, but a general knowledge of them is important. Some studies appear to be "reinventing the wheel." Reviews of the climate forecast literature, including studies dating back to the 1940's, are found in Hill (1999); Mjelde, Sonka, Peel; Mjelde, Hill, and Griffin; Nicholls; Wilks; and Global Climate Observing System. Glantz (1996) and Katz and Murphy are also good sources of important issues and the current state of climate forecasting. Further, Hill (1999) provides a review of the physical-based literature associated with improved climate forecasts.

Another neglected area is the use of true, multi-disciplinary approach to valuing climate forecasts. True integrated research is much harder and time consuming. In this era of publish or perish, integrated climate research is often overlooked in response to quick and dirty studies. Mazzocco et al. outline an interdisciplinary approach to value climate forecasts. Although this approach is more costly in the short-run, long-run benefits appear to accrue to the researchers in better and more published studies.

The objective of this paper is to provide the reader with background material associated with the economic value of climate forecasts. Although, the discussion concentrates on the micro or firm-level decision process, sector-level and other issues are also presented. Given the multitude of literature associated with the above topic, not all previous studies can be reviewed or included. My apologies to those important studies that are omitted.

What is Information?

Improved climate forecast (information) in agricultural decision making processes has been discussed as being either a technological advance (Mjelde 1994; Babcock) or an input substitute (Sonka et al.). Clearly, the ability to forecast climate events is a technological / scientific advance for climatological science. From the decision makers standpoint, the distinction is not as clear. It appears the use of information in production agriculture may either increase or decrease the expected value of relevant economic factors such as production, input usage, costs, and profitability or welfare measures (Mjelde and Hill; Mjelde, Penson, and Nixon; Hill et al. 1999a). Hilton shows there are no monotonic relationships between the value of information and the determinants of information value (see discussion below). Mjelde and Hill generalize this result to include outcomes of the decision making process. The essence is that the use of improved information appears to have characteristics of both technological advances and input substitutions depending on the situation modeled. What one can say is that the use of information allows decision makers to use inputs more efficiently. Distinguishing between technological advance and input substitution aspects is important only for academic discussion; it does not affect the modeling process.

Chavas and Pope define information as a message which alters probabilistic perceptions of random events. Extending this definition, information has value only if the altered perceptions lead to changes in the decisions made. The discussion in this paper is based on this definition of information and value.

Decision Theory Approach to Valuing Information

The general methodology to value improved climate information has its roots in the decision sciences. Most studies assume the decision maker knows the historical distribution (known as the climatological distribution) of climate conditions and uses this distribution in making decisions. Further, for simplicity assume the decision maker is risk neutral (relaxation of this assumption has little impact on the general methodology). Before the climate forecasts are available, the producer maximizes expected net returns given the historical distribution on the climate condition(s) of interest: where B(H) is the maximum expected net returns using the historical climate distribution (without the climate forecasts), the integral is taken over the climate condition(s) of interest, 2, and p(2) represents the historical climate condition(s) probability density functions (pdf), w is net return function, and x represents the decision set. Let x_h^* represent the optimal decision set.

When the decision maker obtains forecast F_i, the decision maker's perception of the probability of climate condition(s) occurring is modified. The problem becomes: where $B(F_i)$ is the maximum expected net returns associated with forecast F_i and $g(2 * F_i)$ is the modified pdf associated with the forecast. Let $x_{F\,i}^*$ represent the optimal decision set for forecast, F_i. Forecast F_i is only one of many possible forecasts. Expected net returns from using the climate forecast information are: where B(F) is the maximum expected net returns associated with forecast system F and $f(F_i)$ is the pdf associated with receiving the different forecasts, i. The expected value of the climate forecasting system is: the gain from information is the difference between the net returns when the information is used optimally and the expected net returns when the decisions are made optimally without the forecasts.

In using the above methodology, it is important consistency is maintained between the pdf's associated with the forecasts, such that the system is forecasting climatic events and not altering the overall probability of occurrence of a particular climate event. For the information system to have value, there must be an interaction between the decisions and the stochastic variables (Byerlee and Anderson 1969). In addition, to have value, the information must change at least one decision over the prior knowledge scenario. If $x_h^* = x_{Fi}^*$ for all F_i, then the information system has no value to the decision maker. Finally, to have value, the decision maker must be willing and able to use the information (Sonka).

Determinants of Information Value

Hilton lists four determinants of information value: 1) structure of the decision set, 2) structure of the decision environment, 3) decision maker's initial beliefs (or prior knowledge), and 4) characteristics of the information system. He shows, in general, there is no monotonic relationship between any of these determinants and the value of information. Although each determinant is discussed separately, the determinants are interrelated.

Structure of the Decision Set

What decisions can be made and at what level is the domain of this determinant. Merkhofer shows that for information to be valuable, the decision variable(s) must take on different levels. This requirement is intuitively simple. If, for example, there is only one way to grow corn, information on climate conditions is of no value in production decision making. The producer has one and only one way to grow the corn; the producer's decisions can not change by use of the information.

Within agricultural production, very little research has addressed the structure of the decision set. Most studies model a given decision set and do not examine how the different decisions may contribute to the over all value of the information system. One exception is the study by Mjelde et al. (1997b) which examines the impact of different decisions on the value of climate forecasts for a corn/sorghum producer in east central Texas. In this whole-farm model, the producer's decision set included decision on which crop (corn or sorghum), how much nitrogen to apply to each crop, 1993 U.S. federal farm program participation decisions, and if crop insurance should be bought. Results indicate crop mix decisions provide the greatest value to the producer with applied nitrogen levels having the second highest value. Decsions concerning participation in U.S. farm program provided approximately one-fourth of the value of crop mix decisions. Their results also illustrate that the total value of climate forecasts can not be obtained by summing the values associated with each individual decision. Finally, they conclude " . . . the analysis implies previous studies that examined only a small set of decision type may have been understating the economic value of improved seasonal climate forecasts" (Mjelde et al. 1997ba p. 169).

Structure of the Decision Environment

This determinant is broad, encompassing all aspects within the decision maker's problem given by w(≅) in equations (1) - (3). Aspects included, range from the decision maker's risk preferences to institutional constraints and opportunities such as government programs. Given economists' bias towards institutional and policy aspects, it is surprising this determinant has not received more attention.

A major contribution by Glantz (1977) is explicitly noting the need to examine the political, social, and economic structure of a country to completely obtain the potential value of climate forecasts. Glantz's (1977 p. 156-157) concluded

> "this preliminary assessment leads to the tentative conclusion that, given the national structures in the Sahelian States in which a potential technological capability would be

> used, the value of a long-range forecast, even a perfect one, would be limited. It appears, however, that its value could be greatly enhanced if its implementation were to be coupled with the removal of the numerous social, political, and economic obstacles . . . "

This was one of the first studies to explicitly recognize that constraints may exist to the use of climate forecasts. Antidotal information presented at a recent National Oceanic and Atmospheric Administration (NOAA) forum indicates that some decision makers did not utilize the information available during the 1997-98 El Niño and 1998-99 La Niña. One stated reason was the fear of being fired if the outcome using the information was bad; it was safer to continue with business as usual. Other reasons for nonuse of climate information include: availability, lack of appropriate structure of the forecasts, cost of obtaining and using the forecasts, value/utility of the forecast, scientific and economic validity of the forecasts, government and corporate policies that limit how climate forecasts can be used, and a need for a scientific explanation of how the outlooks are derived (Lamb, Sonka, and Changnon 1984, 1985; Changnon ; Easterling; and Nicholls).

Besides constraints to using forecasts, other aspects of the decision structure have been examined. Mjelde, Thompson, and Nixon modeled the impact of various government institutions on the value of climate forecasts for east-central Texas corn and sorghum producers. Government and quasi-government programs modeled are the 1993 U.S. farm program for corn/sorghum producers, disaster program, federal income tax law, and crop insurance. This study is limited to impacts at the farm level. With this caveat, improved climate forecasts have the most value when all the government programs are eliminated if no price changes are assumed. In this model, government programs lower the value of the climate forecasts to the producer. The U.S. farm program decreased the value of the forecasts because of the restrictions on the number of acres that could be planted under the 1993 farm program. The disaster program which provides payments to producers for losses caused by weather and related conditions decreased the value of climate forecasts to the producer. To the producer, these payments substituted for the climate information. Crop insurance had little impact on the value of the climate forecasts indicating the insurance is actuary fair or bias towards the insurance company. Including federal tax laws decreased the value of the forecast to the producer, because a percentage of any increase in net income caused by the use of climate forecasts is paid to the government in the form of increased taxes. What is missing in the literature is any study examining the impact of the various government programs from society's viewpoint. Taxes and disaster payments, for example, are transfer payments which are accompanied by potential losses. To my knowledge, no study has addressed these issues.

In a related study, Mjelde and Hill note the changes made in U.S. farm program in 1996 appears to be increasing the value of climate forecasts if no price changes occur. Elimination of many of the acreage restrictions adds additional flexibility to the production process. This increased flexibility is the main reasons for the increase in value. Participation in the 1996 program forced the producer to buy low cost catastrophic crop insurance. This insurance decreases the value of climate forecasts much in the same way the disaster program decreased the value of climate forecasts in the earlier study. From these studies, it is clear government programs are lowering the value of climate forecasts over a world of no programs, at least at the farm level. Again, it must be stressed that a study from societal's viewpoint is necessary to determine the overall impact and interactions between government programs and climate forecasts.

Another component of the decision structure is the objective of the decision maker. Most studies have assumed the decision maker is risk neutral, but there are exceptions. Bacquet, Halter, and Conklin and Byerlee and Anderson (1982) show a decision maker's risk attitude affects the economic value placed on climate forecasts. Further, Byerlee and Anderson (1982) show there is not necessarily a positive correlation between the level of risk aversion and the value of information.

Mjelde, Thompson, and Nixon examine one level of risk aversion assuming a exponential utility function. They note the importance of using certainty equivalence dollars to compare risk neutral versus risk averse individuals. In certainty equivalent terms, risk averse producers value the improved climate forecasts less than risk neutral producers. Concerning the impact of government institutions and the value of climate forecasts, they conclude “it appears that including risk aversion has little effect on the inference concerning the effect of government institutions” (Mjelde, Thompson, and Nixon p. 186). Mjelde and Cochran develop a methodology using stochastic dominance to determine the upper and lower bounds on the value of information for risk averse decision makers. Their results suggest the level of risk aversion, as well as the decision maker’s prior knowledge, are important in determining the value of climate forecasts. As decision makers become more risk averse, the value of climate forecasts do not necessarily increase.

