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

October 23rd-25th, 1995

The following papers were received from the moderators from the breakout sessions at the remote sensing workshop.

Moderator and Author: John LeBoeuf
Session 1; October 23, 1996
Founders Room, Alumni Center

Introduction

Information has been identified as the cornerstone to successful farming in the 21st Century. Agricultural producers already know that information is important and valuable. Many farmers already pay for information ranging from updates on weather conditions, soil and nutrient status, pest management reports and recommendations, to advice on what genetic seed line to plant for various field conditions.

The price that farmers pay for information is usually thought of in cost per acre. A typical cost that many producers think of when judging the value of information is to use the average cost of a single pesticide application, which is about $20.00 an acre. Farmers will judge the expected benefit of acquiring information against this cost of a pesticide application. Technology that provides information to a producer which would cost more than $20.00 an acre will have a very limited chance of being readily accepted. Private consultant fees for agronomic crops in the Midwest typically are around $2.50 an acre compared to a range of $7.00 to $9.00 an acre in California. High value fruit and vegetable consulting fees in California may range from $35.00 an acre for lettuce to $200.00 an acre for strawberries. If information gathered from remote sensing technology is to be used by a large group of producers, the cost should ideally be about half the cost of a pesticide application. This is especially relevant when producers don't even know what benefit they will get from remote sensing images.

What farmers, resource manager, and consultants (agricultural and environmental) need to know about remote sensing is: SWOT, which stands for strengths, weaknesses, opportunities, and threats. These four areas need to be identified so that producers can judge the value of the technology, which for many will be looked upon as a new and unproven source of information. Only by a diligent team effort by a technology provider, along with someone who understands remote sensing to assist the untrained farmer, can the information help and aid in the decision making process in crop production.

S=Strengths of Remote Sensing

There is no doubt that the major strength of remote sensing technology for agriculture is in plant stress detection. Farmers need to learn how remote sensing technology can help them in production by the early detection of plant stress. Examples need to be identified and show how producers can benefit from remote sensing.

1. Water Stress. In irrigated agriculture, where water inputs are controlled by the grower, information that is provided that can pinpoint areas of a field that are under stress from too much water or not enough water would be valuable. In production areas where water is a manageable factor, the timing, amounts, and placement of irrigation water becomes a critical input decision that greatly influences crop yield. If remote sensing technology can assist growers in scheduling irrigation, the technology would be utilized by producers in areas with supplemental water which would be a great advantage compared to farmers depended upon natural rainfall to meet the plant's water needs.

2. Fertility Problems. Stress detection of plants due to fertility problems associated with nutrient deficiencies or excesses is another area that remote sensing technology can help producers. Remote sensing technologies that measure reflectance have been used to detect nutrient defi-

ciencies in agronomic crops. Analysis of plant tissue petiole samples can confirm nutrient levels from different portions of a field. This type of information can have an immediate impact on the grower's decision making if a fertilizer can be applied to a crop in a timely manner. The information can also serve a long-term benefit by identifying areas of concern for the producer in following crop seasons. This will help in site-specific applications of fertilizers and soil amendments such as lime, manure, compost, gypsum, and sulfur.

3. Plant Disease Management. Detection of plant stress induced from disease organisms is a major strength of remote sensing technology. Mapping of fields that suffer from soil-borne fungal pathogens has become very important in setting up crop rotations and planting schedules. Some plant pathogens become problems during periods of warm weather when the plant is under stress from a lack of water. The ability to detect problem areas in a field, that appear to the human eye as looking okay during routine ground-truthing in field inspections, makes the technology a valuable tool worth the investment of time and money. If remote sensing technology can be used to help in detecting small problem areas caused by pathogens, timing of applications of fungicides may be enhanced.

4. Weed Management. One of the expected areas of help from remote sensing is in pest management of weeds. Heavy weed pressure can change the reflectance characteristics of a crop. Mapping of perennial weed species which typically grow in concentrated areas and can spread across fields even during drought years will help producers apply herbicides where they are needed and reduce costs if only a portion of a field needs to be treated. Weeds are first class thieves that rob water and nutrients away from the intended crop. Their vigorous root systems out-compete most cultivated crops. Remote sensing images that are combined with geographical information systems (GIS) and global positioning systems (GPS) for specific mapping purposes will help in site-specific weed management.

5. Nematodes. Plant stress induced by nematodes is also a strength of remote sensing images. Nematodes are unsegmented, round worms that attack numerous crops grown in the United States. Nematodes live in the soil and attack plant roots. Remote sensing images that detect plants under stress from nematodes would help in planning future crops in the rotation and also in the application of fumigants to the impacted areas instead of treating an entire field if costs are of concern to a particular grower.

6. Varietal Differences. Stress detection of a crop that has varietal differences may alert a farmer to a variety that is better suited for various field and/or environmental differences. Remote sensing images have shown differences in variety susceptibility to sucking insects such as aphids which are vectors for plant viruses. Remote sensing images would allow a farmer or consultant to evaluate a particular variety compared to others grown under similar conditions.

7. Change Detection. A major strength of remote sensing is in the detection of changes in vegetation across time. A series of remote sensing images can be used for crop monitoring. Change detection maps that show which areas of a field are under stress can alert field personnel to problem areas. Field maps that detect changes across time can also be used to identify when a crop makes a significant shift in the allocation of plant energy sources from photosynthesis. An example is when a cotton crop shifts from a vegetative state to the reproductive state in boll production. Fruiting signals to the plant that the development cycle is coming to an end. The use of defoliation chemicals in preparing a cotton crop for harvest is a crucial stage in manage-

ment. Remote sensing images would be able to detect changes induced by the defoliants and show if portions of a field needed to be treated a second time.

8. High Quality Field Boundary Maps. One of the surprising uses of remote sensing images that has been identified is in producing high quality road maps for the delineation of field boundaries. Even though this typically is a one time use for remote sensing images, it should be looked upon as a great example of how to show the capabilities of remote sensing to a lot of producers. Many landowners, renters, and leaseholders would like to know the exact acreage involved in each field based on technology that gets a bird's eye view from above. This has been identified as a need and should be used aggressively as a way to get farmers, realtors, bankers, and insurance company personnel into using remote sensing information. Examples of this type of use should be shown to the different industries involved. Another way to think of its importance is that this may be the "ace in the hole" and in this card game, it is time to play the ace.

9. Time Management. The use of remote sensing technology has a major strength in identifying problem areas that a grower, consultant, or ranch manager needs to look at as soon as possible after reviewing remote sensing images. This aids in time management as highly skilled personnel can spend their time addressing potential problems that can impact on crop yield while lesser skilled workers such as field scouts can be sent into portions of a field that don't show problems on the remote sensing images. It has been suggested that agronomists and consultants may be able to cover more acreage by better time management aided by the use of remote sensing images used in a crop monitoring service.

10. Matching Up Sensors, Resolution, and Scale with Specific Crops. If a specific sensor has been identified to be able to detect problems at a specific resolution or scale, it should be matched up properly in situations where benefits will be expected in specific cropping systems. The remote sensing technology providers will need to be careful in the development and promotion of what remote sensing images can or cannot do in specific crop production. A mismatch of sensors or the improper use of resolution in crop production should be avoided. The current movement in precision agriculture in crop production will bring along new users of remote sensing images as long as there is a proper match of the technology. If mistakes in technology can be avoided it will become a strength for the industry. End users will expect success and benefits from the use of the technology and will not tolerate failure due to a mismatch of equipment.

W=Weaknesses of Remote Sensing

Just as end users will want to know about the strengths of remote sensing, they will also want to know if there are any weaknesses associated with the use of the technology. It will be better for the remote sensing industry if they identify any known limitations of the technology up front instead of letting the end user find out about them later.

