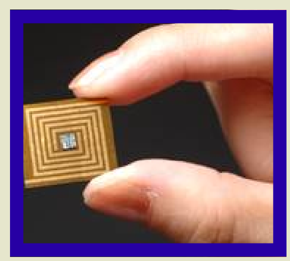
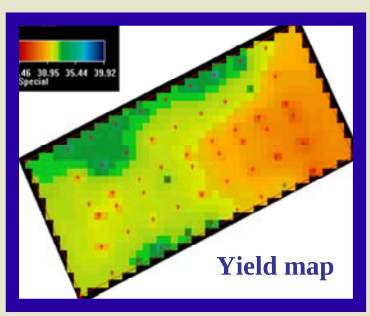
Workshop Report:

Engineering Solutions for Specialty Crop Challenges





Yield map

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EXECUTIVE SUMMARY

The workshop, “Engineering Solutions for Specialty Crop Challenges,” was held April 24-25, 2007 in Arlington VA. Representatives from various specialty crop industries and from several federal agencies planned and organized the meeting. Attendees included federal program managers, specialty crop industry producers and representatives, and researchers, educators, and outreach specialists from numerous universities. The workshop included both plenary sessions and topic-specific breakout groups, intending to inform and engage industry and the R&D community. Industry attendees were able to voice their production and processing needs for engineering and technology solutions, and the R&D attendees were able to offer their insights regarding current and future engineering science and technology capabilities. This workshop report summarizes the dialogs between researchers and industry during those two days. It can be used as guidance for future federal science and engineering investments to assist this important segment of U.S. agriculture. Furthermore, a continuing dialog was created between the science and application communities that we envision will lead to new formal and informal collaborations in the future.

Product quality, labor cost and availability and environmental footprint were identified as major industry concerns. Each of the five industries also noted some unique needs for their particular specialty crop sector. Attendees anticipate that the following engineering advances and technologies are needed: improved and readily available sensors to increase knowledge of plant growing conditions and product quality; more efficient applications/use of water, nutrients, and chemicals; automated systems that can reduce costs of cultural practices; and better economic models and decision support systems that can improve production and management decisions. Some of these new technologies are urgently needed right now, while development of others needs to accelerate now to ensure that advanced engineering systems will be available within the next decade.

Science and technology were not the only foci for discussion, though. Plenary presentations and breakout groups also covered issues related to education and workforce and to society, economic, and enterprise interactions. Greater reliance on engineering and technology solutions by specialty crop industries in the future necessarily means that the future workforce will need new skills and expanded professional training. Similarly, grower business practices, consumer markets, and national and international policies will create a changing climate for development and application of technology. Consequently, “engineering solutions” are more accurately portrayed as the engineering *components* of integrated solutions within the broader framework in which these industries operate.

BACKGROUND AND INTRODUCTION

Different segments of the specialty crop industry (e.g., wine/grape, citrus, apple, stone fruits, ornamentals, etc.) have been organizing independently during the past several years to address critical research needs. However, because each segment, individually, only represents a relatively small portion of the overall specialty crop industry, many of their needs do not receive attention in national research programs. Consequently, those individual industry segments have created a research collective to examine common research needs. What they have found is that one of their primary industry-wide concerns is the availability, skill level, and cost of labor—their single greatest production cost—that harms their competitive position internationally. But, that is only part of the story. These industries also need tools and technologies that can improve production efficiency, product quality, post-harvest operations, and reduce their environmental footprint. They have agreed that automation, robotics, precision agriculture, sensors, and other advanced technologies are needed to help their industries and its producers become more efficient, productive, and sustainable.

On April 24-25, 2007, a workshop was convened in Arlington VA to examine engineering science and technology needs across several specialty crop industries. Workshop attendees also discussed current and future engineering capabilities and how those might be brought to bear on the problems faced by producers and processors. Attendees included program managers from a variety of federal agencies: National Aeronautics & Space Administration (NASA), National Science Foundation (NSF), National Institute of Occupational Safety & Health (NIOSH), Cooperative State Research, Education & Extension Service (CSREES), Agricultural Research Service (ARS), National Institute of Standards & Technology (NIST), and Agricultural Marketing Service (AMS); producers and representative from five specialty crop industries: tree fruit, citrus, wine & grape, berries & brambles, and ornamentals; and researchers, educators, and outreach specialists from both public and private institutions. Including several USDA administrators, there were more than 85 people in attendance (see Appendix VI).