Decision Maker’s Prior Knowledge

Relatively little work has been conducted on the impact of decision maker’s prior knowledge on the value of climate forecasts. Studies have demonstrated individuals may not be accurate in their assessment of the probabilities of historical events (Bessler; Tversky and Kahneman). Mazzocco and Mazzocco et al. allow decision makers to possess subjective priors (ambiguous priors) that differ from historical probabilities. The use of these ambiguous priors resulted in slightly different fertilization decisions than when historical probability priors are used. The value of climate forecasts are higher when ambiguous priors are assumed than when historical probability priors are assumed

As noted previously, Mjelde and Cochran also show the importance of assuming different prior knowledge when valuing climate forecasts. Prior knowledges used are assuming knowledge of historical probabilities (consistent with most studies), assuming last year's climate will occur this year, assuming good conditions will occur (aggressive strategy), and assuming poor conditions will occur (defensive strategy). For their situation, corn production in Illinois, decision makers using a prior knowledge of assuming last year's conditions will occur valued forecasts the most. Decision maker's using historical and the aggressive prior knowledge' value for the forecasts were very similar and smaller than decision maker's using the protective prior.

One note of caution when examining the impact of different priors is necessary. The general framework previously presented must be modified. In equation (1), the climate probability density function is modified to be the decision maker's prior knowledge distribution. Decisions obtained from this maximization problem must then be simulated over the range of potential climate conditions to obtain the value of the decision process without the improved climate forecasts. This change is necessary because the decision maker's prior knowledge does not necessarily represent the historical distribution. The climate forecast valuation methodology must value the climate forecasts and not a change in overall climate conditions.

To my knowledge, no work has been conducted on the impact of prior knowledge on the value of forecasts based on the El Niño / Southern Oscillation (ENSO) phenomenon.

Characteristics of the Information System

Characteristics of the information system for climate forecasting include: 1) accuracy, 2) lead time, 3) specificity, 4) spatial resolution, 5) weather parameters to be forecasted, 6) number of future periods forecasted, and 7) time span of the forecasts (Mjelde 1985; Lamb; Mjelde, Sonka, and Peel). Although presented as if each characteristic is independent of the others, it should be noted interrelationships exist between these different characteristics.

Accuracy. Of the characteristics of information systems, accuracy has received by far the most attention. As noted by Mjelde, Sonka, and Peel, accuracy has received the most attention, because conceptually it is easier to understand how this characteristic affects the the value of climate forecasts. Defining accuracy quantitatively or qualitatively is difficult. In fact, different research has referred to accuracy by different names including quality and predictive skill. Within equations (2) and (3), it is clear accuracy contains two components. As noted earlier, consistency must be maintained within such that climate forecasts are valued. Different measures, such as variance and entropy (Mjelde et al. 1993; Brown, Katz, and Murphy), have been used with varying degrees of success to capture differences in these two components. Chavas and Pope provide a discussion of measures of information content.

Whatever measure of information content is used, it must account for differences in both. Because of difficulties in accounting for both measures, studies addressing different accuracy levels have generally simply presented several accuracy levels based on $g(2|F_i)$ and have let $f(F_i)$ change as needed to maintain consistency. Mjelde et al. 1993 demonstrate the entire structure (both g and f) of the forecast format is important in determining the value of the forecasting system.

With our increasing knowledge of the ENSO phenomenon, most studies have concentrated on the value of using this phenomenon to predict climate conditions (e.g. Mjelde et al. 1997a; Marshall, Parton, and Hammer; Lagos and Buizer). In some studies, the value of improvements in predicting ENSO have been analyzed (Solow et al.). Recent studies valuing climate forecasts have tended to ignore the value of other advances in climatology, such as the North Atlantic Oscillation (Lamb and Pepper), Atlantic sea surface temperatures (Berte and Ward) or other cycles (Burroughs).

One sidelight, based on the author’s experiences, should be noted when classifying climate condition and modeling climate conditions in an economic model. Using the entire distribution of climate conditions within each category rather than the mean climate conditions usually results in a smaller value for the climate forecasts.

Lead time. Lead time denotes the time lapse between when the decision maker receives a forecast for a specific period and the occurrence of climate in that period. The importance of this characteristic can be illustrated in a simple crop management example. Consider a crop which is planted in early April and has a six month growing season. Further, assume by the middle of July the crop is too tall to get machinery into the field. Finally, weather conditions in August interact with applied nitrogen impacting crop yield. A forecast for August rainfall and temperature received before the middle of July may have value. This is because a producer could adjust applied nitrogen levels by side dressing the crop before the crop is too tall to enter the field. A forecast received after mid July would have no value in production, because it is received too late to adjust any inputs. In this case, a lead time of at least one-half month is necessary.

Easterling and Easterling and Mjelde note the importance of lead time in agriculture. Easterling and Mjelde show less accurate forecasts received earlier in the production process may be more valuable than more accurate forecasts received later in the process. Mjelde and Dixon develop a methodology to value lead time. In this methodology, decision makers anticipate when the forecasts are going to be received. Surveys of users and potential users of climate forecasts clearly show decision makers place a high level of importance on this characteristics (Easterling). Unfortunately, research valuing climate forecasts has tended to ignore this characteristic by assuming the forecasts are available when needed.

Specificity. Specificity refers to the number of climate conditions forecasted for each period. Examples of specificity would be forecasting three conditions such as above, near, and below normal versus forecasting five categories. Studies such as Mjelde (1985), Mazzocco et al., and Hill et al. (1999b) examined the impact of specificity. These studies suggest forecasting three versus five categories does not necessarily increase the value of the forecasting system. Hill et al. (1999b) calculate the difference in value associated with forecasting climate based on three versus five ENSO related categories. The three categories are the common categories, El Niño, other, and La Niña, whereas the five categories are based on Stone and Auliciems work. Results suggest for most areas of the U.S. and Canada, using the five category system provides more value to the producer than the three category system. For several locations, however, the three category system provides as much or more value than the five category system. Although these results may seem counterintuitive, they are consistent with earlier studies of information value in that more information is not always more valuable (White; Marschak).

Spatial resolution. The issue associated with spatial resolution is that for a large geographical region the forecast is correct, but for any specific area within the larger region the forecast maybe incorrect. The issue is how small of geographical region should the forecasts cover. At the field-level, the economic impact of spatial resolution is straight forward. The decision maker may be incorporating incorrect information into the decision making process. At the aggregate level, spatial resolution is much more interesting. A climate forecast may be correct for the region as a whole. Knowledge of regional climate conditions provides information on expected supply and thus price. For any individual field, the forecast maybe incorrect for determining input usage, but gives a good price forecast. To my knowledge, no study has examined spatial resolution in an economic context.

Weather parameters to be forecasted. This characteristic addresses the issue of which weather parameters need to be forecasted for the decision maker to value the forecasts. Weather parameters include temperature, precipitation, solar radiation, etc. This characteristic has not been the subject of economic research recently. Most studies either use rainfall or classify the entire growing season weather. Classification of the entire growing season is the common procedure being used in valuing forecasts associated with the ENSO phenomenon.

Some early studies examined the issue of parameter to be included (Rench and Makosky: Wilks and Murphy; and Nelson and Winter). Results suggest this design characteristic is important and the individual decision making process determines the economic value placed on each parameter.

Number of future periods forecasted. This characteristic refers to how many future periods are forecasted by the climate forecasting system. This characteristic is highly related to the time span of the forecast characteristic discussed below. Two studies (Mjelde et al. 1988; 1997b) valued forecasts for different periods. They show within the agricultural production period, different time periods may have different value. In addition, these two studies show the value of a system that predicts two periods maybe more valuable than the sum of two systems which predict the two periods independently. Their results suggest there are synergistic effects of knowing the climate for adjacent time periods in a dynamic system. No study has examined the “optimal” number of periods to forecast.

Time span of the forecasts. This characteristic refers to the time period(s) for which individual forecasts are relevant. Are the forecasts for time periods of one week, month, seasonal, multi seasonal, or yearly? In agriculture, most studies have defined the length of the forecasts to be the growing season. To my knowledge no study has addressed questions relating to the key physical and economic issues associated with varying the length of time associated with forecasts.

Aggregate Issues

Most of the above discussion also applies at the aggregate level. At the aggregate level, however, several complicating factors are present. Adoption of new information systems will not occur instantaneously. Early adopters may gain Schumpeterian profits, because of the more efficient use of inputs over the nonadopters (Mjelde, Sonka, and Peel). Early adopters may be able to increase profits by increasing efficiency while causing only small or no price changes. Adoption of information may also cause changes in aggregate supply. Such changes in supply will have an impact on price in a competitive market. Price changes will impact both consumers and producers.

At the aggregate level, a common welfare measure used in valuing climate forecasts is producer and consumer surplus (Babcock; Adams et al.; Johnson and Holt). The impact of price changes and associated quantity changes on these measures are dependent on the price elasticities of demand and supply. In agriculture, the elasticities are such that a price decrease is often associated with a decrease in producer surplus and and increase in consumer surplus. Studies tend to show or assume climate forecasts will increase overall supply which will hurt the producers and benefit consumers (Mjelde, Penson, and Nixon; Babcock; Lave;). These studies suggest producers' loss is less than the benefit consumers gain, therefore, to society, climate forecasts have a positive value. Mjelde, Penson, and Nixon along with Hill (1999) show in any given year, however, producer and consumer surplus individually may increase or decrease (see preceding result section).

Also, at the aggregate level interrelationships between other commodities and sectors such as input and financial sectors becomes relevant. These interrelationships can be illustrated using the following agricultural example. Let the adoption of climate forecast impact the use of inputs, say nitrogen. Changing nitrogen usage will impact nitrogen dealers, as well as companies which produce the nitrogen. Further, changing profitability at the firm-level will impact banks willingness to make loans to producers. Much of U.S. production agriculture is dependent on operating loans. Changing profitability will impact the ability of producers to purchase new equipment. All of these interrelated impacts has effects on the local farming community economy. As illustrated, the impacts at the sector and beyond level are very complex. Mjelde, Penson, and Nixon using an agriculture sector-level model, which has links to the financial and input sectors, show the use of climate forecasts in agriculture may benefit or have adverse impacts on related sectors depending on the realization of climate conditions.