1. Ground Truthing is Necessary. A weakness that may be perceived by end users is that there are no (or few) unique spectral signatures that diagnose problems at this time. Ground truthing to identify what is depicted in the images still is necessary. Technology providers need to be careful in their marketing efforts and not promote the technology as being able to be interpreted inside an air-conditioned office without the use of field personnel. Time and experience will help producers understand how to interpret what remote sensing detects, records, and analyzes.

2. Mismatch of Sensors Needs to be Avoided. As previously stated, sensors must be matched up properly with products as the end users will remember, and talk about, failures of technology. Farmers like to spend casual time inside coffee shops talking about crop production problems more so than what made them successful. If remote sensing technology provides a bad experience for a farmer in which he or she feels that they wasted their money, you can bet on it that they will be telling about the problem to their friends and associates. The farming community in general is a close knit group of people who will talk about problems.

3. Address Major Uses of Remote Sensing. It is not possible at this time to predict all the uses of remote sensing in precision agriculture and forestry. To list the known uses of remote sensing at this time, or even try to identify all of the types of end users, would be short-sighted at best. We may be only seeing the tip of the iceberg. Rather, let us address a few of the major uses that utilize the known strengths of remote sensing and then let the growers, resource managers, and consultants develop more. It may be that we cannot even imagine what remote sensing technology will find in production agriculture so let us not dwell on trying to predict what the technology will evolve into. Farmers are masters at finding out what works in a given situation and what doesn't work. IMAGINATION LEADS TO INNOVATION. Concentrate efforts on a few known uses or remote sensing and let the end user's imagination take over from there.

O=Opportunities of Remote Sensing

The potential use of remote sensing technology in production agriculture and forestry is incredible. Farmers, resource managers, and consultants will be able to see, and react to, things which are not visible to the human eye. Managers will not longer be restricted to looking out across a field with a limiting point of view. As new sensors are researched and developed, managers will become more dependent on acquiring timely information. Opportunities for remote sensing are numerous.

1. Need for Research to Move On-Farm. Farmers and consultants want research to move away from small plots and be brought onto the farm where they can observe progress under actual field conditions. This is a perfect match for remote sensing researchers as small plots would be hard to analyze and then predict what would happen across larger acreage. Remote sensing of large fields of 150-160 acres would be ideal for producers and researchers wanting to work with cooperating field personnel.

2. Interdisciplinary Teams Need to Get Involved. It has become obvious to many agricultural producers that a team approach is better than an effort by a single farmer. Rules and regulations, changes in pesticide registrations and uses, new genetic improvements including advances in bio-technology, environmental and societal concerns, and numerous other topics have forced major changes onto the farming community. This has led to many producers developing a team of experts to handle different parts of an operation. As businesses become dependent on information, interdisciplinary teams will become part of the farming scene just as they will in the Research and Development of new technology. There will need to be a bridge between farming and science and technology. Consultants and the end users themselves should be involved in the development stages of remote sensing technology.

3. Provide Outreach to Existing Agricultural Professionals. Many existing agricultural professionals have to meet continuing education requirements in order to stay current in their profession and stay licensed or certified. This makes for an incredible opportunity for remote sensing providers to bring the technology into a professional setting for training and teaching of the

basics necessary for the consultants to be the bridge for the farmers. Many state programs can be accessed that would reach the very people who have already dedicated their lives to serving agriculture.

4. Professional Societies Could Provide Training Guidance. There are several professional societies that could be contacted for guidance in development of training and educational needs necessary for the successful implementation of remote sensing technology across the United States. The primary society that should be contacted for this guidance is the American Society of Agronomy. This group along with the Soil Science Society of America, and the Crop Science Society of America is headquartered in Madison, Wisconsin. They should be willing to get involved in providing guidance and development of the necessary educational needs for both existing professionals and new students entering this exciting field.

5. NASA Should Demonstrate Remote Sensing Technologies to Overcome Low Awareness. The lead in demonstration available remote sensing technologies to growers and consultants should be taken by NASA. The overall low awareness in remote sensing in the agricultural community needs to be overcome by involvement by NASA. NASA has the background to be readily accepted by the agricultural community if a strong effort was made to demonstrate what the technologies can detect. There is no doubt an incredible amount of information that could be shown to growers based on prior experience with the technologies in the military, weather analysis, oil exploration, aerial reconnaissance, drug enforcement, and urban analysis to mention just a few areas of involvement with remote sensing.

   The opportunities in this area are numerous. The different types of sensors could be demonstrated by NASA, along with various resolutions, to highlight the differences seen from both satellite and air-borne platforms. Use of the Internet is increasing and would provide a means of reaching individuals in both the agricultural and environmental fields. The use of GRANTS may bring in others able to help overcome the low awareness. Videos could be developed that could be shown at annual meetings of consultants such as the California Agricultural Production Consultants Association (CAPCA) or the National Alliance of Independent Crop Consultants (NAICC). NASA needs to get involved in order to overcome the low level of use of remote sensing by the end users in agriculture. Private industry, when they are primarily trying to sell the technology, does not have the necessary credibility to be taken seriously by mainstream production when they are also trying to demonstrate the capabilities of the technology. NASA needs to demonstrate the technologies - it would be viewed as unbiased.

6. Role of Agricultural Extension Advisers and Specialists. Just as NASA would be viewed as unbiased in demonstrating remote sensing technology, so would Agricultural Extension Advisers and Specialists who would be called upon by some end users for assistance in providing unbiased information about remote sensing. Extension Advisers and Specialists would be contacted by growers who may not be willing to pay a consultant or private adviser. The challenge in such a diverse production region as California, with over 200 different agricultural commodities, is to be able to provide adequate information on remote sensing to producers of agronomic and horticultural crops, trees, and vines, and numerous specialty crops. What a big challenge compared to the Midwest with the bulk commodity production of corn, wheat, and soybean.

7. Quality Attributes will Become Connected to Quantity Parameters. The use of remote sensing technology is expected to help producers understand quality attributes associated with the crop

at harvest time. The sensors will most likely be small, machine-based or tractor-mounted instruments that will detect defective or misshapen produce or unwanted attributes such as too much moisture, dirt, or weed seeds present. Knowing the quality characteristics of a crop being harvested on-the-go has great potential for producers involved with commodities that pay a premium for quality and not just payment based on quantity. The potato industry will most likely see benefits in this area in the near future along with the small grain crops such as wheat and barley.

8. Enhancement of Crop Models and Decision Support Systems. As remote sensing technology becomes adapted into production agriculture, the decision making process used by farmers will be enhanced. Remote sensing instruments that assist in crop models and decision support systems (DSS) will be brought on-line. Weather analysis in the field will enhance pest management, especially plant disease prediction. Remote sensing technology can assist in the decision making process.

9. Crop Yield Monitors Will Bring in New Users of Remote Sensing. As yield monitors are developed for commodities that are machine harvested in a single pass, farmers will begin to analyze field maps that will indicate variability in the yield. Research and development continues in tractor-based and machine harvesters for crops such as cotton and processing tomatoes. When these crop yield monitors are brought into field production (possibly in 1998), there will be an incredible amount of information that will need to be analyzed by agronomists and consultants to help explain why variability exists in a field. Many producers will then be inclined to take a look at their fields with remote sensing instruments to try and help detect problem areas. This will lead right into the strength of remote sensing in detecting plant stress. Crop yield monitors will become a catalyst for bringing about a change in how farmers manage their fields.

10. Variable Rate Technology Will Also Bring in New Users. The precision agriculture movement in the Midwest was based on grid soil sampling and variable rate technology (VRT) that spread fertilizers in differing amounts across the field. Improvement in VRT will also increase demand for remote sensing. As the industry works out all of the problems with the supporting computer software and hardware, VRT will be tried by more producers outside of the Midwest. Remote sensing technology will be a strong component in the next wave of precision agriculture that spreads across the United States. In irrigated agriculture, the use of VRT may become involved with the application of soil amendments such as gypsum (calcium sulfate), elemental sulfur, or sulfuric acid for help in soil related problems pinpointed by the use of remote sensing.