The workshop was organized through the efforts of a steering committee with membership from CSREES, ARS, NSF, NASA, and the following industries: apples and tree fruit, nuts, citrus, and wine/grape.

Objectives for the workshop included the following.

1. Convey to the engineering R&D community the labor productivity and production efficiency needs of the specialty crop industries and how technology solutions would fit into their operations;
2. Highlight some current R&D activities and technologies that could have application to specialty crop labor and efficiency problems;
3. Develop an agenda for short-, medium-, and long-term engineering R&D activities to aid the specialty crop industries (the expectation is that some of this R&D will be supported at the Federal level); and
4. Foster an ongoing dialog among workshop participants and expand options for future networking.

CONDUCT OF THE WORKSHOP

I OVERVIEW

Most of the work of this meeting was conducted in relatively small, breakout sessions (12-15 participants each). There were two separate breakout group sessions: one near the middle of the first day, organized according to specialty crop industry, and one beginning early the second day, dealing with science and technology areas (see Appendix I). Assigned membership in the various breakouts changed from day one to day two. Most of the first day's agenda was spent in plenary sessions to provide the context for breakout discussions. Plenary talks were chosen to inform attendees regarding the various industries or science/technology areas and to help stimulate attendees to think about their problems or their research in a slightly different way.

II DAY ONE PLENARY SESSIONS

The first set of plenary talks on day 1 focused on industry issues and provided an overview of the current level of engineering technology application by those industries. These were provided primarily by industry representatives, and were intended to inform researchers regarding industry issues, needs, and limitations. In addition to providing industry-specific introductions to specialty crop production and processing, industry presenters highlighted numerous cultural operations, e.g., spraying, thinning, sorting, and harvesting, that require considerable human labor and could benefit from new engineering-based technologies. Some industry attempts to minimize labor and to efficiently apply nutrients, water, and chemicals were also described. A brief talk also illustrated growing concerns related to upcoming air quality regulations designed to minimize dust particulates and chemical spray drift. The second plenary session, held late in the afternoon of day 1, featured presentations of innovative engineering R&D that is currently being conducted at various academic institutions. This offered industry attendees a sense of what the research community is developing in robotics, sensors, and precision and information technologies, and how future technologies may transform their operations and industries. These presentations also described some existing technologies that could be commercialized and/or applied. The final two talks in this session covered some social and workforce issues and linkages between science, technology, commercialization, and application.

III DAY ONE BREAKOUT GROUPS

Following the morning plenary session, workshop attendee broke into five "application industry" subgroups (pre-assigned membership). Each breakout group included a facilitator, group leader (responsible for reporting out), and a recorder, in addition to 12-15 attendees (see Appendix for group facilitators and recorders). The charge to each group was to generate prioritized lists of short-, medium-, and long-term engineering-related needs for their particular industry (see Appendix II for a detailed breakout charge). To aid and focus discussion, we asked the groups to organize their thoughts around four topics: production efficiency, product quality, environmental footprint, and post-harvest operations. This breakout session was the shorter of the two sessions, for two reasons: (1) much of the groundwork for these discussions already occurred during prior, industry roadmap development efforts and (2) the steering committee summarized a priori the engineering aspects of those individual roadmaps and provided each attendee with those summaries in advance of the workshop. Immediately after the breakouts, we reconvened to hear short (5-10 minute) reports from each group.

IV DAY TWO BREAKOUT GROUPS

The second day began with a brief plenary session consisting of two speakers from the commercial vendor community. The second breakout, immediately following, was aligned by science/technology area: sensors and sensor networks, mechanization/robotics/automation, precision agriculture, information technology (IT) and decision aids, socio-economic and enterprise, and education and workforce. Individual membership in each subgroup was different from the first day, but each group had the same general organization. The charge for this session was to: (1) identify currently existing technologies that have application to specialty crop industry needs and (2) list and prioritize the engineering science and technology challenges that remain unmet and that can be achieved in the short-, medium-, and long-term. This breakout session was allotted more time that the first breakout session on Day 1. During an extended lunch break, the workshop heard brief remarks from two USDA Under Secretaries, and had a chance to ask questions. A slightly longer plenary than the previous day then convened to hear reports by each of the morning's breakout groups. Following general discussion of these results and wrap-up comments, the workshop formally adjourned. However, immediately after adjournment, an interested group of participants met to form a working group that would continue communication, networking, and organizing activities that were begun at the workshop.