Besides linkages within a country, the global economy will be impacted by the use of improved climate forecasts (Weiss 1981). Hill (1999) shows the use of ENSO-based climate forecasts will have an impact on world trade. Contrary to most previous studies, Hill (1999) suggests overall both producers and consumers may gain using the forecasts. Hill (1999) unlike most other studies has acreage and input decisions being made based on the forecast and other economic conditions. These differences, along with price expectation modeling based on the forecasts, may account for his findings. Producers, however, gain much less than consumers, which is consistent with previous findings.

Another complicating factor is that traders in the commodity markets are using climate forecasts. These traders have an impact on price. To date no study has attempted to link trader actions along with producers' responses to improved climate forecasts.

Finally as illustrated, modeling producers' reactions to climate forecasts at the aggregate level is complicated. The modeling must first account for how changes in the producers' decisions will impact yield. At this level all the determinants previously discussed need to be considered. These yield changes must then be aggregated. An important aspect is the 'fallacy of composition" (Hill 1995). "The fallacy warns us that what is true of the parts is not necessarily true of the whole. Thus, generalizations of a microeconomic nature may not always be applicable to a macroeconomic situation" (Spencer p. 5). Aggregation procedures remain an important issue in any aggregate modeling. Changes in supply must then be related to other commodities and sectors to determine an overall impact. However, producers will learn that their actions may change price, therefore, price expectation mechanisms must be included when determining the producers' actions. It is little wonder most studies at the aggregate level have used previously developed models. Sonka and Lamb note the necessity to develop analytic techniques which allow the linking of analysis at different levels of aggregation to enhance our understanding of how society will be impacted by the use of improved climate forecasts. Currently, aggregation techniques remain an impediment to analyzing the impacts of changes in firm-level decisions on society.

Selected Results

Here results from three recently completed studies are briefly presented to illustrate several additional points. The objective is not to develop the studies' details and models, but rather to illustrate the points. Interested readers are referred to the individual studies for details.

Field Level Study

Hill et al. (1999b) use a crop growth model to simulate wheat yields across the U.S. and Canada. Assuming the producers objective is to maximize net returns from wheat production, the value of Southern Oscillation Index (SOI) based forecast are valued assuming no price changes. The forecasts are based on Stone and Auliciems five categories. In table 1, the value of the ENSO based forecasts as a percentage of perfect forecasts in presented for selected sites. Results show the use of SOI-based climate forecasts have surprisingly high value in some areas of the U.S. Further, the value of the forecasts clearly show distributional aspects. Producers in some areas will benefit more from the forecasts than producers in other areas. The value of the forecast is related to regional/local soil characteristics and the strength of the Southern Oscillation (SO) signal. The strength of the signal is important, but other factors are also important. Texas, Oklahoma, and Washington all have strong SO signals, but Texas and Oklahoma are located near a PNA boundary. Although not modeled or examined, these results may indicated other influences beyond the SO are important.

Aggregated Wheat Supply

Aggregating field-level wheat simulation yields across the U.S., Canada, and Australia, Butler et al. (1999) obtain national level supply curves based on the use of SOI-based climate forecasts. In figure 1, results for Canada expected supply are presented; all countries had similar findings. This figure is used to illustrate climate variability and that part of variability that is either caused by or mitigated by the use of SOI-based climate forecasts. Climate variability is illustrated by the different panels. Shifts caused by the use of SOI-based forecasts are given by the supply curves within a panel. As illustrated, climate variability shifts are much greater than any shifts caused by the use of the SOI-based forecasts. A second interesting feature is the shifts caused by the use of the climate forecasts. Within any phase, the use of climate information may increase or decrease expected supply. Hill et al. (1999a) show similar results for the aggregate Texas sorghum supply curve.

Aggregate Sector-Level Study

Mjelde, Penson, and Nixon linked a field-level decision model with a dynamic agriculture sector-level model. They valued perfect yearly-forecasts by calculating the present value over a 10-year horizon. Of interest is the order the 10 years of climate were inputted into the models. In table 2, differences in the present value of consumer and producer surplus are presented for five different scenarios over the 10-year horizon. Over the 10 years, it is clear producers lose and consumer gain, but overall (producer plus consumer surplus) society gains. An interesting aspect is the differences in the net surplus over the 10 years. Simply by changing the order, a difference in net surplus of 130% is obtained. In figure 2, yearly surplus differences are plotted for the five scenarios. In any given year, producer, consumer, and/or net surplus maybe negative or positive. For policy and farm survivability aspects, these results illustrate the need to look at more than just long-run expected net value of climate forecasts as given by the decision theory approach and previous studies.

Other Issues

The above discussion has only scratched the surface of issues associated with valuing climate forecasts. It is clear each and every situation will be slightly different from previous decision settings. Earlier it was noted that decision makers must be willing and able to adopt a flexible management strategies to use climate forecasts. An important component of this integration into decision maker is the communication channels between forecaster and decision maker (Getz). Roth, Maunder, and Davis and Nnaji argue for the climate information to be in relevant form, cooperation between the forecasters and decision makers is necessary. This argument remains as important today as it was in the 1960's, 70's and 80's when these arguments were made. As early as 1949, Price argued dissemination of probabilistic rather than categorical forecasts increases the economic value of the climate forecasts. With probabilistic forecasts, the public requires a great deal of training regarding the probabilistic nature of this information (Hammer). Further, legal or liability issues associated with dissemination of forecasts has barely been scratched (Weiss 1982).

Discussion

Using the above brief discussion, personal discussions, and other published studies as the starting point, several additional points are made. First, additional and better studies examining the impact of ENSO-based forecast are necessary, but other types of studies may have a larger payoff to society. Examining how other aspects of climatology interact with the ENSO phenomenon to provide increased forecast accuracy is necessary. Other climatological phenomenon may be more valuable than ENSO. How decision makers use climate forecasts and how the different determinants relate to particular decision makers needs to be examined. Relating the determinants of information value to ENSO-based forecasts is necessary. Evidence indicates decision makers have little confidence in climate forecast for use in decision making. This aspect needs further examination. Research on how climate forecasts and government policy could work together to increase value of the forecasts is necessary.

Unfortunately, some scientists have jumped on the band wagon without understanding and correctly using ENSO-based forecasts. This lack of understanding appears to be partly caused by not reading the literature. Along this line, reinventing the wheel seems to be part of the recent literature. Understanding the previous literature is important.

Finally, society will remain vulnerable to climate even though we may be able to provide improved climate forecasts. Another strategy to cope with climate change maybe the ability to provide seasonal-to-interannual climate forecasts that have the capability to allow decision makers to adjust to climate conditions.

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Table 1. Value of Southern Oscillation Based Forecasts as a Percentage of Perfect Forecasts for Wheat Production in Various Regions at the Field-Level.[1]

Region	Low Price[2]	High Price
Texas	23	18
Oklahoma	18	19
Washington	14	5
Kansas	7	0
Midwest	0	0

1) From Hill et al. 1999b.
2) Price various slightly by region based on regional price series.

Table 2. Present Value of Changes in Producer Surplus, Consumer Surplus, and Net Surplus for the Five Scenarios in Millions of U.S. Dollars.[1]

Scenario	Producer surplus	Consumer surplus	Net surplus
Actual occurrence	-4439.74	5793.781	1359.73
Reversed order	-7237.56	9980.48	2742.92
Worse years first	-5953.83	8871.17	2917.34
Best years first	-5058.41	6328.36	1269.95
Randomly drawn	-2530.39	4604.24	2073.85

1) From Mjelde, Penson, and Nixon.

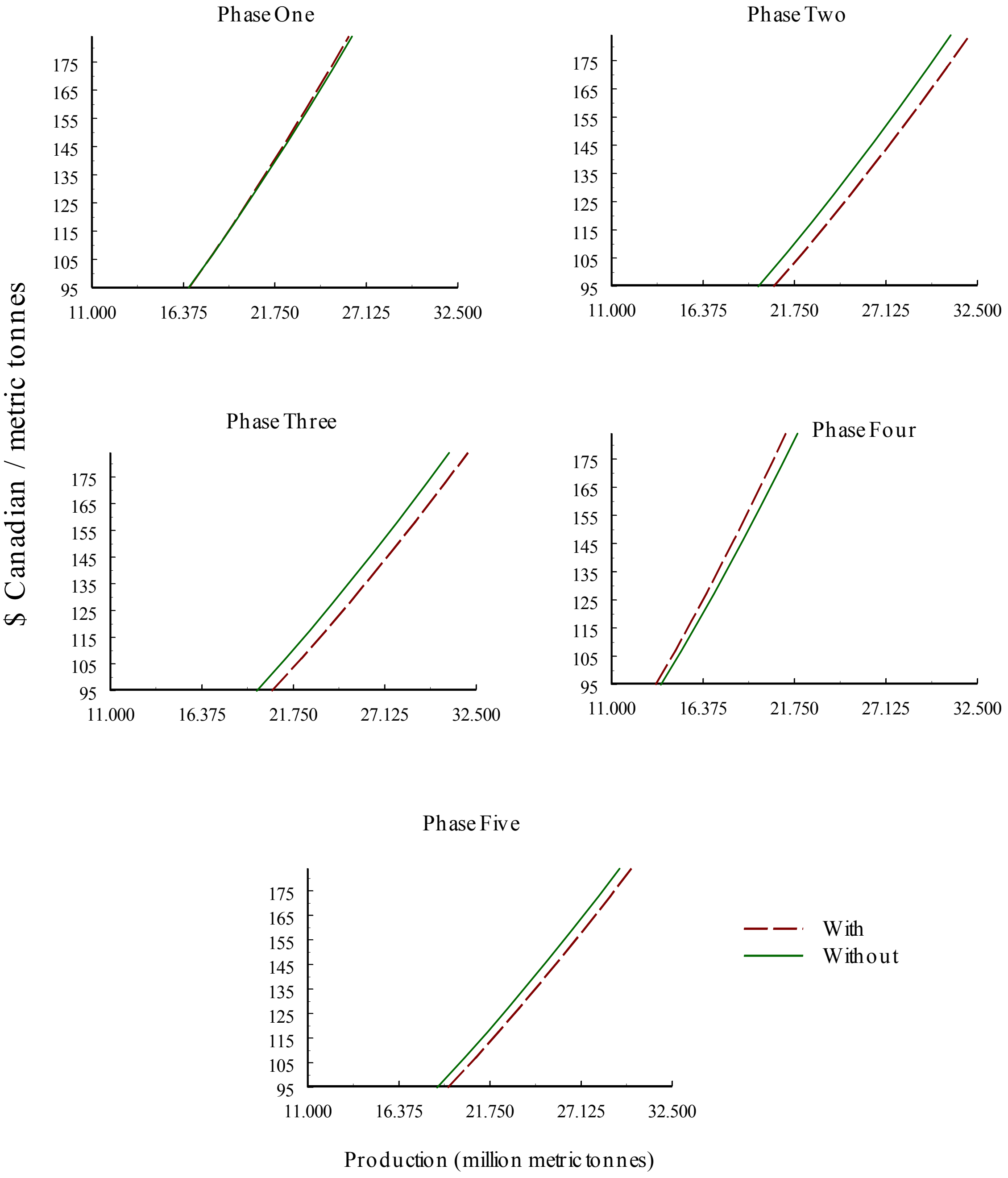

Figure 1. Canadian Expected Wheat Supply by SOI Phase from Butler et al.