    A related issue of VRT is that the area threshold for farmer action regarding the application of a pesticide may be decreased. Currently many insecticide treatments are made when about 25% of a field is threatened by a pest. If remote sensing technology detects smaller portions of a field that is under pest pressure, the use of VRT in the application of pesticides may become a viable business. The site-specific application of a pesticide would be of benefit to the environment and keep costs down for a farmer who would only have to treat a portion of the field.

11. Existing Sensors and Platforms Should be Utilized. Members of the breakout session on the end-users thought that efforts should be made to take advantage of the existing commercial sensors and systems from both satellite and aircraft platforms. While research should continue

with new sensors in areas such as thermal imaging, current technology should be utilized wherever possible. If 20-30 meter resolution of images taken from a satellite is not perceived to be of good enough quality for use in production agriculture, then low flying aircraft platforms should be utilized. Radar imaging of crop land should also be shown to agricultural consultants to see if they can find any valuable information.

One of the exciting developments in remote sensing was the use of sensors that provided digital information instead of having to have camera film developed. There is a great potential use for digital information that could be used to develop crop growth curves and enhance crop phenology models. This has been a very low area in development in getting the actual raw data into the hands of crop consultants. Most of the remote sensing technology providers would prefer to just give out a computer generated picture of a field to a grower without having to perform any actual data extraction for analysis purposes. This may be an area for value added services to take the technology a step farther than just a picture of a field.

Moderator and Author: Dr. John E. Estes
Session 2; October 23, 1996
Allewelt Room, Alumni Center

The task of this session was to assess the following questions:

1. What satellite platforms and sensor capabilities will be available for agricultural research and commercial applications in the next ten years?

2. What aircraft platforms and sensor capabilities will be available for agricultural research and commercial applications in the next ten years?

3. In the area of remote sensing for agriculture, what are the priority areas for remote sensing technologies and research?

Participants ranged between 12 to 15 during the session. Several people came and others went during the session. Chaired by Dr. John E. Estes from the University of California at Santa Barbara, participants spoke at length about the three questions above. Answers to the first two of these questions were straightforward and informational in nature, given the nature of the presentations made at the conference; particularly those made by Bill Stoney and Ames Research Center Personnel. The third question stirred some debate and was developed further by the inquisitive nature of the question.

Question 1: What satellite platforms and sensor capabilities will be available for agricultural research and commercial applications in the next ten years?

Bill Stoney provided this group with an excellent resource. These were the materials from his talk in a previous session about those satellites in operation and currently planned that appear to have the potential to enable this industry. Participants provided additions, such as intermediate resolution systems with higher temporal repeats. Participants grouped these systems into the following categories:

1. **LANDSAT-Like Satellites:** LANDSAT 5,7; Spot 2,3; IRS-1B, P2; IRS-1C, 1D; MOMS; ADEOS-1; CBERS 1,2; Spot 4; IRS-P5; Resource 21; IRS-2A, 2B; Spot 5A, 5B; EOS AM-2

2. **High Resolution Satellites:** Spin-2; EarthWatch EB-1, 2; SpaceImaging 1, 2; EarthWatch QB-1, 2; OrbImage 1, 2; GDE 1, 2; IRS - CARTOSAT 1, 2

3. **Experimental Satellites:** CTA Clark, TRW Lewis, EOS AM-1, EO-1, Warfighter

4. **Radar Satellites:** ERS-1; JERS-1; ERS-2; Radarsat; POEM; ALMAZ 1B, 1C, 2; ALOS-A, A1, A2; Sir C/X-SAR

5. **Additional Sensors:** EOS AM-1; MODIS; Light SAR; GOES, NOAA, Sackajawea

Question 2: What aircraft platforms and sensor capabilities will be available for agricultural research and commercial applications in the next ten years?

Participants concluded that there currently exist aerial platforms and sensors that will do anything needed in the area of agricultural remote sensing. The only limitations to the temporal, spatial, and spectral resolutions of the data to be acquired by these systems would only be determined by the tasks and the budgets associated with a given operation. At this point, sensors on aerial platforms include but are not limited to; Passive imagers, cameras, sweep, pushbroom linear and area arrays; active imagers, sounders, lasers, and active microwave devices. Portions of the EM Spectrum covered by these systems include UV, Visible multiband (VIS), Short wavelength (SWIR), Middle infrared (MIR), Thermal infrared (TIR), Microwave (Pan to Hyperspectral, etc. — K-band, X-band, KA-band, L-band, P-band, C-band, and VHF). Platforms include: aircraft from single engine, light aircraft flying low altitudes, to high altitude, high performance aircraft and multi-engine planes. Temporal and spatial resolutions are typically mission unique. For example, if you want to fly the Centuri Romano near Padua in Italy where typical field sizes are on the order of 2.5 ha, you may need to fly a sensor with greater than one meter spatial resolution. This is in sharp contrast to the type of sensor that would be required in an area such as the U.S. mid-west or San Joaquin Valley or the Kazakh Republic where very large field agriculture (section or quarter section) are practiced. Temporal resolutions would be determined by the particular mix of phenologies of crops present crop identification were an objective or the specific cycle of a vector or pathogen if looking for disease or infestations. Irrigation scheduling would also require knowledge of phenologies as well as specific local weather conditions. Again, the only limitations to acquiring aircraft data were felt to be in the area of cost and scheduling.

Question 3: In the area of remote sensing for agriculture, what are the priority areas for remote sensing technologies and research?

The first two questions were considered by participants to be fairly straightforward and relatively painless to answer. There are a number of governmental and, of increasing importance, commercial remote sensing solutions being brought to bear on the need to the agricultural community. The third question is, however, more difficult and requires considerable feedback and discussion. In order to examine this question properly, some questions needed to be answered first. These provided a baseline from which the group could proceed to answer the question posed. These “baseline” questions were:

A. Who are the end users?
B. What are the potential uses of remote sensing that can currently address their needs?
C. What is the cost of remote sensing? What prices can the market bare?
D. How are changes in the way we conduct agriculture going to effect the remote sensing applications industries?
E. What are some of the expectations of remote sensing and the market forces? And,
F. What data products will be determined to be useful to the agricultural industries?

Finally, based on a thorough discussion of these baseline questions, it was clear that there are issues that still need to be addressed by NASA, the commercial industry, and the research community. The following summarized the discussion among the participants related to the baseline questions that this session’s participants felt should be addressed. Recommendations and conclusions follow the summary of these questions.

A. Who are the end users?

End users were considered by the participants as anyone who has a stake in agricultural industries and those interested in this industries use of remote sensing. These end-users can be broken down into three main categories; producers, regulators, and other interested parties. Producers are those individuals and corporation responsible for farming as well as their agriculture and environmental consultants. Regulators are those groups and agency responsible for general oversight and legal compliance such as state federal agencies, environmental protection groups and those in the related legal fields. Other interested parties consist of other stakeholders such as insurance companies and those individuals and institutions involved in commodity markets.

B. What are the potential uses of remote sensing that can currently address their needs?

There are essentially two extremes to the way that remote sensing can be used in agriculture as well as a wide variety of uses between. Participants felt the extremes were to use remote sensing globally over large areas and regions in order to get an overview; or locally, often termed site specific or precision agriculture. In this area of precision agriculture remote sensing is used to assess very specific characteristics of individual sites on the ground.

Participants felt that Regional/National/Global applications that could be addressed with spatial resolutions of 10-30 meters+ included but were not limited to; determination of Planted Acreage, Crop/Species Identification, and Damage Assessment.