RESULTS FROM THE INDUSTRY-SPECIFIC BREAKOUT SESSION

BERRIES AND BRAMBLES

The group addressing berry and brambles industries generated a list that will require substantial collaborations with non-engineers (Table 1). Food scientists, social scientists, geneticists, and economists will need to be engaged by the engineering R&D community to solve many of these problems. Overall production costs were mentioned, but with regard to labor, the issue was primarily quantity and quality of the workforce, rather than availability. Again, most of the listed concerns are important in the short- and medium term, so there is considerable urgency for finding solutions. The group listed only one barrier, specifically, noting that disease management techniques are not curative or preventative, but rather merely post-incident treatment. The implication is that they would like to see disease management efforts that are more proactive.

Table 1, Needs identified by the berries and brambles breakout group.

Issue/need/concern	Priority[a]	Urgency[b]
Optimize genetics for growth and mechanization, increase genetic variety selections	3	6+
Processing technology (e.g. sorting)	3	3-6
Environmental scope of production (nutrient mgmt, water and energy use, chemicals, assessment, monitoring)	3	6+
Research and production knowledge gaps are substantial	3	6+
Cost, quality, and quantity of seasonal labor	3	0-3
Manage food quality and understand consumer preferences	3	0-3
New markets (foreign and domestic) are needed	3	3-6
Economic and decision support tools are lacking (in particular, forecasting)	2	3-6
Cost of disease management and lack of resistant cultivars	2	3-6
Lower costs of production/inputs to compete globally	2	3-6
Planting and bed preparation protocols are lacking	2	3-6
Outdated/inefficient chemical application technology	2	0-3
Changing regulations and policy demands increase costs	2	6+
Crop production variability (soils, pests, weather)	2	6+
Resource competition/cost (air quality, land, water, energy)	1.5	6+
Harvest timing is poorly understood, and picking selectivity too low	1	0-3, 3-6

[a] High (3) to low (1).
[b] Years: near term (0-3), medium term (3-6), long term (6+)

II ORNAMENTALS

Ornamentals constitute the one industry present at this workshop that deals with non-food commodities only. Necessarily, then, some of their industry needs will be different from the other industries, e.g. no concern for food safety. Aside from the first concern listed in Table 2, the needs express for the ornamental industry are largely not biologically based production, but deal mostly with business, enterprise, and other operational parameters. It should be noted, however, that representatives from this industry at the workshop came exclusively from greenhouse and controlled-environment operations. We can only assume, at this point, that field-based nursery operations would have many similar perspectives and needs, but might have more biological concerns due to their field-based production setting, where they have less direct control over growing conditions.

Table 2 Needs identified by the ornamentals breakout group.

Issue/need/concern	Priority[a]	Barrier
ACESys (automation, culturing, environment), including monitoring, decision support, and chemical application technologies	3	Lack of sensors Tech. flexibility No unified approach Infrastructure
Business operations mgmt (including supply chain, inventory control, and transportation)	3	Lack of models Data gathering
Enterprise automation (production-to-consumer systems)	2	No standardization High capitalization Inertia to change Loss of flexibility
Renewable resources for containers	2	Lack of technology No standards Lack of raw materials Economic incentives
Energy use, price, and availability	2	Controlled-environment facilities are expensive to operate
Lack of standardization (e.g., containers)	1	Industry resistance

[a] High (3) to low (1)

The group spent significant time describing an automation, culturing, and environment system (ACESys) that captures the full sphere of crop production, but also includes IT, economics, social/policy issues, and product quality components. While implementation specifics for the various components of crop production under an ACESys would vary between greenhouse and field operations, the needs for monitoring, control, optimization, plant health, culturing, water, nutrients, and growing medium would be similar. Extending this idea beyond the growth environment leads into enterprise automation and a producer-to-consumer system. Energy use is one issue that would be less of a concern for field-based nurseries, where heating, cooling, and airflow are not controlled. Nevertheless, automation (both in production and business practices) and standardization represent the key themes here, and could be expected to reflect interests for both greenhouse and field nursery operations.

III WINE AND GRAPE

As is reflected in Table 3, anything related to labor is a big concern at the present time for the wine and grape industries. These issues will continue to be problematic until labor costs, inefficiencies, and reliance on manual labor are reduced. Most of the listed concerns are important in the short and medium term, so there is considerable urgency for finding solutions. However, many of the concerns are also labeled as "long term" (6+ years, which suggests that the group expects them to persist for some time to come. That is, it is unlikely that there exists any "quick fix" that can be readily adopted that will resolve the identified issues soon.

Table 3. Needs identified by the wine and grape breakout group.