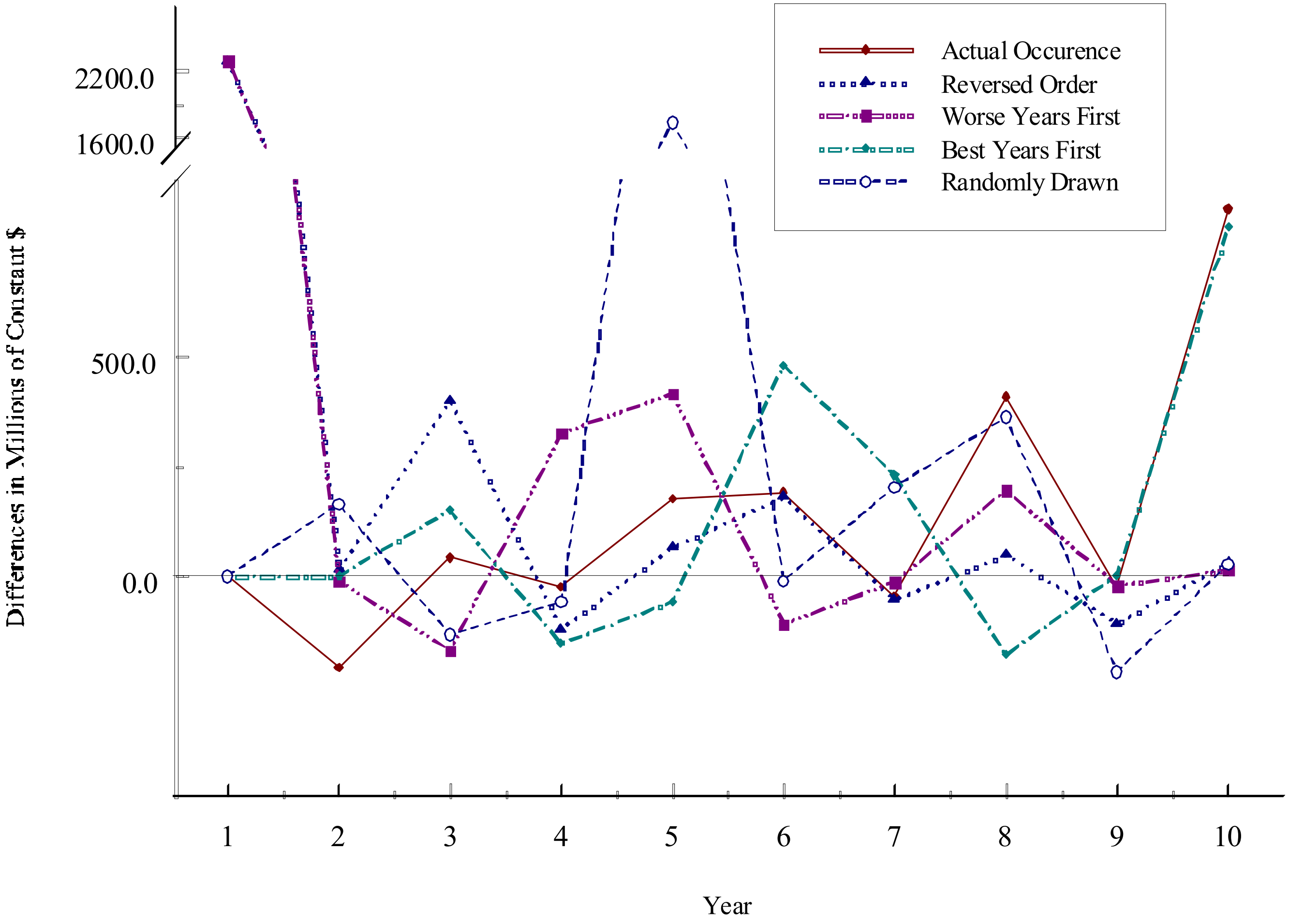

Figure 2. Differences (w/ forecast - w/o forecast) in Present Value of Consumer Plus Producer Surplus for the Five Scenarios from Mjelde, Penson, and Nixon.

Economic Evaluation of Variable Rate Nitrogen Application on Cotton

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Economic Evaluation of Variable Rate Nitrogen Application on Cotton

Introduction

Farmers have in recent years have been applying inputs as if their fields were uniform in yield potential. Agricultural fields consist of numerous areas that differ from one another with respect to the factors that condition crop growth (Carr et al.; Hannah, Harlan, and Lewis; Hibbard et al.; Malzer et al.; National Research Council; Sawyer; Spratt and McIver). The concept of precision farming recognizes that farm fields can be rather heterogeneous units. Precision farming refers to treating within-field variability with spatially variable input application rates using a set of technologies to identify the variability and its causes, and prescribe and apply inputs to match spatially variable crop and soil needs. Two important benefits claimed of precision farming include increased profits to farmers and reduced environmental harm as a result of more precise placement of inputs (Kitchen et al.; Koo and Williams; Sawyer; Watkins, Lu, and Huang). The key, however, to the acceptance of site-specific farming is the profitability of the technology (Daberkow; Swinton and Lowenberg-DeBoer; Reetz and Fixen; Roberts, Kemper, and Christensen; Sawyer).

The presence of variability in soil and field characteristics is key to the economic viability of precision farming (English, Roberts, and Mahajanashetti; Forcella; Hayes, Overton, and Price; Snyder). From an economic standpoint, the factors that drive the adoption of precision fanning technology are spatial variability, or the distribution across a field of land types with different yield responses, and the magnitudes of the differences in yield response (English, Roberts, and Mahajanashetti; Forcella; Roberts, English, and Mahajanashetti).

Numerous private crop consulting firms and local cooperatives currently offer variable rate fertilizer application services to farmers for a fee (Lowenberg-DeBoer and Swinton; Swinton and Ahmad). The question of interest is whether the potential increase in revenue is sufficient to offset the increased cost of hiring those services. The objectives of this paper are 1) to illustrate the potential economic and environmental benefits of using variable rate nitrogen application services and 2) to identify the information required to evaluate the costs and benefits of variable rate fertilizer application technology.

Hypothetical Cotton Field

The objectives are accomplished by presenting a hypothetical example of nitrogen applied to a cotton field that is initially assumed to be 50 percent high yield response land and 50 percent low yield response land. In this example, each land quality is assigned a hypothetical quadratic cotton lint yield response function that reflects high yield response or low yield response to fertilizer nitrogen. The assumed yield response functions are:

High yield response land:
Low yield response land:

where Y is cotton lint yield in pounds per acre and N is pounds of nitrogen applied per acre.

Returns above nitrogen costs per acre are compared for variable rate technology versus uniform rate technology for 1986-95 average nitrogen and cotton lint prices of $0.29 per pound of nitrogen and $0.627 per pound of cotton lint (Tennessee Department of Agriculture). Differences in returns above nitrogen costs for variable and uniform rate technologies are compared to the additional cost of hiring variable rate application services instead of uniform rate application services. Finally, the sensitivity of the results is addressed with regard to changes in the proportion of a field in low yield response land, differences in the marginal physical products of the yield response functions, and changes in cotton lint and nitrogen prices.

For variable rate technology, the application rate for a particular land class is determined as the amount of nitrogen that maximizes return above nitrogen cost. Then, the average return above nitrogen cost per acre for the field is determined by averaging the returns from the land classes. For uniforin rate technology, the uniform rate is determined by averaging the land-class yield response functions to get a whole-field yield response function and determining the corresponding nitrogen rate that maximizes return above nitrogen cost.

Figure 1 graphically depicts the yield response functions for the two land classes and for the field average. As the amount of applied nitrogen increases, yield increases faster on the high yield response land than on the low yield response land; hence, the marginal physical product of nitrogen is higher for the high yield response land than for the low yield response land.

Uniform Rate Technology

Assuming uniform rate technology, the nitrogen rate that maximizes return above nitrogen cost is determined from the average yield response function to be 102 lb/ac (Figure 1). This rate is applied to both high yield response and low yield response lands using uniform rate application technology. The farmer makes this decision by treating the field as a uniform entity, without regard to how cotton yields respond to nitrogen fertilization spatially across the field. With 102 lb/ac of nitrogen applied, the high yield response land yields 1333 lb/ac of cotton lint and the low yield response land yields 619 lb/ac. Average yield for this field using uniform rate technology is 976 lb/ac.

Table 1 presents returns above nitrogen costs per acre for each land class when uniform rate technology is used. Return above nitrogen cost for the high yield response land is $806/ac, while return above nitrogen cost for the low yield response land is $359/ac. The typical farmer would probably know that yield was lower on the low yield response land, but without the information attainable through precision farming technology, the extent of that lower yield may not be apparent. Low lint profitability on the low yield response land is masked when the farmer uses the less precise information associated with the field average yield of 976 lb/ac and the average return above nitrogen cost of $582/ac.

Variable Rate Technology

Figure 1 also shows the amounts of fertilizer nitrogen required to maximize return above nitrogen cost for each land class. The high yield response land receives 19 lb/ac more nitrogen (121 lb/ac) and the low yield response land receives 27 lb/ac less nitrogen (75 lb/ac) than when uniform rate technology was used (102 lb/ac). Yield on the high yield response land increases by 27 pounds to 1360 lb/ac, while yield on the low yield response land increases by 13 pounds to 632 lb/ac. Yield on the low yield response land increases as nitrogen decreases because too much nitrogen was applied under uniform rate technology. Average yield for the entire field is now 996 lb/ac, which is 20 lb/ac higher than when uniform rate technology was used to apply nitrogen. Also, average nitrogen use for the field is 98 lb/ac compared to 102 lb/ac when uniform rate technology was used.