Applications in the area of precision agriculture that require high spatial resolution (1 meter or better) include but are not limited to Crop Stress detection for short-term and long-term management, calibration of soil maps to ground truth findings, and looking at newly acquired property in real estate markets.

C. What is the cost of remote sensing? What prices can the market bare?

Cost is really determined by user requirements for a given application three areas; resolution, data volume, and timeliness. General consensus was that you could and will be able to get good data from anywhere from $8 to $14 an acre. It was thought by participants that to be really viable within the context of the larger agricultural community to farm level, the data really needs to be priced under $4 an acre, and less than 1$ for non-irrigated row crops, such as those found in the Midwest.

D. How are changes in the way we conduct agriculture going to effect the remote sensing applications industries?

One of the participants felt strongly that the concept of the traditional family farm of 160 acres does not exist to any relevant extent any more. The producers we are primarily concerned with here are the 200,000 farmers in this country who will be producing 95% of the produce in the year 2001. That is much different than the USDA's number of 2 million producers. Farms in the U.S. today, typically consist of 2,000 to 3,000 acres and few, if any, of the farmers who work these farms own all 2,000-3,000 acres that he or she farms. NASA, commercial industry, USDA and others need to gain an improved understanding of the needs, products, and resources of these farmers. As they do, this will produce better-tailored remote sensing applications.

E. What are some of the expectations of remote sensing and the market forces?

The idea that you can determine nitrogen fixation from the colors of the leaves is just not proving itself to be reliable enough for operational remote sensing applications. Remote sensing can not do everything. Remote Sensing has been oversold in the past for certain applications as well as undersold for others. Currently, it is not practical to design a system tailored to detecting a particular problem or occurrence, as there is no single problem that can justify the total cost of the research and instrument development, ground system and distribution network development at this time. The systems today and that are planned for the future are in reality facility systems that we hope will have appeal to a broad market. Perhaps the introduction of hyperspectral systems will help alleviate this problem of the use of general systems for specific needs.

F. What data products will be determined to be useful to the agricultural industries?

Certainly aerial photography and standard satellite data products have already proven their ability for specific applications. This question was taken to mean data from advanced sensors for expanded agricultural applications. This was an area that participants felt was not straightforward. Most felt that some research would be required here to really specify products. The following are areas were research is needed.

The background and affiliation of the 12 to 15 participants in the room admittedly bias these research areas. Participants felt that research was required in the areas of:

1. SAR, multi-frequency, multiple-compression, multi-polarization is an important area.

2. Thermal infrared. The sensitivity tradeoffs need to be examined. Very fine temperature resolution and very fine emissivity resolution make for very expensive technology because of the cooling that has to go on. Research directed towards a form of uncooled detectors and thermal technology would be appropriate. Such sensors would be a lot cheaper to fly.

3. Calibration. Bill Stoney stipulates that all sensors are calibrated. Other participants felt that they may be, but we must examine inner-sensor calibrations and multi-sensor multiple platform calibrations of the sensor and how to do that in a more effective way.

4. Atmospheric correction. Participants felt that we must do better at taking the atmosphere out of the signal better.

5. Soil moisture. Participants also felt here that SAR and other radar data could be very important for the detection of soil moisture. Soil moisture is a critical variable for agriculture. If possible, the farmer needs surface soil moisture, seed zone soil moisture, and root zone soil moisture. This application needs to be looked at from satellite, aircraft and potentially even ground to give us better data.

6. Research would also be useful directed at sensors for the chemical makeup of crop residue. How much organic carbon is left in the field, for example, would be useful information for the agricultural community.

7. Ground-truth sensors. Research in this area can be difficult to do and expensive. More particular applications where ground truth support operations with the aircraft and satellite data are needed.

8. Throughput. A very important area is research directed towards getting the information derived from remotely sensed data or the data itself out to the farmer within a reasonable amount of time. George Sielstadt, at the University of North Dakota, has formed alliances with individuals and companies to get the data out to the farmers in “near real” time, yet most participants felt that “Real-enough” time is the key. Real enough to be able to do something productive with the information.

9. Hyperspectral. More research needs to be done on the potential of hyperspectral sensors on satellites. Some of the participants agreed that more work needed to be done, others did not agree that this should be a priority in this area at this time.

Conclusions and Recommendations

1. The fundamental conclusion of the participants at this session was that: At this time, it appears that agricultural remote sensing capabilities will exist and be available over the next ten years to support a wide variety of research and commercial applications for agriculture.

2. Research is still needed in a number of areas. But for more of the focused research that needs to be done, people want to use both existing and coming commercial remote sensing data projected from "private" systems.

There were no specific recommendations from the people in our session. The recommendation I, as chair, would include here is that NASA should fund research in some of the areas identified. Participants accepted this.

Moderators and Co-Authors: Larry Biehl and Susan Moran
Session 3&4; October 23, 1996
West Room, Alumni Center

Introduction

There was significant discussion in the breakout session about several topics most of which dealt with the assigned topic and some which did not. It was all good none the less. Also it was apparent during the presentations of the breakout session summaries on Friday morning that there were similar threads across several breakout sessions.

The group made a general observation that there was a discontinuity between remote sensing research and the implementation of that research in an operational business environment. Related to this observation is that there is a prolonged time required for adoption of high-tech agricultural applications which is significantly longer than the normal funding cycles of government agencies such as NASA. However, the group recognized that the funding cycle was not something that can be influenced practically speaking.

We did not divide the ‘how will data be used’ and ‘the priority science issues’ since in many cases the two parts overlapped in the points that are discussed below.

The recommendations and observations that this group developed are:

- There is a need for pilot projects to demonstrate the operational applications of remote sensing.
- Significant consideration should be given to temporal data. This is particularly important in relationship to crop calendars.
- The required resolution of spatial, spectral, temporal and radiometric parameters for remote sensing data needs to be considered as a function of the application. There is no hard and fast single number.
- There is a broad range of potential products from “raw” images provided quickly to users to highly-processed images or just recommendations to be used for management decisions.
- Remotely sensed data may rarely be a stand-alone product.
- It is important for users of remotely sensed data to understand the image characteristics and what can and cannot be done with specific levels of processing.
- Future research should include the use of other wavelength regions in agricultural remote sensing including Synthetic Aperture Radar (SAR) and Thermal.
- The development of standards for hardware and software related to precision agriculture is an issue to be resolved.
- Government has a technology transfer role in the use of remote sensing for agricultural applications.

- There is a significant variation in communication technology available to the end users which will impact, at least in the near term, how remote sensing technology can be applied at the local grower level.

Additional details follow:

Pilot Projects

These pilot project(s) should occur at the end user's (e.g. grower's) location of business and therefore the end user should be included in all stages of the pilot project - from inception to conclusion of project. The pilot projects should focus on the operational implementation of remote sensing and not on research per se. The results of the pilot projects should include a good understanding of the costs and savings involved in the implementation of the technology and recommendations as to what are some priority research areas.

Temporal Data

Significant consideration should be given to temporal data. Temporal data is very useful to differentiate species in remote sensing data. The temporal data is important because each crop has its own development cycle or crop calendar. The differences in development cycles between crops can be a very valuable diagnostic tool. Also the temporal information can play an important role in monitoring the 'health' and potential yield of the crop. The use of multitemporal data in the past decade has been deterred because of image costs.

Required Resolution of Spatial, Spectral, Temporal and Radiometric Parameters

The required resolution of spatial, spectral, temporal and radiometric parameters for remote sensing data needs to be considered as a function of the application. There is no hard and fast single number. Spatial resolution decisions should account for signal-to-noise, registration accuracy required, issues unique to agriculture, such as crop row spacing or orchard tree spacing, and the question to be addressed such as the variability within a field or the crop production for the world.

