Position Papers from the Workshop on Remote Sensing in Agriculture in the 21st Century

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The following position papers were received from participants at the remote sensing workshop.

OPPORTUNITIES AND LIMITATIONS OF IMAGE-BASED REMOTE SENSING FOR PRECISION AGRICULTURE

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Recent advances in technology for variable rate material applications, with concurrent advances in global positioning systems (GPS) and the ubiquitous use of geographic information systems (GIS), have provided a powerful analysis tool for precision farming (PF). These advances have also led to intense informational requirements. Image-based remote sensing may provide the timely, spatially distributed information on crop and soil conditions that is needed to implement precision chemical and water applications and field operations.

Information requirements for PF fall into four general categories:

- real-time information for on-the-go management,
- information on seasonally-stable conditions (mapping long-term variability),
- information on seasonally-variable conditions (mapping short-term variability), and
- information required to determine cause of variability and develop a management strategy.

Conventional means for acquiring such information rely on tractor-mounted instruments, within field point sampling using conventional instrumentation, crop yield monitors, soil and crop models, expert systems and decision support systems (DSS). Image-based remote sensing approaches could be used to supplement or supplant some of these conventional measurements, and in some cases, provide information that is unavailable using conventional means. There are at least eight shortcomings in current information gathering methods that could be remedied using image-based remote sensing approaches:

1. Conventional univariate kriging is inadequate for converting point samples to field maps.
2. Combine-mounted yield monitors have limitations in resolution, accuracy, and flexibility.
3. Currently available soil maps are not suited for most applications in PF.
4. There are few viable means for monitoring seasonally-variable soil/crop characteristics.
5. Methods are needed for determining the cause of variability.
6. Spatially-distributed information on meteorological/climate conditions is needed.
7. Available digital elevation data are too coarse for within-field management.
8. Due to lack of timely information, time-critical PF applications are not being addressed.

Image-based remote sensing has potential to address each of these eight shortcomings, either directly or in combination with other measurements or models, using common wavelength regions at spatial resolutions of 1 km or less: reflected radiance in the visible, NIR and shortwave infrared (SWIR) wavelengths (0.4 - 2.6 μm), emitted radiance (3-16 μm), and backscatter of synthetic aperture radar (0.9 to 25 cm referred to as SAR).

One of the greatest obstacles to incorporation of RS images in PF will be the inherent limitations of currently-available sensors. Satellite-based sensors have the advantages of good geometric and radiometric integrity; the disadvantages include fixed spectral bands that may be inappropriate for a given application, spatial resolutions too coarse for within-field analysis, inadequate repeat coverage for intensive agricultural management, and long time periods between image acquisition and delivery to the user. Though sensors aboard airplanes, helicopters and zeppelins will be able to meet the requirements for fine spatial resolution, flexible and narrow spectral bands, frequent repeat coverage and quick turn-around times, the previously-discussed difficulties in image registration may preclude such data from many applications.

We propose that the following rules could be used to evaluate the proper sensor pixel resolution, image delivery time, and repeat cycle relative to the size of the management unit, the requirements for turn-around time, and the required revisit period (as defined below).

1. The relation between sensor pixel resolution (PR) and the PF management unit (MU) is a function of the sensor signal-to-noise ratio ($f_{S/N}$) and the geometric registration accuracy (f_{RA}), where

$$PR = MU / (f_{S/N} + f_{RA})^{1}. \quad (1)$$

2. Turn-around (T_T) time is the total time the user can afford to postpone treatment while waiting for the desired, processed information; it must be greater than the sum of the image delivery time (T_D) and image processing time (T_P), where

$$T_T > T_D + T_P^{2}. \quad (2)$$

3. Revisit period (RP) is the user's requirement for repeat image acquisitions for the specific farm management application; for sensors on a fixed repeat cycle (RC), it should be a function of the potential for cloud interference (f_C) and for scheduling conflicts with other users (f_S), where

$$RC = RP / (f_C + f_S)^{3}. \quad (3)$$

Additionally, one must consider that the total cost of instrumentation and processing cannot exceed the perceived economic benefit.