These results suggest that variable rate nitrogen application may not only reduce the amount of nitrogen applied, but also increase the efficiency of the nitrogen that is applied. For example, the 20 lb/ac higher yield is obtained with variable rate application from 4 lb/ac less nitrogen, implying that a higher portion of the applied nitrogen is going to create cotton lint rather than being lost into the environment compared with uniform rate application.

Table 2 shows returns above nitrogen costs per acre for the two land classes and for the average of the entire field when variable rate technology is used. Return per acre is $818/ac for the high yield response land and $375/ac for the low yield response land. The field average return above nitrogen cost per acre is now $596/ac, which is $14/ac more than when uniform rate technology was used.

Return to Variable Rate Technology

This $14/ac increase in return above nitrogen cost compared to the uniform rate situation comes from the cotton lint price times the 20 lb/ac increase in yield ($13/ac) plus the nitrogen price times the 4 lb/ac reduction in applied nitrogen ($1/ac). Thus, the $14/ac increase in return above nitrogen cost is a net increase in economic benefit emanating solely from using variable rate rather than uniform rate technology. In other words, the return from using variable rate technology is the return above nitrogen cost using variable rate technology ($596/ac) minus the return above nitrogen cost using uniform rate technology ($582/ac), or $14/ac.

The question that now must be addressed by the farmer is whether this $14/ac is enough to cover the fee required by providers of precision farming services. Two farmers' cooperatives (names withheld to prevent disclosure) would charge about $ 1.00/ac to create a nitrogen application map for a farmer from soil survey maps and from a site visit to talk with the farmer and view the field. An additional $2.00/ac would be charged for variable rate nitrogen application compared to uniform rate application. Hence, the total additional charge for variable rate nitrogen services above uniform rate services would be about $3.00/ac. For this hypothetical field, the farmer would increase profit about $1 I/ac ($14/ac - $3.00/ac) by contracting for variable rate nitrogen services.

Sensitivity Analysis

Assume that the aforementioned field is one of many fields within a particular geographic region and that all fields within this region have between 0 and 100 percent low and high yield response lands. Figure 2 shows the range of spatial variability (the proportion of a field in low yield response land) for which the hiring of variable rate application services would be profitable (the return to variable rate nitrogen technology is greater than the cost of hiring the services). Clearly, if a field had no low yield response land, variable rate nitrogen application would not be profitable. However, as the proportion of a field in low yield response land increases, the return to variable rate technology increases to a point were it equals the cost of hiring the services. In Figure 2, this "spatial break-even variability proportion" is 7 percent low yield response land, or 93 percent high yield response land [93 = 100*(I - .07)]. Alternatively, if a field were all low yield response land, variable rate application also would be unprofitable. As the proportion of a field in low yield response land decreases from 100 percent, the return to variable rate nitrogen technology increases until it equals the cost of hiring variable rate services. This spatial breakeven variability proportion is 95 percent low yield response land (5 percent high yield response land). For the cotton fields portrayed in Figure 2, hiring variable rate nitrogen services would be profitable for fields within the range of 7 and 95 percent low yield response land (93 and 5 percent high yield response land).

Given the shape of the return-to-variable-rate-technology function in Figure 2, one can easily see that the range of spatial break-even variability proportions narrows (widens) as the cost

of variable rate nitrogen application service increases (decreases). With wider (narrower) ranges of spatial break-even variability proportions, more (less) fields within this geographical region would likely meet the spatial variability requirements for variable rate technology to be profitable. Consequently, wider (narrower) ranges of spatial break-even variability proportions give farmers an economic incentive to increase (decrease) their acreage under variable rate application contracts. Furthermore, with greater divergence in the yield response functions (greater divergence in the marginal physical products), the return-to-variable-rate-technology function would move upward (except for fields with 0 and 100 percent low yield response land), causing the range of spatial break-even variability proportions to widen (Roberts, English, and Mahajanashetti). Thus, economic incentive to adopt variable rate nitrogen application services would be higher for geographic regions with soil that have wider variation in yield response. Previous research also indicates that lower crop and nitrogen prices generally cause the range of spatial break-even variability proportions to narrow, reducing the economic incentive to adopt variable rate nitrogen services (Roberts, English, and Mahajanashetti). Therefore, in today's situation of low crop and nitrogen prices, farmers may be less inclined to adopt variable rate fertilizer services than under more favorable economic conditions. As in this example, Swinton and Lowenberg-DeBoer found that reduced nitrogen cost was not as valuable to the producer as the incremental yield increase. Consequently, farmers of higher valued crops, such as sugarbeet, would have more economic incentive to adopt variable rate fertilizer services than farmers of lower valued wheat and barley.

Conclusions

The example in this paper was presented to demonstrate the potential benefits to farmers of variable rate nitrogen services rather than to economically justify their use by farmers. The actual benefits can only be determined on a field-by-field basis because they depend on the particular characteristics of each field. Nevertheless, this example has demonstrated that variable rate nitrogen application potentially can help farmers increase profits by: 1) giving them opportunities to make more informed decisions about agricultural input application, 2) increasing average yields, and 3) reducing input use. Furthermore, variable rate nitrogen application potentially can reduce the quantity of nitrogen applied and allow the amount that is applied to be used more efficiently. This combination of less applied nitrogen and more efficient use can lead to less nitrogen being lost into the environment.

The example in this paper allows identification of the types of information needed to make informed input application decisions and to fully utilize variable rate application technology in an economically optimal fashion. To employ variable rate input application optimally from an economic standpoint, management zones (areas of a field with relatively homogeneous yield responses) must be identified and measured; yield/input response ftmctions for these management zones estimated; and expected prices for the input and output identified. Furthermore, the costs of identifying the management zones and of variable rate application must be incorporated into the analysis. Although not explicitly addressed in this analysis, the impacts on the return to variable rate technology emanating from residual or carry-over input levels also should be considered.

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Table 1. Return Above Nitrogen Cost per Acre Using Uniform Rate Technology, 50 Percent Low Yield Response Land, 1986-95 Mean Nitrogen and Cotton Lint Prices.

High yield response land	
Gross return ($/ac)	835.79 = $0.627/lb x 1333 lb/ac
Nitrogen cost ($/ac)	29.58 = 102 lb N/ac x $0.29/bl
Return above nitrogen cost ($/ac)	**806.21**
Low yield response land	
Gross return ($/ac)	388.11 = $0.627/lb x 619 lb/ac
Nitrogen cost ($/ac)	29.58 = 102 lb N/ac x $0.29/lb
Return above nitrogen cost ($/ac)	**358.53**
Field average net return ($/ac)	**582.37**
Field average lint yield (lb/ac)	**976**
Field average nitrogen applied (lb/ac)	**102**

Table 2. Return Above Nitrogen Cost per Acre Using Variable Rate Technology, 50 Percent Low Yield Response Land, 1986-95 Mean Nitrogen and Cotton Lint Prices.

High yield response land	
Gross return ($/ac)	852.72 = $0.627/lb x 1360 lb/ac
Nitrogen cost ($/ac)	35.09 = 121 lb N/ac x $0.29/bl
Return above nitrogen cost ($/ac)	**817.63**
Low yield response land	
Gross return ($/ac)	396.26 = $0.627/lb x 632 lb/ac
Nitrogen cost ($/ac)	21.75 = 75 lb N/ac x $0.29/lb
Return above nitrogen cost ($/ac)	**374.51**
Field average net return ($/ac)	**596.07**
Field average lint yield (lb/ac)	**996**
Field average nitrogen applied (lb/ac)	**98**

Figure 1. Response functions for a hypothetical cotton field, 50% low yield response land

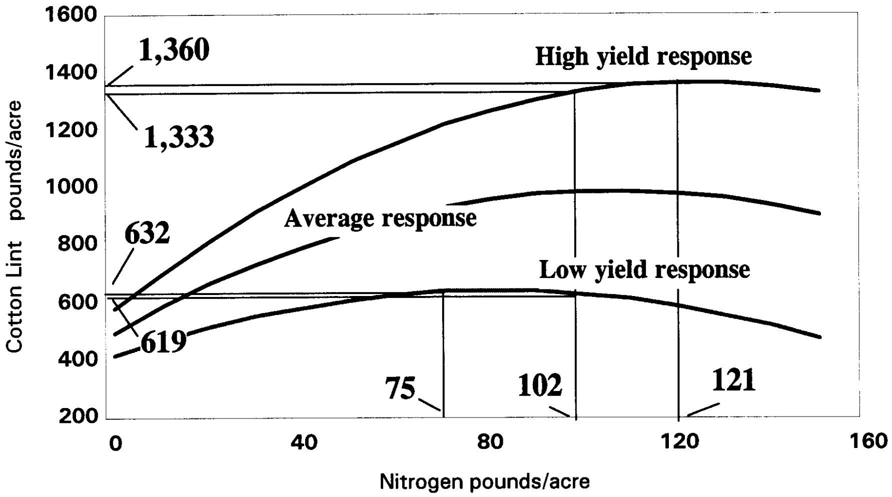
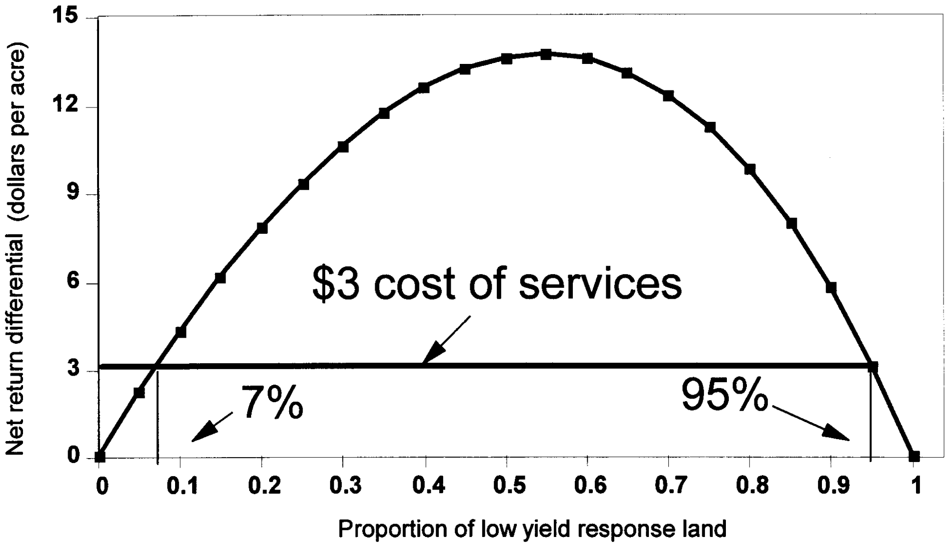


Figure 2: Return to Variable Rate Technology and Spatial Break-Even Variability Proportions.