Also the resolution to be used needs to address any interaction of sampling interval and the frequency of the variation in the scene. For example if one uses a spatial sampling for a vineyard which is close to the row spacing of the vines, one may obtain moiré=E9 patterns in the remotely-sensed image. The spatial sampling should be more coarse so that several rows will be integrated for each sample, or finer to sample the area between the rows. The choice depends upon the question being asked and/or the management unit being considered.

Temporal resolution requirements should consider cloud cover interference, conflicts with requests with other users, use of pointable sensors and crop calendar. One may also need to consider time-of-day if aircraft-mounted sensors are being used.

There was not a lot of discussion about spectral and radiometric parameters except that a comment was made that they felt that multitemporal data was more important to have than hyperspectral data.

Another issue related to this topic is that there is a growing need for soil maps and digital elevation models (DEM) at the resolution of the remotely-sensed data. These data are currently not readily available for 1-10 meter spatial resolution.

There is a broad range of potential products from "raw" images provided quickly to users to highly-processed images or just recommendations to be used for management decisions.

The "raw" images provided quickly to end users may be used for damage assessment or anomaly identification. These end users may be growers or value added businesses that use these data for analyses to make recommendations or reports to growers.

The highly-processed images may be designed for specific applications such as weed maps for variable rate chemical applications. The final product may be just a report that recommends a specific management decision or a report that will be used in a management decision. For example, one company present indicated that as their customers became confident in the irrigation recommendations obtained by remote sensing illustrated on images, the only information requested now is a list of their fields in priority order based on the need for water.

Remotely-sensed data may rarely be a stand-alone product.

To derive the most information from remotely-sensed images, they will be combined with meteorological data, agricultural management information (e.g. planting date), soils maps, DEM's etc.

Remote sensing data will also be used as inputs to physical models of crop growth, canopy architecture, and spectral mixture models where appropriate. An example where these models may be used is to make crop yield estimates. Some issues related to yield estimation that were discussed included estimates at mid-season and estimates for crops for which the biomass and yield are not well correlated. The group recognized that these were not easy issues to resolve but will be very important for the commodity business.

It is important for users of remotely sensed data to understand the image characteristics and what can and cannot be done with specific levels of processing.

There was quite a bit of discussion of calibration and sun-view angle effects and some on registration effects.

Calibration during this session was defined to be conversion of digital number (DN) to radiance-at-sensor. The group agreed that the level of calibration precision should be appropriate for the product being developed. Products which depend on remote sensing data from only a small, flat area and one date may not need the calibration precision that those products do that are derived from multidate or multiyear data or from large areas over significant terrain variations.

Also a note was made that current atmospheric correction models are only good to 5-10 percent at best. If the variation in the scene of interest caused by the atmosphere is less than this amount, the correction may actually add noise to the image. Also an atmospheric correction in this case may significantly reduce the value of second order statistics if they are being used.

View and sun angle effects are both a source of information about canopy LAI, canopy architecture, plant height, and a source of confusion when one attempts multitemporal analyses with multi-view images. One of the approaches to obtaining multitemporal data is to build pointable sensors. Remote sensing data may be collected by these space sensors using more than one view angle to work around cloud cover or to obtain the temporal sampling required. The user needs to be aware of the fact during multitemporal analyses that the scene may be significantly different when viewed from different view angles even if collected at the exact same time. The crop canopy is not a Lambertian reflector.

Also the user needs to be aware of the effects of the image registration process if used. Resampling by nearest neighbor retains the integrity of the multispectral data. Resampling by cubic convolution may make a better looking picture but since data is averaged spatially, the resulting value of the spectral statistics may be reduced.

Future research should include the use of other wavelength regions in agricultural remote sensing including Synthetic Aperture Radar (SAR) and thermal.

SAR images from unifrequency systems have a role for agriculture. Also multifrequency SAR systems should be developed and tested for agricultural applications and in a more ‘blue sky’ category bistatic SAR (different transmit and receive directions) could be very useful for agriculture. Even though there was not a lot of discussion about thermal in these breakout sessions, it was noted during the workshop that thermal data is a very important portion of the spectrum to use for some applications. There are some commercial companies which are using thermal data collected from aircraft platforms to help growers make management decisions about crop irrigation.

The development of standards for hardware and software related to precision agriculture.

End users have requested standards for precision agriculture hardware, image transfer formats and GPS transfer formats. The position paper from the American Farm Bureau Federation noted this need in their position paper for the workshop. Also a question was raised about map projection formats by one of the growers present at the workshop. The breakout session agrees with the American Farm Bureau Federation that these issues need to be resolved through the appropriate national and international committees. We understand that at least some of these questions are already being addressed.

The question about map projections is probably best addressed by making information available about the commonly used projections and their advantages and disadvantages. The hard part of this solution is how best to make the information available to the end user.

Government has a technology transfer role in the use of remote sensing for agricultural applications.

Remote sensing technology transfer can occur through pilot projects and education awareness. As was discussed on Friday morning of the workshop, there may already be some avenues for this already in place including Space Grant, NASA Core Curriculum Modules, GLOBE, USDA Extension Service.

Another related item that was discussed by the breakout session was the potential need for an “agency” to assist end users with questions about this new technology that is separate from the commercial companies. This agency was perceived to be used as an unbiased source for information. Could the USDA Extension Service be used in this role. No conclusion or recommendation was made on this topic.

There is a significant variation in communication technology available to the end users.

The communication technology that is available to the end user varies from community to community across the country. This variation will impact, at least in the near term, how remote sensing technology can be applied at the local grower level. Some areas may be able to download data or access information such as the Web via a modem across a phone line. Other areas will find this too costly if it has to be a long distance phone call or not workable if the phone lines will not allow “high speed” connections.

However, technology transfer can still occur whether high technology, e.g. Internet, Web, high speed modems, a farm TV channel, is used or simple technology, e.g. exchanging video tapes of interactions between the provider and the user, is used.

Moderators and Authors: Minghua Zhang and Edwin Sheffner
Session 5 & 6; October 24, 1996
Founders Room, Alumni Center

Introduction

As more and better remote sensing data becomes available, the desire to combine remote sensing data with ecological models for developing new sustainable agriculture and other environmental resource monitoring programs is compelling. Sessions 5 & 6 discussed this subject. The issues covered in the discussion included 1) what models are available or should be developed to address integration of remote sensing and sustainable agriculture; 2) what remote sensing datasets should be collected to implement the models; and 3) how can the work be accomplished, i.e., what must be done to get remote sensing technology and datasets into common usage.

Participants in these sessions included representatives from the remote sensing industry, interested precision farming consultants, modelers, and agricultural researchers. The discussion among the participants indicated the still "youthful" state of remote sensing technology and the gap between technology developers and users of the information products derived from the technology. The need for more, high-quality, and cost-effective information was a recurring theme, but the process of identifying the key information products required by ecological modelers and other users and translating remotely sensed datasets into those products is proceeding slowly. No one seems to be certain about the appropriate scales of remotely sensed data required for ecological models in general. Education and training of potential users of the technology remains deficient. Remote sensing application research is still very basic for agricultural issues.

Issues related to modeling in sustainable agriculture and resource monitoring.

1. Needs and concerns

The group discussed remote sensing and related technologies as sources of readily available spatial and temporal data for various modeling applications in the areas of sustainable agriculture and ecological process models. Data inputs for the models include the percentage canopy cover in a field for evapotranspiration estimation, weather parameters, soil characteristics especially soil moisture estimation, commodity production prediction, water pollution and distribution estimations, and canopy structure for forest and range land studies. These basic data is not only required in crop simulation and resource management, but also in ecosystem and landscape ecological models. The proposed improvements in remotely sensed data included the accurate, geo-registered base maps for GIS (Geographic Information Systems), improved spectral/spatial resolution for within-field work, thermal imaging as an indicator of crop stress and indicators of the vegetation stage in the field to calibrate production and potential yield. Details from the discussion for the potential technology application in precision farming are described in the following section.