Based on Eqs. (1)-(3) and estimates of M[J size, minimum turn-around time, and required revisit period, an assessment could be made of current aircraft- and satellite-based sensors and upcoming satellite-based sensors (Table 1). The following conclusions can be made:

- Qualitative images (without sensor calibration or signal atmospheric correction) from aircraft-based sensors will be useful for limited, but important, applications, e.g., converting on-site samples to field maps, mapping soil/ crop "anomalies", providing a quick assessment of crop damage.
- Quantitative images from aircraft-based sensors will be quite useful for PF, particularly in monitoring seasonally-variable soil/crop conditions and determining the cause of the

[1] Due to adjacency effects with optical sensors and speckle with SAR sensors, $f_{S/N}$≈10 for both optical and SAR sensors; f_{RA} can be 1 for most registered satellite-based images and 10-20 for many aircraft-based systems with automated or semi-automated registration procedures.

[2] For many satellite-based sensors, T_D is generally no better than 24 hours and such "rush" products are very expensive; best estimates of T_P for images from both satellite- and aircraft-based sensors is 16-24 hours.

[3] Most studies report that for optical RS, f_C≈4 (depending on location); for SAR RS, f_C≈1. For nonpointable satellite-based sensors, f_S=l; for pointable sensors, f_S≈4.

variability. Rapid advancements in digital camera technology should improve the utility of aircraft-based systems.

- Current satellite-based sensors have little potential for PF (coarse spatial / temporal resolution).
- The upcoming commercial satellite-based sensors will be suitable for many PF applications. For example, the Earlybird satellites (planned launch 1997) will provide RC=3 days, T_D=15 min, and PR=3 m panchromatic and 15 m multispectral (visible / NIR). The Quickbird satellites (planned launch 1998) will improve the RC to 1 day and PR=4 m for multispectral data. None of the upcoming commercial satellite systems will support thermal or SAR sensors.
- The advanced, high-resolution remote sensing systems aboard DOE, DOD and NASA aircraft should be considered for mapping "seasonally-stable" conditions such as soil type (during fallow periods) and yield variability (toward the end of the growing season).

Table 1. Evaluation of RS as a source of information for PF Applications using sensors aboard small aircrafts (where Ar : raw image data and Ac : calibrated data converted to values of reflectance, temperature or SAR backscatter), sensors aboard currently-orbiting satellites (CS), and sensors planned for future commercial satellites (FS). The check mark (√) indicates that the application is appropriate for the designated sensor; √L indicates that the application is appropriate, however the fields must be large; and √W indicates applications which are only appropriate "within fields" because the data are not calibrated and cannot be reliably compared over time or space.

EVALUATION OF RS AS A SOURCE OF INFORMATION FOR PF APPLICATIONS	Ar	Ac	CS	FS
1. Converting point samples to field maps				
1a On-site measurements of soil and crop properties could be combined with multispectral imagery to produce accurate, timely maps of soil and crop characteristics for defining precision management units.	√	√	√L	√
2. Mapping crop yield				
2a Multispectral images obtained late in the crop growing season could be used to map crop yields with approaches as simple as regression or in combination with agro-meteorological models	√	√	√L	√
2b Remote sensing information could be combined with crop growth models to predict final yield		√	√L	√
3. Mapping Soil Variability				
3a Multispectral images obtained when soils are bare could be used to map soil types relevant to PF with approaches based on models and / or on analysis of single or multiple image acquisitions	√	√	√L	√
3b Maps of spectral variability (obtained under conditions of either bare soil or full crop cover) may prove useful for revision of maps of management units	√	√	√L	√
4. Monitoring seasonally-variable soil and crop characteristics				
4a Soil moisture content		√		
4b Crop phenologic stage		√		√
4c Crop biomass and yield production		√		√
4d Crop evaporation rate		√		
4e Crop nutrient deficiencies	√W	√		√
4f Crop disease	√W	√		
4g Weed infestation		√		√
4h Insect infestation	√W	√		√
5. Determining the *cause* of the variability				
5a RS could provide accurate input information for agricultural decision support systems (DSS)		√		√
5b RS information could be combined with agro-meteorological models to determine cause of soil / crop variability		√		√
5c Hyperspectral sensors could be used to determine cause of soil and crop variability		√		√
6. Mapping spatially-distributed information on meteorological/climate conditions				
6a Multispectral images of coarse spatial resolution and fine temporal resolution should be used to produce local or regional maps of meteorological parameters such as insolation, PAR, rainfall, and others			√	
7. Producing fine-resolution digital elevation data				
7a Accurate, fine-resolution DEMs could be produced from stereopairs of aerial and satellite images			√	
8. Addressing time-critical crop management (TCCM) applications				
8a For TCCM, multispectral images from aircraft-sensors could be used as a quick means of assessing the extent of the damage and identifying units for damage control	√			√