Mapping Multi-temporal Agricultural Landuse in the Mississippi Alluvial Valley of Arkansas

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at the

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Abstract

Optimal use of soil and water resources is one of the principal challenges facing the agricultural resource community. Numerous water and soil conservation problems are directly related to agriculture including surface water pollution, ground water pollution, topsoil loss, increasing soil salinity levels, and ground water depletion. Specific crops have different impacts on soil and water resources (e.g. cotton generally requires more pesticides than other crops, rice requires more water, etc.). Therefore, it is important to know where specific crops are being grown. Accurate agricultural land-use maps can help soil and water scientists to identify potential problem areas, predict where problems are likely to occur in the future, and to model appropriate solutions.

Nearly all of Arkansas' agricultural crop production occurs in the eastern contiguous counties of the Mississippi Alluvial Valley (MAV) commonly known as the "Delta." This area also displays many of the problems associated with large-scale agricultural production. In 1996 the Arkansas Soil and Water Conservation Commission (ASWCC) provided funding to the Center for Advanced Spatial Technologies at the University of Arkansas to develop digital land-use/land-cover maps focusing on agricultural land-use for the 27 Arkansas counties within MAV. Combined with existing spatial data, the information produced from this project will serve as a basis for the formulation of water, soil, and farm management policies and practices. This paper outlines the development of the "Mississippi Alluvial Valley of Arkansas - Landuse Landcover" (MAVA-LULC) project. The paper discusses the multi-temporal approach based on crop phenologies and levelized feature extraction employed in the project. Each significant step in the mapping process from training data collection to image classification and accuracy assessment is examined.

Acknowledgments

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Background

Throughout the mid-1990's natural resource planners in Arkansas became increasingly concerned about a number of critical soil and water conservation issues. The Mississippi Alluvial Aquifer and Sparta Aquifer, which together provide most of groundwater for cropland irrigation and aquaculture, are at dangerously low levels, and are considered to be in "critical" condition by the Arkansas Soil and Water Conservation Commission (ASWCC). There are also problems associated with non-point source pollution from agricultural runoff to both ground and surface water throughout the MAV.

In December 1996 the ASWCC funded a proposal submitted by the Center for Advanced Spatial Technologies (CAST) at the University of Arkansas - Fayetteville. The proposal entitled "Development of a Digital land-use/land-cover Map for the Arkansas Delta" presented details on the development of enhanced digital land-use/land-cover maps focusing on agricultural crops for the twenty-seven Arkansas counties located within the Mississippi Alluvial Valley. The proposal stipulated that CAST would, with provided ASWCC funding, "Create a detailed, consistent land-use/land-cover map and a digital database for the 27 counties of the Delta." The database would include LULC maps derived from Landsat Thematic Mapper (TM) satellite imagery for the counties of the Delta. The LULC maps would build upon, and substantially improve the existing but incomplete digital LULC maps already available. CAST personnel would produce three digital maps (seasonal maps) focusing on agricultural landuse for each county. The maps would be derived from satellite scenes acquired at three periods throughout the growing season: Spring, Summer, and Fall; and would focus on the year 1992 to coincide with the latest USDA Census of Agriculture.

Specific Needs

NASS and other available crop data were developed for the sole purpose of measuring the areal extent of specific crops. These datasets present, with the exception of double-cropping information (e.g. Winter Wheat/Soybeans), a static picture of agricultural landuse. No seasonal information about the temporal movement between landuse types is presented. In order to better meet the needs of water resource planners, the three seasonal maps produced by the MAVA-LULC project depict changes in landuse patterns such as locations of bare soil, and flooded fields throughout the growing season. Mapping categorical changes from season to season such as the movement from bare soil in Spring, to rice in Summer, and to flooded in Fall is made possible by the this dataset. This dataset also provides information on urban density, transportation, and forest type.

ASWCC and other concerned entities hope to better understand the impact of heavy irrigation and non-point source pollution on underground water resources with the data generated from this project. Combining crop location information, for example, with data from well monitoring could result in more meaningful water use calculations. Combining the crops database with soils maps and would be useful for identifying areas of potential non-point source pollution. Likewise, mapping the frequency of flooding on cropped fields could possibly be used to identify farmed wetlands. With the information generated, appropriate water resources management plans can be formatted. An accurate crop location database would also be useful in large scale pest management projects such as the boll weevil eradication program. In the past boll weevil eradication programs relied on a general indiscriminate spraying of all cropland. The crops database would provide the necessary information to deliver a more localized application of pesticides by supplying information about the location of cotton fields, overwintering habitat (dry deciduous leaf litter), adjacency to surface water, urban areas, and other sensitive areas. Costs to farmers, taxpayers, and the environment would go down as a result.

Study Area

Nearly all of Arkansas's harvested acreage is devoted to six principal crops: soybeans, rice, cotton, wheat, sorghum, and corn. The vast majority of Arkansas' harvested cropland is found in the eastern third of the state in 27 contiguous counties oriented north-to-south along the Mississippi River. The study area covers 13 million acres (20,000 sq. miles), more than half of which is harvested cropland. The majority of this area is in the Mississippi Alluvial Valley (MAV), a physical division stretching from the confluence of the Mississippi River northward to the juncture of the Ohio River in Illinois. The soils of the MAV are very fertile and well suited to large-scale crop production. The Arkansas portion is mostly flat with the exception of the western portions of the northern project area where the foothills of the Ozark Plateaus and Quachita Province begin. Crowley's Ridge, a three to 10 mile wide north-to-south erosional remnant rises up to 50 meters above the MAV in Northeast Arkansas. Crowley's Ridge is composed of sediment from the Tertiary period and was formed by fluvial processes during the mid to late Quaternary period. The Ridge rises 100 to 200 feet above the fertile plains of Clay, Greene, Craighead, Poinsett, Cross, and St. Francis counties. Crowleys Ridge is dotted with forest, pasture, orchards, and residential areas. The Grand Prairie of Arkansas, though technically part of the MAV, is often differentiated from the MAV due to its unique soils, poor drainage, and very flat terrain. Historically, the Grand Prairie was used as pastureland. Today, these aglands are used predominately for rice and soybean production. The Grand Prairie of Arkansas is nationally recognized as a premier rice producing area. The southwestern portion of the project area is characterized by an expanse of temperate mixed evergreen forests comprising the West Gulf Coastal Plain.

Ground-Truth Data Collection

Cooperation from the U.S Department of Agriculture Farm Services Agency (FSA) was crucial to the success of this project. FSA county-level offices collect and archive the most extensive farm field data available. FSA data provides information on crop type, acreage, and field location. For this project selected samples of the field data were used to both "train" computer software to differentiate between crop types as well as to assess the overall accuracy of the final LULC map product. No information regarding crop yield, owner/operator characteristics, or USDA program participation was generated or sought.

Nine of the 27 study area counties were chosen to be sampled. The nine counties were chosen based on 4 broad factors: geographic distribution (an even spread north to south and east to west across the study area), crop diversity/specialization (some counties must be taken into account for their specialized crop production: Arkansas County for rice, Mississippi County for cotton), total harvested acres of principal crops, and driving distances between county offices (3-county proximity groups for travel logistics purposes). The acquisition of all field data required three weeks. Visits to individual county offices ranged from one to one-and-one-half days, and did not exceed two 8 hour days. The counties sampled were Arkansas, Chicot, Clay, Craighead, Lee, Lincoln, Lonoke, Mississippi, and Monroe. The project goal was to sample not less than 2.5% of the harvested acreage for each crop in each sampled county. The actual sampling was approximately 5% for each crop in every county. Approximately 2% of all cropland in the MAV was sampled.

FSA filing method: Each county office archives a complete coverage of the most recent USGS NAPP aerial photographs for their county. A standard Arkansas Highway Department county series map overlain with an alpha-numeric grid system (B-13, J-4, etc.) corresponding to individually archived NAPP photographs. To find a particular farm field one must first go to the index map, find the approximate location of the farm on the map, pull the corresponding photograph, and find the farm/field on the photo. Each farm and field is given a unique identifier (farm 54 field C) That identifier is prominently labeled (indexed) on the photograph. To obtain crop information for a particular farm/field one must pull the file folder which corresponds to that index number. (Usually several fields are found in each farm folder).

A random letter-number pair generator was developed and used to select photographs from the photo index mentioned above. If the selected photo had a farm-field containing a targeted crop, one or more of the fields on that photo was sampled. If no fields were located on the photo it was be passed over for the next randomly selected photo. A spreadsheet was used to keep a running total of all crop categories in order to obtain crop target numbers and to maintain known proportion between crop categories (i.e. soybeans 47% of sampled area, rice 28%, cotton 16%, sorghum 8%, corn 1%). Both crop target numbers and the known proportion came from the 1992 USDA Census of Agriculture. Crop target numbers were simply the total number of sampled acres desired for each crop type. The target number for each crop was calculated by, first, determining the total number of acres for each target crop using 1992 Census of Agriculture figures, and then by multiplying the result by 2.5%. A laptop computer was used to collect the training data in the field offices. Field acreages were recorded using Microsoft Excel. ImageWorks by PCI ran concurrently with the spreadsheet and was used to display a satellite image of the county with roads and Public Land Survey System overlain. First, farm fields on the NAPP photos were located on the satellite image. Next, employing heads-up digitizing methods (Edit Graphic in PCI's ImageWorks) field/crop information was reproduced as a collection of binary maps (one for each sampled crop, see "Landuse Landcover Themes" below). Before use, the binary maps were "cleaned" to remove noise. All pixels outside of a three standard deviation ellipse on a scatterplot of Summer (Spring for Wheat) TM bands 3 and 4 were removed from the samples. Thirty percent of the sampled area selected would be used for training data during feature extraction (supervised classification). Seventy percent were reserved for accuracy assessment purposes.