Determination of ET

Estimating evapotranspiration (ET) using remote sensing data would be beneficial. However, one of the biggest problems is determining the percent of canopy cover. The crop coefficient used to estimate ET from a reference value is based on the percentage of land covered by plant material. One big concern was the accuracy of determining the percentage of canopy cover because of cloud shadows. Plant material cannot be differentiated from the shadows, so it is necessary to trace the shadows by hand and estimate the percentage. Another concern was that estimating ET from one measurement during the day would not be reliable, because ET fluctuates throughout the day depending on temperature, cloud cover, wind direction and velocity.

Soil mapping

Soil mapping provides necessary basic spatial information for agricultural production systems and ecological models. These spatial data are valuable to farmers and researchers, and they can assist insurance companies track the quality of fields for each insured client. However, insurance companies were not interested in developing a relationship between yield and soil information because they would have to assess a true risk for a location, which might put a grower out of business.

Determination of soil characteristics

Growers would like a better soil model that includes more soil characteristics. Growers can determine soil characteristics by using soil grid sampling techniques or remotely sensed data. Because of the high cost associated with soil grid sampling, growers would prefer to use remotely sensed data.

Remote sensing could be used prior to planting and throughout the season to locate optimal sites for one or more soil samples within major soil groupings. Although soil survey maps from USDA Natural Resources Conservation Services are available for most locations in USA, remote sensing can provide a validation to the soil survey. The goal is to make the single sample soil model more efficient by understanding the differences within the field.

Using remote sensing to map soils was a concern to some participants who stated that soils are based on the parent material which could only be viewed through a soil profile. Some participants did not agree with the comment, reasoning that agricultural soils are tilled so there is no soil structure or soil profile in most agricultural soils. Of course, the impact of soil structure also depends on the cropping system.

Soil type determination

One of the first people to apply site specific technology sought to prove the fundamental relationship between soil type and yield that governs agriculture. There should be a fundamental, testable assumption, but no relationship was found. USDA was asked to map the soil types in a small area and still no relationship was found. USDA took 30-foot borings so they could look at the underlying soil structure and again no relationship was found at that resolution. Therefore, the true patterns were not detected with the scale of these studies and data resolutions.

Weather model predicting frost protection

Satellite data could help frost prediction. A thermal image of the ground right at sunrise would reveal information about frost conditions. Better resolution of weather data than AVHRR (1 km resolution) is necessary to be useful in temperature prediction. Historical knowledge of the climate is essential in weather modeling. Cropping and planning are dependent on temperature for the next growing season. For example, citrus cultivation in Florida has moved southward to avoid frost damage. Some participants felt that weather models have not done a good job yet, whether based on ground measurement or on remotely sensed systems.

Risk assessment

Risk assessment was an application potential highlighted by the participants. Potential environmental/ecological risks can be minimized through spatially managed agriculture and precision farming with the sufficient spatial data from remote sensing. With the monitoring and assessment capabilities available through remote sensing, crop risks can also be reduced. This kind of information will be of benefit to the local farmers, farm advisers as well as crop insurance companies and regulatory agencies.

Population demand and agricultural market impact

With the pressure of increasing human populations, the demands for highly productive agriculture will increase. Remote sensing provides an excellent tool for use on a national or global scale to monitor agricultural conditions and the agricultural market.

The Australians, for example, they implemented a hyperspectral imaging program to try to systematically start following components of the ecosystem. They modeled microorganisms, chemicals, etc. to trace the mass flows from their source.

Assessment of regional concerns

It would be ideal to use an existing satellite system to provide the spatial data. Though most experimental data are available at the local plots or field experiment level, the regional assessment is necessary to have an overall picture of the problem scope and to satisfy the needs for the regulatory agencies. The aerial photos and/or satellite coverage serve as a data supply for the assessment of regional concerns in agriculture.

Need for geo-registration

The utility of remote sensing has increased with the advent of systems for accurate geo-registration. Application of remote sensing in precision agriculture would not be possible without global positioning systems (GPS).

Need for Calibration Data to Increase Accuracy/Predictability of Models

There are two ways that remotely sensing data may help to improve the accuracy of an agricultural model. First, using “within season calibrations” where a model indicates that certain things will happen during the growing season and then to remotely sense or observe the occurrences. Given the fact that a model is only an approximation of what happens in the real world, it is not going to be completely accurate. However, observations and measurements in the field can be used to re-calibrate the model to produce a new simulation that is more accurate. Second, spatial variability can be utilized and incorporated into the model accordingly. In the past, predicting yield required assigning an average value to a field parameter representative of all the plants in the field. By using remotely sensed data and looking at the variation of the vegetation index across the field, it is possible to classify a field into various portions that have similar vegetation indicators of growth and then run the model for each portion of the field to produce an aggregated yield estimate. This method is more accurate than assuming one average value for the entire field. Moreover, remotely sensed data can help to schedule crop harvests and provide other within field information.

Remote sensing data can provide spatial and temporal datasets to drive the model versus “traditional” modeling techniques. Remote sensing may save energy and money when the technology is applied to various crop and ecological models to better manage agricultural production.

2. Current methodologies and available sensors

Much uncertainty remains regarding what remotely sensed data will be needed in the next 10-50 years. Current space-borne systems supply data with 5m to 3km resolution. New sensors, primarily commercial, will provide data with up to 0.8m resolution. The variety of data sets likely to be available in the next century poses a question about how best to use these data. More research needs to be done to identify how best to employ high resolution data sets to address within field problems and how best to integrate data with vastly different resolution to “scale up” ecosystem models from site specific to regional observations.

Discussion and recommendations

From reviewing the roles of government and the commercial sector in supplying data and information, there was general agreement that the government should assume responsibility for regional and global issues primarily. The commercial sector should take the lead in within-field issues.

There was a noted lack of input on agricultural issues from city representatives (not present), which was unfortunate given such concerns as the urbanization of the Central Valley of California. There should be more emphasis on ag/urban issues.

Economics

The economics of using remote sensing are of concern. One participant mentioned that we need to tell NASA which databases are worth fighting for and worth committing $4-6 millions/year or are worth a $35 million launch of a light satellite or a $75 million launch of a larger satellite.

Suggestions were made that USDA and NASA should discuss who will pay for agricultural applications. Long-term strategic planning should be carried out, because the benefits of remote sensing applications often cannot be implemented immediately. In addition, technology development advances daily, and thinking and planning ahead will provide better economic returns in the long run.

When computers were introduced, it took years and the equipment didn’t work at first, but the government invested in them in the early stages. Similar situation applied at the present for remote sensing development. At first the satellites may work for a while, but there may be new technology that appears later on that makes them obsolete. Having more information on a broader basis across the world will give us a better quality in modeling. To design an infrastructure system that can be used to distribute the information will be the immediate need for the public to access the needed information.

Scales

One meter was generally agreed upon as the crucial ground resolution for within-field work, although a few participants argued 3-5 meters was sufficient. The equipment bar on the back of a tractor is usually around no smaller than 3 meters across, so using a resolution of one meter will guarantee at least one full pixel “within the bar” - the minimum required to make realistic inferences from the remotely sensed data. Appropriate scale and resolution are always dependent on the specific task, crop, row spacing, etc. Regional work requires a coarser resolution. There is also great amount of utility in having high resolution information and what standards and uniform applications should be. The variable rate technology requires high resolution soil distributions so that the applications of fertilizers and pesticides can be made more precise to increase the production and minimize the potential environmental impacts. Real time soil moisture content can be measured through good radar data, and the depth of rooting zone can probably be estimated with the radar data.