Herein, a case has been made for the potential benefit of remote sensing for PF. The real challenge is to develop a system that will be readily adopted by the agricultural community. Our experiences have confirmed that the factors cited by other researchers for successful technology transfer of any innovative agricultural program will also work for acceptance of RS in PF; that is,

- Early interaction with the producer is essential.
- The system must be based on the clients needs (identified by the client).
- A gradual implementation of new programs allows the user to maintain an understanding of the new
- technology.
- Participants must understand the operation of the program.
- Providing information is not enough; users need help assembling the information and applying it.
- Ownership of a system affects farmers' attitudes and behaviors.

An infrastructure that may have promise for incorporating aircraft- or satellite-based RS technology into PF is illustrated in Figure 1. The four "entities" portrayed in Figure I illustrate the four requirements for skills and knowledge necessary to produce the three intermediate products; actually, a single company could encompass the skills of the first three entities and provide the final product to producers. Until an infrastructure similar to that illustrated in Figure 1 is in place, there is little hope for widespread adoption of image-based remote sensing for PF.

Future work should be focused on determining which RS applications listed in Table 1 are most economically beneficial and technically feasible. Season-long experiments with ground-, aircraft- or satellite-based sensors designed specifically to investigate the economic and scientific viability of RS products for PF applications should be given high priority. These experiments should be designed with input from the end user (farmers and consultants), and the potential commercial provider. Such validation will provide the confidence in RS that is required for technology transfer and eventual commercial development.