Issue/need/concern	Priority[a]	Urgency[b]
Mechanization of cultural practices (e.g., pruning, thinning, canopy mgmt, harvesting)	3	all
Water management	3	3-6, 6+
Waste stream management	3	3-6, 6+
Energy use/capture/renewal	3	3-6, 6+
Food safety (including traceability, sanitation, data mgmt)	3	0-3
Pest management & application technology (e.g., spraying, weeds, environmental and human safety, nutrient mgmt)	2	all
Crop development forecasting (e.g., yield, maturation, quality)	2	3-6, 6+
Site selection & assessment	2	3-6, 6+
Soil chemistry, physics, and dust mgmt	2	0-3, 3-6
Post harvest	1	all

[a] High (3) to low (1).
[b] Years: near term (0-3), medium term (3-6), long term (6+)

Barriers identified by the group were not issue specific, but rather addressed broader concerns related to R&D resources and collaborations, technology transfer and adoption, and commercialization. Some of the non issue-specific barriers that could hinder resolution of the above needs are detailed in the following list generated by the group:

- Identifying core research competencies,
- Coordinating projects with widely multi-disciplinary/inter-disciplinary aspects,
- Adequate and appropriate scientific infrastructure,
- Intellectual property issues,
- Commercialization of technology,
- Multi-agency/interagency agreements/support for grant programs,
- Lack of integrated, multidisciplinary approaches,
- Bridging the gap between research and industry acceptance/adoption of processes or products,
- Funding for research,
- Integrated teams (industry, research, all involved persons/groups),
- Policy constraints,

- Technology constraints (e.g., current sensor technology),
- Lack of early adopters and technology diffusion/technology transfer mechanisms,
- Technological distrust—whether consumers or producers (e.g., genetically modified organisms)

IV TREE FRUIT AND NUTS

This breakout group felt that their two industries were too dissimilar for them to provide a single unified list of priority needs. Consequently, they generated separate "need" lists for nuts (Table 4) and for tree fruit (Table 5).

A. Nuts. Environmental issues surrounding chemical applications (including soil fumigation) and dust generation head the list of priorities for this industry. Chemical applications add significant costs to production, and are facing increased regulatory pressure. An alternative to current fumigation practices is urgently needed. Nut quality is both high priority (#1) and urgently needs to be addressed. Quality in this context relates to contaminants in the bulk product and pathogens that may have entered the nut shell. Both input and output water quality are of particular concern for nut processing operations. Food safety concerns demand high-quality input water for processing operations and post-processing discharge water needs to meet water quality standards.

Table 4. Needs identified by the nuts segment of this breakout group.

Issue/need/concern	Priority	Urgency[a]	Barrier
Environment and sprayer technology	3	3-6	Unfavorable economics Regulatory policy
Product quality (pathogens, contaminants)	3	0-3	
Soil fumigation	2.5	0-3, 3-6	No testing alternatives
Dust and air quality during harvest	2	0-3	Regulatory machinery Equipment-generated dust
Input water quality	1.5	6+	
Processing water effluent	1	3-6	

[a] Years: near term (0-3), medium term (3-6), long term (6+)

B. Tree fruit. Costs of production, processing, and handling, associated with labor, are the biggest issues for the tree fruit industries, and require immediate attention. The group felt that currently available sensing technologies make this a difficult problem to solve. In fact, for each of the identified issues here, inadequate sensor technology appears as a significant barrier to addressing industry concerns. Information technology solutions will be needed to complement new sensor technologies and the data that they generate. Environmental concerns associated with chemical applications are an immediate and high priority problem, as it is for nut production. Improved efficiencies are needed in both crop production and in processing operations. This is both an immediate and a long-term need.

Table 5. Needs identified by the tree fruit segment of this breakout group.

Issue/need/concern	Priority	Urgency[a]	Barrier
Reduction of labor costs and improved efficiency (including both cultural and post-harvest operations)	3	all	Lack sensors for product quality, tree/attribute assessment
Environment and sprayer technology	2	0-3	Lack sensors to target pests, diseases
Delivering fruit quality	1	3-6	Consumer/grower quality perceptions, Inadequate sensors

[a] Years: near term (0-3), medium term (3-6), long term (6+)

V CITRUS

The citrus group developed seven broad *categories* of issues; these appear in Table 6. In each case, these issue categories contain many related subtopics; however, some subtopics within a category also fit within some of the other six identified issue categories. So, there is overlap in several instances.