Precision agriculture and remote sensing was the underlying theme, but there was acknowledgment that significant information can be derived from coarser resolution imagery that could assist a grower in making management decisions about what and when to plant, for example. Imagery with broad area coverage may provide insight on agricultural trends around the field of interest and may be as equally valuable to the grower as information about within-field status of the crop.

The ability of model to predict depends on having input data of proper spatial resolution. Most of models developed are based on case-specific conditions. Another problem with regard to scale is that the producers need field-size scale and the commercial industry wants landscape scale. The models were developed at a scale in between. How should this situation be resolved? No solutions were came up in this discussion. However, it was suggested that sub-field scale should be used to address evapotranspiration estimation expressed as percent canopy cover, crop stress as indicated in thermal radiation, within season calibration for fields for application in models, soil moisture, soil characteristics within the field, and digital geo-registered dataset for each year registered to a base map. Landscape-scale data should be used to address the issues of water pollution and water distribution, and regional/global food production.

When looking at the sub-field scale, solutions must come from the growers. Their needs would more appropriately be addressed by private industries. NASA could not effectively design a program from the top down. Regional scale data may be better collected by government agencies. Data on the regional/global scale (like global warming) can have a tremendous impact on agriculture and our ability to sustain agriculture systems that can feed the world population.

It is important to incorporate environmental issues into sustainable agriculture, therefore, the aspects of environment should be considered in scale selection for the data acquisition.

Awareness and outreach

There is nothing that will make a grower use remote sensing if he/she does not feel the need for it, regardless of the quality of the data or the information derived from it. The quantity of data available is increasing rapidly, but a significant need remains for programs to develop specific, cost-effective products from the myriad data sources and data processing techniques. There is also a need to develop the educational tools and approaches that will show growers how to either generate the information products themselves or apply the data and information effectively.

Funding from NASA and other sources for education at the graduate and undergraduate levels would help tremendously. In addition, there must be efforts to make potential customers aware of the technology. In the Napa Valley, growers are participating by installing weather stations. These stations are leading the growers to inquire local technology applications. The most effective approach to growers may be to start small and have the word spread through the grower community, not from the university or government research lab. However, long-term pilot programs with NASA and USDA working on applications of data are needed. No other institution or individual is likely to undertake the research necessary to find the most useful data for growers and develop application techniques.

This group suggested that the report should be distributed through NASA's education office. A module on remote sensing and agriculture will also be part of NASA's Remote Sensing Core Curriculum. A quick solution and immediate acceptance is clearly not at hand. Gradual conversion through example and education is more likely, assuming the technology can deliver cost-effective products that can satisfy the necessity in precision farming.

SESSION 7: WHAT ARE POTENTIAL IMPEDIMENTS TO TECHNOLOGY TRANSFER TO THE AGRICULTURAL/RURAL SECTOR?

Moderator and Author: Wayne Mooneyhan
Session 7; October 24, 1996
West Room, Alumni Center

The discussion group in this session consisted of approximately thirty participants. The session consumed the full four hour time period that had been allotted. There was significant interest in the subject of technology transfer and the discussion was very lively at times. The participants represented remote sensing industry, universities, ag business and government. In addition a representative of the growers/users participated part time. There were numerous representatives with many years of experience who brought many 'lessons learned' to the discussion as well as several representatives of newly organized remote sensing industries who brought a few suggestions and new approaches. It should be noted, however, that the vocal in this discussion were the representatives of universities and government. The growers/users were under-represented and representatives of the remote sensing industry were, except for one or two, mostly observing.

This discussion group, in an effort to limit the debate to the most critical areas of concern, made the following assumptions at the opening of the session:

1. That the existing and planned satellite systems are, or will be, capable of providing data that when processed appropriately will be of significant value to the agricultural/rural sector and that the capability will continue to improve. (Sensor development is not an impediment to technology transfer to the agricultural/rural sector.)

2. That the technology base is capable of support data product development in an operational/ timely fashion and will continue to improve. (Hardware and software capability are not an impediment to technology transfer in the USA.)

3. That the technology base is capable of supporting data product delivery in an operational/ timely fashion and will continue to improve. (Communications and data networks are not an impediment to technology transfer in the USA.)

There was a general consensus on the above assumption but there were some concerns expressed by individuals with regards to the bandwidth for data transmission on rural telephone lines in some areas. The group response was to acknowledge the problem and to choose not to debate the issue because there was no expertise present in this workshop to address the issue. Further there was concern that there was no clear option as to whom the problem should be addressed other than the communications services industry in general.

An outline of impediments to technology transfer to the agricultural/rural sector was presented to stimulate the discussion as follows:

1. Culture of the users.

2. Inadequate understanding of the users needs by the remote sensing industry.

3. Inadequate interaction between the end users and the remote sensing industry in the definition of final product development.

4. Perceived unfairness of high tech impact among agricultural community elements.

After a brief discussion on the proposed outline the group expressed agreement on the following:

1. There are new technologies that would increase the return on investment to growers in particular and/or to the ag-business in general.

2. There exist some potential impediments to the successful transfer of the emerging technologies to the ag/rural sector.

3. The responsibility/opportunity to solve the technology transfer problems rest with all the players involved in agricultural applications development which include universities, the remote sensing industry, agricultural business, government, and the growers.

The group then adopted the following approach:

1. Identify the major impediments to the transfer of specific technologies or to technology in general.

2. Develop a list of actions/activities that if implemented would either partially or completely remove the impediments.

3. Identify the sector of the agricultural community that could best perform each of the activities on the list (universities, remote sensing industry, agricultural business, extension, government agencies, etc.)

In addition the group noted:

1. Rural access to high speed data links will take some time. Similar to the chicken and the egg situation, the technical capability is rather responsive to the demand.

2. Hardware and software are more of an institutional problem than a technical problem. Hardware and software will be developed when the demand is there.

3. The price of space hardware/data systems sets the cost of deliverables and while there can be some minor adjustments in price of data up front, the long term pricing must reflect system development and operational cost. The one exception to this is government operated systems.

4. The culture of the growers is generally resistant to new technologies that require significant change.

5. There has been little or no effort in the entire agricultural business community to integrate data systems.

6. There has been little or no input from growers in sensor design and product development.

The group then discussed five major impediments to technology transfer to the agricultural/rural sector:

1. The general farmer/grower public is not aware that earth observing satellites exist.

The group was essentially unanimous in its agreement that user awareness is the number one impediment to the transfer of technology to the ag/rural sector. Contribution to the discussions were numerous and enthusiastic. Close analysis indicated that approximately 25,000 of the 285,000 growers in the USA have some knowledge of the value of information derived from remote sensing as applied to agriculture. It was also noted that for the most part, however, that the GPS combined with ground instruments is the most used system to date. There was a strong consensus that there should be a concentrated effort, perhaps led by NASA, to increase the awareness of remote sensing contributions to agriculture. Issues involved with this discussion were:

- There is a need to present the value of remote sensing for precision farming to growers in particular and to agricultural business in general.

- There is a need to persuade the faculties in agricultural schools to teach remote sensing as an important tool for precision farming.

- There is at present a lack of success stories to persuade growers in particular and agricultural business in general that remote sensing is an important tool in high resolution agricultural management.

- There is not a clear understanding in the remote sensing community of the key decisions that growers need to make and exactly how remote sensing can help.

Recommendation:

There should be an activity lead by NASA, implemented by the leading agricultural university and supported by the remote sensing industry to collect success stories from government agencies, agricultural extension, universities and the remote sensing industry. Maximum media exposure of these stories could be made possible through farm press, agricultural journals, university press, space grant publications and trade journals. After media exposure, a follow on phase might include some face to face activities with grower organizations in the ‘town meeting’ style.