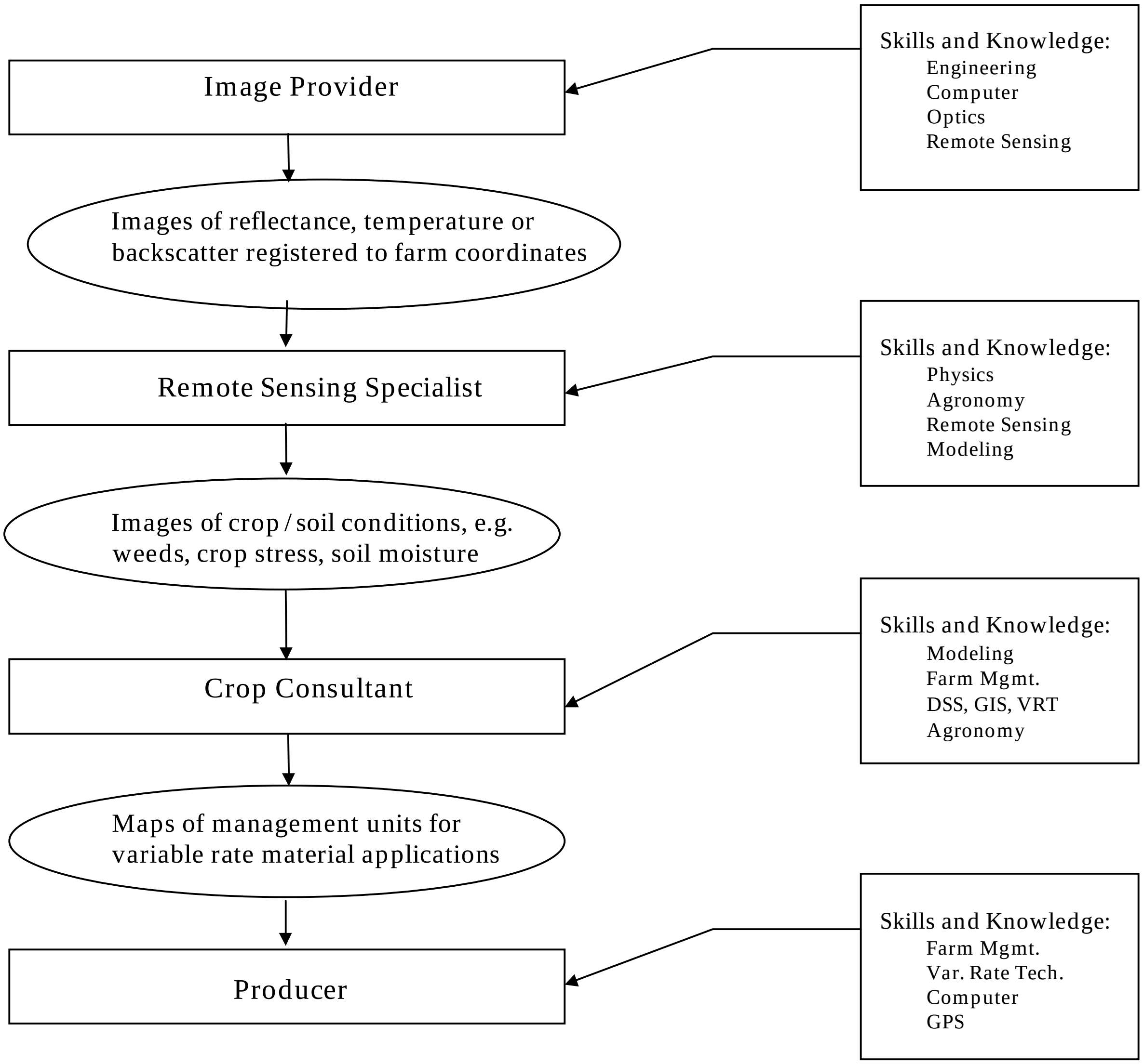

Figure 1. An infrastructure that may lead to widespread adoption of image-based remote sensing for site-specific crop management.

Reference:

Moran, M.S., Y. Inoue and E.M. Barnes, Opportunities and Limitations for Image-Based Remote Sensing in Precision Crop Management, *Remote Sensing of Environment*. 61:319-346. 1997.

ACHIEVING RESPONSIVE AND EFFICIENT RESEARCH IN REMOTE SENSING APPLICATIONS FOR AGRICULTURE

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The success of agriculture in the future will depend on how well performances in international markets, production yields and efficiencies, natural resources conservation and environmental protection are optimized. Achieving these greater levels of performance will demand more intensive management inputs throughout agriculture, therefore, increasing requirements for more informed decision-making.

Remote sensing holds enormous potentials to agriculture for meeting these decision-making challenges. However, in order for these potentials to be fully recognized, agricultural applications for remote sensing must be tailored to the decision-making processes that they are intended to support. This not only means to provide more timely or accurate information for improved decisions, but also to be understood and appreciated by the decision makers as valued and trusted information sources.

The aspects of efficient research not only include the obvious of achieving maximum results in research from the resources expended, but also making greatest use, where practical, of past or on-going research. Not only can the use of relevant research already existing complement the planned research and conserve resources, it can also prevent wasting of resources from duplication of efforts.

The following are important considerations for ensuring responsive and efficient research m remote sensing applications in agriculture.

1. Finding technology for applications, not applications for technology.

   This consideration should be the fundamental principle in establishing research objectives. In establishing research objectives for a planned project, conscious assessments should be made on whether they are driven by research interests or driven in support of application needs. Research interests should not be the primary influence in defining research for remote sensing applications in agriculture. Instead, remote sensing must be viewed as a support tool in agricultural decision-making processes. Therefore, it should be the decision makers' information requirements, FROM THEIR PERSPECTIVES, on which the objectives of research initiatives should be based.

2. Knowing decision makers and their decision-making processes.

   Knowledge of who the decision makers are, the decisions they make and how they make them will help define research needs for advancing particular remote sensing applications. With a better understanding of the decision-making requirements, research can be defined for areas most critical for making remote sensing applications more effective as decision-making tools and more compatible with the decision-making processes.

3. Evaluating information requirements of major agricultural decisions.

   Identifying the spatial and temporal information requirements of major decisions in agriculture provides a basis of need for research in remote sensing applications. Knowing the technical parameters of the information requirements is the link for finding specific remote sensing applications in agriculture. Grouping and prioritizing information requirements according to, 1) their potential economic or environmental values of the decisions supported, and 2) leveraging common information requirements among different categories of decisions establishes the need and justification for remote sensing applications and supporting research.