Citrus diseases can result in both permanent tree loss (citrus greening in Florida), and major crop losses (citrus canker in Florida). Better methods of disease detection (e.g., remote sensing, robotic scouting) could aid early treatment. Effective equipment decontamination methods could also help prevent spreading diseases between and within groves.

Table 6. Needs identified by the citrus breakout group.

Issue/need/concern	Priority[a]	Urgency[b]
Disease detection & management	3	all
Product quality & product harvesting	3	3-6, 6+
Application technology (e.g., spraying insecticides/herbicides/fungicides)	2	0-3
Water management & utilization	2	6+
Systems approach to production (including plant, environment, and business economics)	1	all
Processing for products and traceability	1	3-6, 6+
Packaging & post-harvest operations (including quality and disease mgmt)	1	3-6, 6+

[a] High (3) to low (1)
[b] Years: near term (0-3), medium term (3-6), long term (6+)

The urgency of mechanization is not quite as prominent here as in the two previous breakout groups, although it is still a high priority. This results, in part, from the fact that mechanical harvesting of juice citrus has been fairly successful, although still needing improvement. Mechanical harvesting of fresh fruit, on the other hand, still needs to be developed. Notable barriers to fresh fruit harvesting are the plant architecture (large trees with interior fruit), the consequent lack of a harvest-ready fruit wall, and terrain. Although numerous attempts have been made both nationally and internationally, technology barriers, such as, fruit visibility, manipulator dexterity in the canopy, end-effector performance, harvesting cycle rate and picking efficiency have prevented the development of any commercially viable systems. The other aspect of production addressed here is fruit quality, which is treated as on-tree grading and labeling. Using biochemical and optical sensing, fruit could be graded and labeled by attached “smart” tags or by automated scouting or harvesting machines.

Crop protection and chemical application technology is also an immediate problem. More efficacious, cost-effective and environmentally friendly chemical application methods for herbicides, fungicides, and insecticides are needed that use fewer chemicals and apply them to the proper location at the right time. Precision water management could, similarly, provide cost savings though monitoring of plant water needs and improving the timing and delivery of moisture.

All of the above-mentioned needs can be considered as part of a systems-level approach to production, wherein grove siting and architecture are also addressed. Such a production environment would be data-rich and offer the grower instantaneous information about plants and fruit, and eventually allow for highly specific spatio-temporal management.

VI PROMINENT THEMES

As was noted in advance of this workshop, labor costs and availability, product quality, and environmental concerns are some of the primary issues facing these industries. The labor situation was borne out during this meeting, as a common issue expressed by nearly all attendees, primarily as it relates to the shortage of labor and the prospects for automation using robotics. Pest management, with regard to emerging insects and diseases and chemical-application dependency, is also a high priority across industries. Economic, decision support, risk management, and business management tools were also mentioned as need areas that could help these industries become more efficient. While not highlighted in these condensed lists, understanding, educating, and marketing to consumer preferences received some attention at the meeting, especially as they relate to product quality and new product markets.

Beyond specific industry issues, such as the availability of labor, attendees noted that the forces of globalization are forming a new competitive environment for many high-margin specialty crops. This creates a need for better methods of determining production costs (and projected profit) for domestic growers along with improved understanding of supply chain dynamics and global economic systems. Many growers stated that increasing the yield of specialty crops was the best way to meet competitive challenges from overseas.

Many specialty crop growers live and operate in ex-urban environments, where there is increasing suburban development pressure, and its concomitant loss of “rural-ness” and escalating land values. This also creates traffic, water use, and tax problems and can lead to conflicts and misunderstandings with new, formerly suburban, neighbors. While ex-urbanization puts growers in closer proximity to consumers and opens up more direct marketing opportunities, it does so at the cost of ever-increasing numbers of dwellings, roads, shopping centers, and businesses that can be anathema to growers’ traditional rural way of life.

Not surprisingly, industry needs identified at the workshop cannot be met exclusively by engineering solutions, but will likely require considerable cross- and inter-disciplinary research, development, and application. This idea was also reflected at the workshop through focused discussion involving the application of “systems” ideas as a way to develop effective technological solutions. Many industry problems are interrelated, so integrated approaches are needed that take a more inclusive perspective of the producer-to-consumer system.