Satellite Image Data Acquisition

This landuse mapping project is primarily a study of temporal agricultural patterns. As such it generally required Spring imagery of the entire Delta to capture ripening Winter wheat, Summer scenes to identify the warm season crops, and Fall scenes to visualize harvesting patterns. In order to take advantage of maximum spectral variance between crops for optimal scene selection, the planting patterns and phenologies of the major crops, as described by the Arkansas Agricultural Statistics Service (1993), were examined. Informal interviews with both FSA field office personnel and local University of Arkansas agronomy department faculty were also conducted for that purpose. Satellite images not then archived at CAST and corresponding to optimum crop identification dates were identified. Prior to purchase these scenes were screened for system error and cloud cover. Acceptable scenes were selected and purchased. A total of twelve Landsat Thematic Mapper satellite scenes were acquired. An additional twelve Landsat TM scenes, used for the 1992 Arkansas GAP analysis project, were archived at CAST. The study area is covered by six TM scenes (23/35, 23/36, 23/37, 24/35, 24/36, and 24/37). For three season coverage a total of 18 scenes were needed; a total of twenty-four scenes were available for the project. The entire study area was covered for all of the following time periods: March/April, June, July/August, and October, . Upon receipt, all purchased scenes were inspected for any sign of system error. One scene was found to have irreparable system errors. It was returned and exchanged for another scene.

Data Preprocessing

PCI Geomatics' GCPWorks module was used to register the uncorrected TM scenes with Arkansas Highway and Transportation Department road vector data (UTM projection, NAD83 datum). A first order polynomial transformation model with nearest-neighbor resampling was used to rectify the image. The residual root mean square error was consistently less than one pixel on both the X and Y axes.

The twenty-seven county study area was divided into four groups roughly corresponding to TM path-row position. Group 1 (23/35 part of 24/35): Clay, Craighead, Greene, Independence, Jackson, Lawrence, Mississippi, Poinsett, Randolph counties. Group 2 (23/36): Arkansas*, Crittenden, Cross, Lee, Monroe*, Phillips, St. Francis, and Woodruff counties. Group 3 (23/37 parts of 23/36 and 24/37): Arkansas*, Ashley, Chicot, Desha, Drew, and Lincoln counties. Group 4 (24/36): Arkansas*, Jefferson, Lonoke, Monroe*, Prairie, Pulaski, and White counties. (* Training data for both Arkansas and Monroe counties were used in two or more groups in order to maximize available data. The final LULC maps for these counties come from the group classification which produced the best results: for both Monroe and Arkansas counties this was Group 4.

Upon inspecting the images for radiometric errors, several bright spots, flanked on both sides by rays of either maximum (255) or minimum (0) DN values were discovered in the mid IR bands of several scenes. The rays extended outwards horizontally as little as a few hundred meters to as much as several kilometers, and ranged from one to five pixels wide. It was discovered that these were fields which were being burned as the sensor passes over. These very bright spots (in bands 5 and 7) caused a calibration. To correct this radiometric error, a binary masks for effected area was screen digitized, and an averaging filter with a 1 x 7 pixel kernel was run under the mask. Three iterations of the filtering process were needed to correct the calibration error. No radiometric corrections were made to adjust atmospheric conditions, or scene illumination (sun angle compensation).

Feature Extraction

For the purpose of this project we will define image classification as the extraction of differentiated classes or themes (land-use/land-cover information) from raw remotely-sensed digital satellite data. The classification process for this project involved a two level approach. The first step in this approach was to separate the raw data into six broad LULC themes. These "Level 1" themes were (1) Urban, (2) Transportation, (3) Water, (4) Forest, and (5) Agriculture. The second step involved separating Level 1 themes into more specific "Level 2" themes.

Landuse/Landcover Themes

Level 1	Level II
10 Urban	11. Intensity 1 (Low Intensity)
	12. Intensity 2 (Moderate Intensity)
	13. Intensity 3 (High Intensity)
	14. Other Urban (Parks, Cemeteries, etc.)
20 Transportation	21. Major Roads
	22. Railroads
	23. Airports/Landing Strips
40 Water	41. Perennial Water
	42. Flooded
100 Forest (GAP Analysis)	101. Forest Unclassified
	102. Shortleaf Pine
	103. Loblolly Pine
	104. Eastern Red Cedar
	105. White Oak, North Red Oak, Shortleaf Pine, Hickory
	106. Loblolly Pine, Shortleaf Pine, Oak
	107. Eastern Red Cedar, Mixed Pine-Hardwood

	108. American Beech
	109. White Oak, Mixed Hardwoods
	110. Northern Red Oak, Mixed Oak
	111. Southern Red Oak, Mixed Oak
	112. Post Oak
	113. Eastern Red Cedar, Oak
	114. Shortleaf Pine, Oak
	115. White Cedar, Oak
	116. Oak, Black Hickory
	117. Overcup Oak (Quercus Lyrata)
	118. Water Hickory (Carya Aquatica)
	119. Cherrybark Oak (Quercus Falcata var. Pagodifolia)
	120. Sugarberry (Celtis Laevigata)
	121. Nuttall Oak
	122. Willow Oak
	123. Sweetgum (Liquidambar Styraciflua)
	124. Baldcypress, Mixed Hardwoods
	125. Baldcypress
	126. Tupelo Gum (Nyssa)
	127. Willow, Cottonwood
	128. Birch, Sycamore, Maple
30 Barren Land	31. Sand, Rock Outcrops, Mining Operations
200 Agiculture	201. Soybeans
	202. Rice
	203. Cotton
	204. Wheat/Oats
	205. Sorghum/Corn
	206. Other Cropland
	207. Weeds/Pasture/Forage
	208. Bare Soil

The purpose of this levelized approach was to eliminate, as much as possible, potential error from the classification of agricultural land. All Level 2 (raster layer) categories were combined into 3 final landuse/landcover maps: Spring, Summer, and Fall. All urban, transportation, forest, barren, and perennial water categories remained the same for each season (permanent categories). Flooded and agricultural categories varied from season to season (variable categories).

Urban Features

The Level I urban theme was extracted by identifying all areas within 120 meters of any road or railroad which fall within the boundaries of an incorporated urban area (U.S. Census Bureau TIGER incorporated areas). Those areas were treated as potential urban areas. Next, an ISOCLUSTERING classification algorithm under a potential urban area binary mask was performed on TM data from two image dates (bands 2,3,4,5, and 7 from Summer and Fall). The resulting clusters were aggregated, based on visual image interpretation of Fall TM scene bands 5,4,3 (RGB), into 3 categories: Level 1 Urban (Low Intensity), Level 2 Urban (Moderate Intensity), Level 3 Urban (High Intensity), Other Urban (Parks, Cemeteries, etc.), and Non-Urban. Non urban areas were subtracted from the potential urban mask to create a new binary urban mask. Finally, a logical NOT operation was performed on the urban mask to produce a binary mask that covered all non-urban areas.

Transportation Features

Level 1 and 2 Transportation theme comes directly from rasterized Arkansas Highway and Transportation Department (AHTD) and National Transportation Safety Board (NTSB) vector transportation data. Level 1 transportation is comprised of all Level 2 transportation themes: Major roads, railroads, and Airports. Major road and railroad data came from the AHTD, and airport data came from the NTSB. These vector layers were rasterized. All transportation pixels were subtracted from the non-urban area binary mask to create a new non-urban/non-transportation binary mask.

Water Features

Level I water was extracted by taking a ratio of bands 1 and 7 (B1/B7) for each scene date. Water pixels have relatively high values (DNs) in band 1 and the lowest DNs in band 7. Therefore the highest values resulting from the ratio corresponded exceedingly well with water. Water was extracted from the 1/7 ratio image using a simple grey-level threshold. For each scene footprint a permanent water category was created by comparing the water extent in each date and applying a logical AND operation. Anything that was water in all three scene dates was labeled permanent water. Correspondingly, water in any scene that was not a part of the permanent layer was considered flooded for the particular scene date: spring flooded, summer flooded, fall flooded.

Level 1 Forest, Barren, and Agriculture

Level 1 forest, barren, and agricultural features were extracted by applying an unsupervised clustering algorithm on TM bands 2, 3, 4, and 7 of the Autumn image. The resulting clusters were aggregated into one of three categories: forest, barren, agriculture. Barren contains only one Level 2 category, so Levels one and 2 are identical. The Level 1 agriculture scene varies from season to season due to the existence of flooded fields (from the water: flooded category). Flooded fields were subtracted from the Level 1 agriculture binary map for each season.

Level 2 Forest

Level 2 forest categories came directly from the Arkansas GAP analysis project's (2 hectare minimum mapping unit) vegetation map. All pixels beneath the forest binary bitmap were assigned the corresponding GAP category in the resulting Level 2 forest theme. Any pixels identified as non-forest by GAP that were in the forest binary map were labeled as forest-unclassified.

Level 2 Agriculture (While all four county groups were processed in a similar manner, the specifics discussed below relate to group 2).

Spring

The only crops grown during the Spring season in the study area are wheat and oats. Most of the land is being prepared for planting, or is still weed covered. It was found that Winter wheat and oats were confined to a fairly discrete range of DN values in TM band 4 of the March/April scene dates. A significant amount of other cool season grasses and legumes, forages often used for pasturage along the levees of the major rivers, were spectrally close to wheat and oats across all TM bands. These pastures, however, remained green throughout the growing season. By incorporating bands 3 and 4 of the June TM coverage with the March/April coverage in an unsupervised classification it was possible to separate forage crops from forage pasture. Other aggregates from that unsupervised isoclustering algorithm included fallow vegetated (weedy) fields and bare soil/seedbeds. All Level 1 and 2 Spring map themes were then combined to create the Spring LULC map.

Summer

The differentiation and extraction of warm season crops was accomplished with a two step process. The first step was to perform an unsupervised isoclustering classification on TM bands 2,3,4,5, and 7 of the Summer and Fall scenes under the Level 1 agland mask. As noted above, 30% of the collected ground-truth data was to be used for classification purposes. A report was generated to compare the results of the unsupervised classification with the ground-truth binary maps. The report made it obvious that three Level 2 agriculture categories fell into well-defined cluster groups and were easily separated spectrally. All rice (grown in standing water), fallow vegetated, and fallow bare soil acreage was extracted with the initial unsupervised classification. The remaining agriculture categories were not as readily separable spectrally. Only three clusters, comprising 21% of the soybean binary map area, were clearly soybean. Similarly, only two clusters, comprising 33% of the cotton binary map, were clearly cotton. The figures were only 37% for sorghum and 26% for corn. These known clusters were aggregated into their respective categories. The aggregated image was examined for inconsistencies based on visual interpretation of the Summer TM scene bands 5,4,3 (RGB), a knowledge of cropping patterns, and crop phenology information. Upon examination, one cluster was removed from the rice aggregate. All aggregated areas were removed from the agriculture binary mask before step two: supervised classification.