4. Developing multi-disciplinary approach, including decision makers involvement to research.

   Inputs and coordination among multi-disciplines are critical to the success and responsiveness of research in remote sensing applications. The kinds of disciplines to include would depend on the nature of research to be conducted, but most often would include the basic biological sciences in agriculture An essential condition for responsive research is the input and feedback from decision makers at key stages of research projects. Decision makers must be partners in research that supports their decision-making.

5. Maximizing utility of existing research or technology in planning research projects.

   An important step in planning research is the search for existing research that would complement the planned approach of a research project Research from nonagricultural remote sensing applications should be an area given special attention. Efficient research demands reasonable efforts maximizing utility of existing research. Ideally, new research would be reserved for "filling the gaps" that remain after existing research findings.

6. Establishing realistic research completion schedules.

   Schedules for completing research projects should be based on realistic projections of time for achieving the research objectives. Influence of budget cycles or time lines for research publications should be kept to a minimum. The major consideration is that completion schedules should not arbitrarily affect the quality of research. Efforts should be made to keep factors that affect research project schedules, other than achieving the research objectives in a timely and efficient manner, to a minimum.

7. Requiring accountability of completed research.

   A final step in completing research should be research management accountability to the funding source(s). A significant requirement in this accountability should be; an assessment of the research results in terms of achieving the originally stated objectives, how the research is being disseminated for further utility beyond the intended agricultural application(s), and recommendations on future areas of research raised by the research just completed.

Agricultural Decisions Having Spatial/Temporal Dimensions

AGRICULTURAL DECISION MAKERS

1. Agricultural Producers:

2. Input Suppliers:

Agricultural loan suppliers
Agricultural insurance (underwriters and brokers)
Crop consultants
Labor suppliers
Land owners / brokers
Farm equipment (manufacturers, distributors and wholesale)
Fertilizers and pesticides (manufacturers, distributors, wholesale, applicators)
Seed (producers, distributors and wholesale)
Energy suppliers
Veterinarians

3. Output Services:

Commodity trade
Feed processors
Food & fiber processors
Futures (brokers)
Livestock (buyers, distributors, meat packers / processors)
Storage
Transportation

TYPES OF DECISIONS

1. Assess Natural Resources Quality / Quantity
2. Determine Optimum Fertilizer and Pesticide Application Rates / Timing / Locations
3. Determine Optimum Harvest Timing / Locations
4. Determine Optimum Planting Timing / Locations
5. Determine Crop Acreage
6. Identify / Assess Environmental Risks
7. Identify Conditions Affecting Crop Yields
8. Identify Existing / Forecast Future Levels of Pest Risks
9. Identify Locations with Desired Vegetation / Vegetative Qualities
10. Identify Locations with Optimum Crop Growing Conditions
11. Predict Crop Yields

SPATIAL DATA INPUT PARAMETERS

1. Air Temperature (historical, real-time and forecast)
2. Crop moisture (real-time)
3. Crop reflectance (real-time)
4. Crop temperature (real-time)
5. Crop yield (historical, real-time and forecast)
6. Landscape features (characterize)
7. Leaf wetness (historical, real-time and forecast)
8. Precipitation (historical, real-time and forecast)
9. Radiation (historical, real-time and forecast)
10. Relative humidity (historical, real-time and forecast)
11. Soil moisture (historical, real-time and forecast)
12. Soil nutrients (characterize and forecast)
13. Soil organic content (characterize)
14. Soil temperature (historical, real-time and forecast)
15. Soil texture (characterize)
16. Soil water holding capacity (characterize)
17. Topography slope / elevation (characterize)
18. Vegetative profile (classify)
19. Wind speed / direction (historical, real-time and forecast)

FINAL REPORT
OF THE
AFBF GPS/GIS TASK FORCE

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Background

As recently as mid-1992, IBM market research indicated little or no market potential amongst farmers for information systems using remote sensing data. That all changed in two short years. Suddenly, Star Wars technology originally developed for the military became commercially available. Computers got smaller, faster, more tolerant of harsh agricultural production environments and prices came down dramatically. All of this brought some leading edge farmers to the conclusion that the time was right for another major evolution in agricultural technology. The technology, they found, could help them manage inputs and crop production on many smaller areas of each field, rather than treating each field as a single homogenous unit.