2. Cost of the data.

Data cost was discussed at length. There was a strong consensus that those satellite systems paid for with tax dollars should provide data to everyone at the marginal cost of reproduction. There was also general consensus that commercial systems should make some concessions in cost to users during the start up phase of their system and that they should develop a separate pricing structure (with appropriate non-competition restriction) for agricultural universities and research institutions.

- The increase in cost of satellite data that occurred with the commercialization of LANDSAT reduced the active research at universities and applications by government and industry by two orders of magnitude. For example, since the commercialization of LANDSAT some 14 years ago, Purdue University, a premier remote sensing research and applications organization, has purchased a total of 12 LANDSAT scenes. In the 10 years of LANDSAT operations prior to commercialization, the same university purchased more than 4000 scenes. Research and development essentially stopped at commercialization of LANDSAT.

- Since the real cost of satellite data systems is high, the only long term solution to the pricing problem is to increase volume by expanding the user community.

Recommendations:

- NASA should reconsider sponsoring an applications program where data is provided by NASA funding to the applications projects.
- NASA and the remote sensing industry should consider providing data free of cost to university and research institutions involved in application demonstration projects.
- Data suppliers, such as EOSAT, SPOT, and NASA should consider pricing data on unit area basis (price per acre as opposed to full or quarter scenes). The grower is only interested in his own land holdings.
- Data suppliers, such as EOSAT, SPOT, and NASA should consider providing data free of cost to university training programs to promote both undergraduate and graduate level education.
- Copyright regulations should be relaxed to allow multiple users to benefit from data purchases.

The group felt that a statement on pricing policies should be developed and presented as an output from this workshop. The following is a draft of such a statement:

> The high cost of data to the academic community has caused many academics to stop using remotely sensed data and instead to concentrate on GIS layers and databases. This has resulted in a significant decrease in the number of graduates with remote sensing expertise since the commercialization of LANDSAT. The demand for trained graduates in remote sensing by the many commercial remote sensing companies, distributors and users of remotely sensed data has been increasing significantly over the past several years. If the increase in the demand is to be met with high quality graduates trained with the latest technology then the latest high quality remotely sensed data must somehow reach the faculties of the universities and research institutions who can train these students. Consideration should be given to providing data to colleges and universities at 1/10th or less of the normal list price. This is especially critical with regards to the newly developed and developing commercial systems with high spatial, spectral and temporal resolutions. Minimally, universities and research institutes should receive data over their home area at the reduced cost from licensed commercial and government data systems for general use in undergraduate studies. For graduate studies a limit should be placed on the number of frames of data per graduate student per year that any one university should receive at the reduced cost. The result would be a steady increase in enrollment of students in remote sensing studies resulting in increased numbers of high quality graduates.
>
> The second area that was on the rapid increase before the enormous increase in cost of the LANDSAT was the development of applications in virtually every sector of resource management, both renewable and non-renewable, as well as environmental monitoring and assessments. While some of these applications were nearing maturity with the use of the LANDSAT data, most of them have not been tried with the higher spatial, spectral and temporal resolutions of the newly developed sensors to be launched in the next few years. The applications and consequently the market for these new data is not developed basically because the simulated data is either too expensive or non-existent. The U.S. suppliers of remote sensing data, both government and commercial, should develop pricing policies that will provide those institutions and individual users engaged in applications development with data at an introductory cost low enough to encourage development of new applications. The results would no doubt be increased demand for the data and improved profits for all parties.

The participants in this workshop recommend that each of the suppliers of data should develop pricing policies to promote the critical areas of student education and applications development. The participants recognize that it is not feasible for any supplier to continually underprice data to all its users and history has several times recorded the results of suppliers continually overpricing data.

3. Lack of trained agricultural personnel in the applications of remote sensing to precision farming in particular and the agricultural business in general.

The discussion group acknowledged that the current level of student support for both graduate and undergraduate level studies in remote sensing in general and in agriculture related programs in particular has impeded the development of critical mass of agriculture/remote sensing technical and scientific personnel by the academic institutions. This has been further compounded by the high cost of satellite data since the commercialization of LANDSAT. While the group acknowledged that NASA should probably take the lead initially to expand student opportunities, it suggested that the United States Department of Agriculture (USDA) should be an equal partner up front and should assume the long-term responsibility to expand agricultural research support in remote sensing. The group further suggested that the new and growing remote sensing industry that is pushing the demand for new graduates should also be prepared to contribute to the education programs for agriculture/remote sensing studies.

- The number of graduates at the undergraduate and graduate levels is inadequate to support the near and long term requirements of the remote sensing industry.

- There is a lack of money to fund remote sensing student programs in general and applications in particular.

Recommendation:

The group made the following recommendation which was later endorsed by the workshop participants as a whole: NASA and USDA should initiate remote sensing funding of the applied departments of agriculture, range and forestry in both universities and research institutions, including their involvement in the application projects, as well as fellowship funding. This was seen as key to sustaining the growth of remote sensing from a research tool to applications, and to future sustained operational use.

4. Government, industry, and academia could increase their effectiveness by an order of magnitude by closer coordination in programs and activities.

There was a suggestion from some of the participants that an organization patterned after the ‘Pacific Remote Sensing Alliance’ (PRSA) which was active during the mid-1980s, could perhaps stimulate cooperation and information exchange among the developers, providers and users. The PSRA was funded by NASA with membership from remote sensing industry, software industry, agriculture business, universities and government. The by-laws of PSRA were developed to promote commercial interest and restricted voting privileges to members with profit making charters. During the detailed discussions it was clear that any proposed new alliance should have a strong representation from the grower/user sector. The objective should be information exchange among policy makers, the suppliers of services/information the growers/users. Also, it should address specifically the application of remote sensing to agriculture. It was further acknowledged that while NASA or USDA should fund the alliance for the first two years, the cost should soon shift to the remote sensing industry. It was further acknowledged that the cost of operation should be minimal allowing for meeting facilities, communications, publications, and travel of university participants. The consensus was that commercial and government members should pay their own travel expenses.

- The group noted that the objectives of NASA, industry and academia seemingly converge at the user level.

Recommendation:

NASA should facilitate and fund the formation of an alliance among government agencies, remote sensing industry, academia and users which would meet twice annually to give policy and program guidance to the participating parties. A major objective of the alliance would be to deliver simulated or early return high resolution data sets to the research and applications development community to promote early product development and personnel training activities at land grant universities.

It is noted that at the closing session of the workshop with all participants, there was a proposal from the floor to form such an alliance as a product of the workshop. A few participants were very supportive but, in general, there was no support for the proposal. It is, however, the general opinion of the conference organizers that the growers/users, which were under-represented at the workshop might have more strongly supported the proposal. Because the growers/users are the single most important sector to successful applications of remote sensing for agriculture it is suggested that NASA should investigate the 'alliance' idea further.

5. The group felt that this workshop should issue a strong statement to NASA to consider funding a significant applications development and demonstration program that would enhance the transfer of remote sensing technology to the agricultural/rural sector.

The following is a draft of such a statement:

> The workshop participants believe that the agricultural user community will be a significant potential market in the future. However, the consensus was that the market does not yet exist in any significant form. At present, there is perceived to be a significant lack of user awareness of the potential of remote sensing and related technologies and a lack of success stories to demonstrate and communicate to the user how remote sensing can be of value in their day-to-day decisions and operations. There was a strong consensus among the participants that NASA should take the lead in bringing the science research and data to the potential user community through the conduct of a substantive and continuing Applications Development Program. These applications efforts should be taken, in concert with USDA and should involve the public and private end-users such as cooperatives, and the agribusinesses serving the growers, as well as the remote sensing value-added industry. The results of these projects should be widely disseminated through agricultural associations and societies, specialized media and conferences. The end-users should be involved from the start in all aspects in defining the application project needs, as well as project design and implementation.