Several spectral scatterplots (variations of Summer and Fall TM bands 2, 3, 4, 5, and 7) were generated for the four remaining Level 2 categories: soybeans, cotton, sorghum, and corn using the ground-truth binary maps. It was found that the soybean scatterplots were bimodal in the Summer and Fall 3-4 and the Summer and Fall 2-4 combinations. When the cotton and soybean scatterplots were displayed in the same feature space, it was found that cotton coincided greatly with one end member of the bimodal soybean scatterplot. All crop phenologies, interview records, and field notes were carefully examined once again. With this information the Summer and Fall scenes were examined once again, it was discovered that the bimodal nature soybean scatterplot was directly related to the presence of early and late soybeans. Cotton was strongly correlated with early soybeans. Therefore, two non-parametric soybean signatures for Summer and Fall bands 2, 3, 4, 5, and 7 were created (drawn in feature space) using the 3-4 Summer scatterplot: early soybeans and late soybeans. Parametric signatures for cotton, sorghum, and corn for Summer and Fall bands 2, 3, 4, 5, and 7 for areas under the binary ground truth crop maps were also created . A maximum likelihood supervised classification was performed with mixed results. The separability of soybeans and cotton category had improved dramatically, but sorghum and cotton were still virtually inseparable. New signatures were created using only the Summer bands 2, 3, 4, 5, and 7. The results of the second maximum likelihood classification for sorghum and corn only were only slightly better, and it was decided that the corn and sorghum categories would be merged.

Fall

The extraction of Level 2 Fall agriculture categories was a straightforward process. Only two crops are in the ground in October: Cotton and Soybeans. In the southern portion of the study are the cotton harvest can extend well into mid November. Soybeans are harvested as late as mid December. All rice, sorghum, and corn has been harvested by mid October, and the empty fields are usually left bare. An unsupervised isoclustering algorithm (Fall TM bands 2, 3, 4, 5, and 7) was performed on all areas under the Level 1 agland mask. The resulting clusters were aggregated, based on visual image interpretation of Fall TM scene bands 5,4,3 (RGB), into 3 categories: fallow vegetated, fallow bare, and cropped. All pixels in the cropped aggregate were assigned either to a soybean or cotton category based on its Summer category value (i.e. pixels that were cotton in the Summer and cropped in the Fall would be labeled cotton in the Fall map).

Post Classification Processing

After all Level 2 themes were extracted each seasonal map was constructed by combining all themes for that season into one image. Each seasonal image was examined for theme continuity by farm-field. Small pixels clumps (stray pixels) of one crop category were found within large pixel groupings (fields). In order to make fields more homogenous a 3x3 mode filter was performed on only the crop categories of all three season maps. Next, using a "sieve" filter, all Level 2 agriculture pixel clumps smaller than 11 pixels (approximately 2.5 acres) were merged into the category of its largest neighbor. The mode and sieve filters produced a map with homogenous farm fields.

Results

Overall, the crop accuracies achieved in this study met or exceeded those of all previous crop mapping studies. As noted above 70% of the field data collected at the FSA offices was reserved for accuracy assessment. Since ground truth was only collected for crops there was no way to quantify the accuracies of non-crop categories. Accuracy for Winter wheat was a simple comparison of wheat on the output LULC map to areas known to be wheat from ground truth. Accuracies for Winter wheat were, as expected, high (92.4% in County Group 3 to 95.9% in County Group 1). The summer crop accuracy report was in the form of a confusion matrix: a report on how much of each original training area was actually classified as being in the class that the training was meant to represent also showing confusion between categories.

Summer Crops Accuracy Assessment Confusion Matrix: County Group 3

	# Pixels	Soybeans	Rice	Cotton	Sorghum/Corn	Totals*
Soybeans (201)	44062	89.4	1.9	6.9	0.9	99.1
Rice (202)	24122	1.3	97.8	0.3	0.4	99.8
Cotton (203)	14687	7.3	1.1	88.7	1.6	98.7
Sorghum/Corn (205)	5369	9.7	1.4	5.3	77.2	93.6

Average accuracy = 88.28%

Overall accuracy = 90.84%

Kappa Coefficient = 0.87552

Confidence Level: 99% 0.87552 +/- 0.004783
95% 0.87552 +/- 0.003633
90% 0.87552 +/- 0.003051

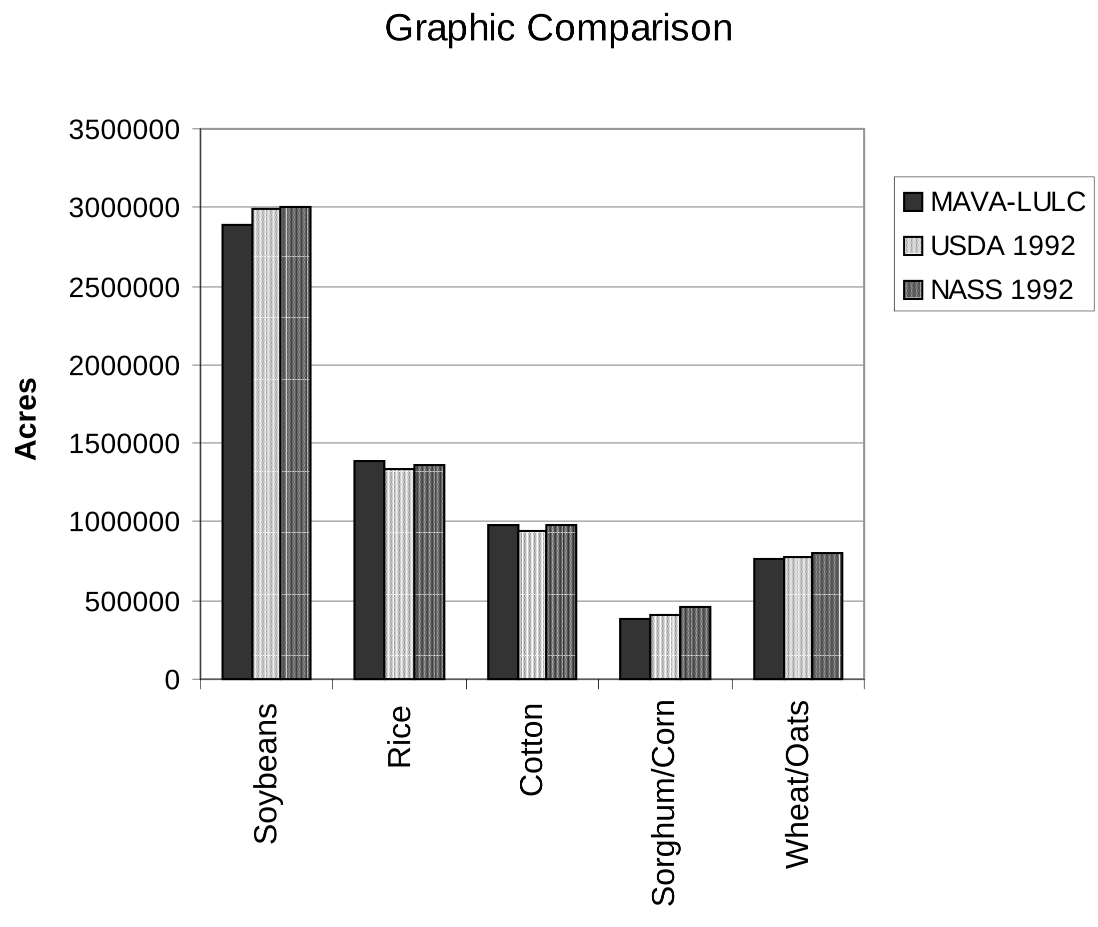
* Totals do not add up to 100% because confusion with non-crop categories was not calculated.

Accuracy numbers for rice were also above 90% mark in all four county groups. Numbers for the sorghum/corn category varied significantly between county groups ranging from 58.2% in Group 4 to 83.5% in Group 1 (Much of the training data was obscured by clouds in Group 1). Soybean accuracies were better than initially expected, ranging from 89.4% in Group 3 (see above) to 72.3% in Group 1. Cotton numbers, once again, ranged from a high of 88.7% in Group 3 to 74.4% in Group 1. Considerable confusion between soybeans and cotton were still evident in the final reports for all county groups. In Groups 1 and 3, confusion between soybeans and sorghum/corn was also a problem.

Crop accuracy numbers for all 27 counties compare favorably with other crop surveys for 1992 as well as with the NASS crop data.

Comparison of MAVA-LULC Results with NASS and US Census of Agriculture

Dataset	Harvested Acres	Soybeans	Rice	Cotton	Sorghum/Corn	Wheat/Oats
MAVA-LULC	6391421	2882990	1387177	977383	376034	767837
USDA 1992	6440247	2992069	1330271	935657	401796	780454
NASS 1992	6607200	3007600	1356000	982000	453600	808000



In order to visualize multitemporal agricultural landuse patterns, a cross-tabulation map was produced. The existence of three season categories such as flooded-cotton-flooded, or bare-bare-bare pointed to potential unsound farming practices: farming wetlands, and allowing soil to go bare during the entire growing season.

Conclusions

Overall, the results of the study are quite positive. The dataset produced for this project has several deficiencies mostly dealing with issues of resolution. Increased frequency in temporal resolution offers the most promise for improving agricultural studies. Large portions of Northeast Arkansas (Group 1), an important cotton growing region, were obscured by clouds on four consecutive TM acquisition dates from mid June to early August. The addition of TM 7, and anticipated 8 day temporal resolution, could be very beneficial to the study of intra-annual temporal landuse patterns and crop identification: finding the right date to separate cotton from soybeans using cotton's defoliation period.

An increase in spectral resolution: hyperspectral sensors, or the addition of thermal IR data, will also improve future agricultural landuse mapping projects. Fine spectral detail will allow analysts to detect subtle differences between and within various crop types, making it feasible to conduct large scale studies of crop varieties.

Spatial resolution was not a major factor in this study. While the new high resolution sensors may benefit precision ag studies, the high cost of the data and tremendous disk space requirements are currently cost prohibitive for large scale mapping projects. TM 7's improved thermal band resolution, however, could benefit future studies of the type conducted here, and TM 7's new 15 meter resolution panchromatic band may help to better delineate field boundaries at a considerably lower cost than SPOT imagery.

In the past most agricultural landuse maps portrayed a somewhat static, year to year, picture of the landscape. The maps generated for the MAVA-LULC project depict season to season landuse/landcover patterns. Combined with other natural resource and socio-economic data, the information discussed here should prove to be a very useful information base for natural resource planners.