In early 1994, three Iowa farmers, Varel Bailey, Tom Dorr and Lon Crosby were referred to the American Farm Bureau Federation (AFBF) by the Iowa Farm Bureau Federation. They shared with AFBF officials their vision of Global Positioning Systems (GPS) and Geographic Information Systems (GIS) as being the future of agriculture. GPS/GIS was discussed at the AFBF's Board Meeting in June.

In July of 1994, AFBF President, Dean Kleckner, named a task force of state Farm Bureau presidents. Its purpose was to "address the needs of producer decision makers in terms of data ownership computer hardware and software needs, and the necessary Farm Bureau organizational and financial structure if any, needed to deal with the GPS/GIS issue." The task force was charged with bringing its recommendations back to the President in time for consideration at the December, 1994, meeting of the AFBF Board of Directors.

Task Force Methodology

At its initial meeting August 25, 1994, the Task Force divided itself into three subcommittees and drew up an initial list of topics for which internal white papers were developed.

The Task Force met a second time on October 12 and used two of its subcommittees to consider the white papers and make preliminary recommendations to the financial subcommittee. This meeting ended without a recommendation for the financial subcommittee.

At this point it was obvious that the whole issue was very complex and was moving so fast, on so many fronts, that President Kleckner extended the Task Force's life to March, 1995.

The Task Force then met again on November 17. Because of the urgency of a number of issues, the Task Force produced an interim report with seven recommendations Eat it believed the AFBF Board needed to act upon at its December board meeting.

In the interim, Purdue University was contracted to produce an interdisciplinary report looking at as many of the GPS / GIS information systems issues as possible, strictly from a farmer perspective.

The Task Force met for the fourth and final time on March 2-3, 1995, to develop its final report and recommendations.

Findings of the AFBF GPS/GIS Task Force

The Task Force finds that critical mass has been reached in the potential to use Global Positioning Systems (GPS) and Geographic Information Systems (GIS) in farm-level decision making and management of agricultural production systems. The key elements are now in place to allow most farmers to begin to adopt some of this technology within the next ten years. These elements include:

1. reliable yield monitors have been perfected,

2. the military GPS locational signals are now available for civilian use allowing latitude and longitude to be determined with the 4 to 6 inches accuracy needed for farm equipment while it is moving through the field,

3. personal computers are now big enough and fast enough to handle the gigabytes of information that can potentially be produced from each farm field,

4. communications systems using fiber optics, cellular and satellite transmissions have greatly expanded capability to transmit information and data, and

5. agribusiness at all levels, ad a number of companies in the aerospace and electronics industry are very interested in the technology and are gearing up to offer integrated sensors, controllers, hay logic and systems research as well as a wide variety of other related products and services to support agriculture's use of this technological advancement.

- The Task Force also finds that farmers arc buying yield monitors as fast as they can be produced. Farmers are asking cooperatives and consultants to help interpret the yield maps and other fertility information.

- The Task Force finds that the technology of gathering information is far ahead of the understanding of how to use it to help farmers make decisions. Knowledge-based decision making systems need to be developed quickly in order to allow this technology to fulfill its promise.

- The Task Force finds that university research into GPS / GIS and precision farming systems has, for the most part, been piecemeal, not interdisciplinary, and not coordinated.

- The Task Force believes that on-the-go sensors for soil, plant, and growing conditions are crucial to fully developing the concept of precision measurement of many field conditions and ultimately the precision placement of farm inputs. The Task Force finds that relatively few of these types of sensors are readily available, (yield monitors, an organic matter sensor, a nitrate sensor and some limited machine vision sensors for detecting weeds are the ones the task force is aware of.)

- The Task Force finds that databases are the basic building blocks of this knowledge driven system. The Task Force believes that control of access to a database holds the key to control of that segment of an industry. Any bias in access to databases will create "haves" and "have-nots" within production and marketing agriculture.

- The Task Force finds that standards for electronic transfer of data inputs and outputs are lacking and that standards for physical connections of one piece of equipment to another are also lacking. These need to be resolved as quickly as possible through appropriate national and international standards efforts without stifling innovation.

- The Task Force finds that an "open architecture for electronics and data compatibility is the preferred method for development of this information system, as opposed to many proprietary architectures that would impede transfer of information, Open architecture would allow competition in the marketplace over time to produce better solutions to problems.

- The Task Force finds that access to high capacity communications infrastructure is critical to the development and use of this technology, especially in rural communities

- The Task Force finds that many special interests adverse to agriculture see this technology as a key to furthering their policy agendas.

- The Task Force finds numerous questions exist regarding the issues of intellectual property rights, the ownership of farmer generated data and the public policy implications of this data These issues need to be resolved as-quickly as possible to protect the interests of producers in this emerging technology.

- The Task Force finds tremendous interest in GPS/GIS and precision farming systems among Farm Bureau members, as evidenced by the large turn out at special conferences held at the AFBF Annual Meeting in St. Louis.

- Finally, the Task Force finds there is no coordinated overall GPS/GIS development effort. There seems to be some interest within industry for surfacing a coordinating entity for such an effort.

Recommendations of the AFBF GPS/GIS Task Force

General Recommendations

1. The Task Force recommends that AFBF work to insure farmer ownership and control of farmer generated data and of databases compiled from such data, and to make sure that systems research generated from the databases provides the products and services which farmers need to move agriculture forward in a knowledge driven, competitive, international marketplace. The number one priority of this effort should be to secure legal protection for intellectual property rights of farmer owned GPS/GIS data.

2. The Task Force recommends that AFBF further explore the idea of a non-profit entity as a vehicle for protecting farmers' precision farming data and for developing the necessary legal, business and computer capabilities to fully develop profitable farm, and off-farm, opportunities for farmers from this new technology.

3. The Task Force recommends that AFBF work to assure that farmers and rural areas have access to high capacity communications systems.

External Contacts

4. The Task Force recommends that AFBF work with state Farm Bureaus to make sure that the appropriate researchers at Land Grant Universities, Agricultural Research Stations, ARS, and electronic and technical institutes arc apprised of the Task Force's findings and that there are major research needs in the areas of sensor technology and knowledge-based systems.

5. The Task Force recommends that AFBF continue to work with the Ag Electronics Association (AEA) as long as the relationship is beneficial for Farm Bureau and the AEA moves fast enough to position farmers at the forefront of GPS / GIS opportunities.

REMOTE SENSING REQUIREMENTS FOR AGRICULTURE

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1. Primary Requirement: decision support information.
    1.1. Information, not data
    1.2. Answers, not questions
    1.3. Solutions, not problems
    1.4. Conclusions
        1.4.1. The only farmers and ranchers who will be interested in remote sensing data are those who have the possibility to change their practices based on the information. Every remote sensing product must answer the farmer's question, what would I do differently if I had it?
        1.4.2. During the growing season, farmers have little time to manipulate data. They need information presented concisely, enabling quick decisions for how to act upon the information.
        1.4.3. Applications of remote sensing should permit interactivity, so that individual users can arrange the information into a form most relevant to their needs.
        1.4.4. All remote sensing images present historical information, namely the conditions at the time the image was acquired. The most useful information will incorporate forecasts or models, advising what conditions will become and therefore what to do about them.

2. Reasons remote sensing has been used little in agriculture
    2.1. Unfamiliarity. Farmers and ranchers not aware of what is available, how to interpret it, how it can help.
    2.2. Access to information has been inconvenient; the user has to initiate acquisition.
    2.3. Cost-Benefit Analyses are scarce. How does remote sensing information increase income and reduce expenses?
    2.4. Cost. Images are too expensive, given that their usefulness has not been demonstrated.
    2.5. By themselves, devoid of context, remotely sensed images are not very valuable.
    F. Conclusions
        1. Education and training are essential for creating a demand for remotely sensed products.
        2. The market needs "pump priming." Until value is demonstrated and success stories are generated, demand will be small and commercial products unprofitable. This industry must be treated like the Internet or the GPS system: government funding and no-cost data until the market is established.
        3. Products must be syntheses of various sources of information in addition to remotely sensed images.

a) Weather is the dominant factor in crop yield and quality. Farmers should be encouraged to install weather stations distributed across their fields. The integration of microclimate information with yield maps and remotely sensed images will be more useful than any of them individually.
b) In situ measurements made in the field with modern yield monitors must be layered in GIS's with remotely sensed data.
c) GPS-guided records of applications of water, fertilizer, pesticides, herbicides, seeds must be incorporated into the same GIS systems.
d) Historical comparisons provide context. Examples are this week's vegetation index vs. last week's, vegetation at this date vs. the same date last year or vs. the average on this date of the last five years, etc.
e) Crop models must be refined so that the progress of a crop during a growing season can be projected to its final yield.
f) Regional, national, and international comparisons are useful.

4. Information must be accessible locally. The information providers need to be part of a distributed system, not a centralized one.
a) Agriculture practices vary with region. Generic products need to be fine-tuned to local characteristics.
b) Individual farmers and ranchers prefer to interact with familiar organizations of a size that is not intimidating.
c) The flow of information needs to be multi-directional. Providers and users of remotely sensed products function interactively as co-equals. The goal is to create "learning communities", in which experiences are shared, questions asked and answered, ideas for new products discussed.

III. Changes that make Agriculture ready for remote sensing

A. The Global Positioning System now assigns precise place and time to every action and observation.
B. Yield maps display variability across individual fields, triggering a demand for explanations.
C. Yield maps are acquired at harvest time and therefore can only be used to change practices during the next growing season. Remote sensing could provide potential yield information during a growing season in time to take corrective actions before harvest.
D. The Information Superhighway makes distribution of information quicker and easier. Individuals can directly access information, not needing hierarchies of providers trickling it down to them.
E. The new Freedom to Farm Agriculture bill thrusts decision-making onto the individual businessperson. Wise decisions must be based upon accurate and current information. The demand for such information will increase dramatically.
F. More data from satellites is going to be acquired than ever before. EOS and commercial satellites will provide a rich menu of spatial and temporal resolutions, as well as spectral responses. Cost will still be a factor but perhaps competition will keep it reasonable.

IV. Special needs of agriculture

A. Frequent information--i.e., at least once per week or 10 days--during growing season

B. Fresh information, i.e., 48 hours old at maximum, preferably <24 hours old

C. Trade-offs among frequency of coverage, spatial resolution, and spectral bands are complex but important. The trade-offs may vary with region and crop. A first need, though, is to create a community of agriculture experts, so that remote sensing systems can address their needs. At present, agriculture has to bend its wishes to fit what will be provided from satellites designed for other purposes.

V. Special Parameters of Interest

A. Location and date of Crop Growth Anomalies--permitting scouts to ascertain cause of anomaly

B. Potential crop yield, i.e., biomass as a function of time

C. Crop health, i.e., a measure of the quality of the crop to complement assessment of its quantity

D. Crop stress--inadequate water, onset of insects or disease

E. Weed invasion

F. Soil moisture

G. Precipitation distributions and rates

H. Soil temperature

I. Delimitation of hail (and other storm) damage

J. Preview of water supply from snow pack measurements

K. Soil type and organic matter content

VI. Characteristics of Successful Agriculture Public Access Resource Centers

A. Activities driven by needs of users, i.e., farmers and ranchers

B. Distributed, not centralized. The distributed centers must themselves be networked to other similar centers.

C. Interactive, not one-way conduits for information flow

D. Targeted toward individuals, permitting them to create the demand for consulting services; but excluding no one--totally open access to information provided.

E. Connected to the research community so that only the highest quality data sets and processing algorithms are used in the creation of application products

F. Nuclei of learning communities: flexible, responsive to changing needs and circumstances, information sharers, stimulants for advanced ideas, educators

G. Funded adequately enough to have an impact. Funded long enough to accomplish significant and demonstrable successes.

1. Actions to satisfy the conclusions expressed in 1.4 and 2.5 will require contributions from several and varied experts and will take time to implement.

2. The learning curve for users to master the technologies mentioned in Section 3 is steep: GPS, GIS, NII, Remote Sensing.

3. The parameters listed in Section S do not emerge automatically from the data. Considerable collaborative work, including comparisons with field trials, needs to be done. Five years is probably a minimum trial period.

H. Realistic in promises to users. Because the benefits of remote sensing have been over-touted to agriculture for years, an initial skepticism now must be overcome.

I. Is inclusive rather than exclusive. Private businesses, academia, and government should work together.