RESULTS FROM THE ENGINEERING-TOPICS BREAKOUT SESSION

SENSORS AND SENSOR NETWORKS

Because sensors are integral to precision agriculture and mechatronics technologies, there are many common themes and cross-correlations. The “wish list” for sensing is pretty well established and was reiterated by the group: cheap, fast, easy to use, reliable, and field deployable. Given that economies of scale are not favorable for agricultural sensor applications in general (and specialty crops in particular), cost-effectiveness will be a significant challenge. The group selected at least one high-priority issue from each industry-specific breakout from the previous day, but did not prioritize the knowledge, technologies, or capabilities of their engineering solution set (Table 7).

Table 7. Engineering science and technology challenges for sensors.

Issue/need/concern from Day 1	New knowledge/technology/capability
Water management	Runoff and waste water; plant-level water mgmt: soil moisture, plant water use
Food safety	Need sensors for: chemical and microbial contaminants, defects, and allergens
Disease/pest management	Need sensors for: soil pests, spray efficacy, pest detection, and phytosanitary plant condition
Product quality	Need sensors for: sorting & grading, sugar content, pests, sensory attributes, traceability, inventory control
Crop management	Need sensors for: yield, maturity, soil and in-plant nutrients, plant health, canopy management
Crop harvest	Need sensors for: yield, maturity, fruit location, mobile platform tracking, dexterous manipulation, inventory tracking, quality mapping

Though the use of sensors in agriculture is in an early stage, there seems to be two basic types: (1) sensors and sensor networks that are placed in a distributed manner, covering many acres of orchards, vineyards, vegetable fields, etc. or (2) sensors attached to agricultural machinery (or processing equipment) to measure yield per area, to scout for insects, diseases, or pre-harvest fruit, to assess foliage density, or to measure product characteristics during processing. In all cases, cost will be an overriding factor in the deployment of sensors, unless their added cost brings new capabilities that add substantial value to grower operations. There are many ideas for developing agricultural sensors. Some include:

- A sensor placed on a tree or grape vine to measure internal water uptake for irrigation planning/application purposes.
- Development of a new family of sensors designed to analyze the internal quality of fruit. This might also include measuring maturity of fruit and vegetables in the field (sugar and starch content and the rate of growth).

- From a food safety perspective, sensors are needed to measure pathogens and other chemical contaminates in the field.
- In terms of the efficiency of agricultural production, sensors could measure the concentration of pests and perhaps various plant diseases that appear in the field. This would provide better information on when and where to apply chemicals.
- Forecasting crop size and timing presents an interesting opportunity for sensors relating to the measurement of maturity rate and weight. This might include detection of certain chemicals such as phenols that have significant pharmacological properties.
- Nanotechnology offers some opportunities for creation of agricultural sensors.

In all applications of sensors, there is concern about making the data interoperable and applying various means, such as mathematical or economic models, to analyze the data. Data-rich environments lacking appropriate data management and information technology tools create a production setting with a low signal-to-noise ratio. In that scenario, a grower would have no additional information on which to make profit-critical decisions. Many of these concerns were discussed by the following breakout group.

IT AND DECISION AIDS

The biggest issue with IT and decision aids is that in most cases we don't have the modeling baseline data to know how to make decisions (Table 8). Subsequent data collection, then, lacks real purpose. Existing models are crude and generalized, with poorly understood economic decision points. Data collection is currently still expensive, but when it becomes cheap the volume of data will overwhelm producers/processors unless adequate models and decision aids shield the user from the data tsunami. Plant-based management will then require new models and data tools.

Table 8. Existing capabilities and barriers related to IT and decision aids.

Issue/need/concern from Day 1	Existing knowledge/ technology/capability	Barrier
Crude, generalized models for diseases, insects, water management, plant/fruit growth; plant-based data collection is needed	Some models exists; some data exist; some states have existing web-based modeling systems that pull sensor data statewide and make recommendations	Clean data; adequate data; scientists to adapt models for different species; accurate recommendations often lacking; no economic thresholds
Date management and standardization of reporting	Assortment of programs available; mapping capabilities; macro systems available; spatial data	Wide variety of programs; can be expensive, depending upon # of licenses; training requirements; ease of use
Traceability and supply chain management	Successful supply-chain management and data integration (e.g., discount department stores)	RFID for specialty crops

Data management tools crosscut all topics (Table 9). Appropriate data management tools are necessary to gathering good data. They also need to be standardized. Growers also require user-friendly systems that aid reporting and record-keeping while maintaining privacy of individual farmers. Delivered systems will need to add value to grower operations with a short payback period. IT and decision tools will also need to work with a variety of off-the-shelf hardware, e.g., RFID, scanners, GPS, PDAs, desktop computers, and bring convergence to their capabilities. While most producers want something specific to them, these tools will need to employ various standards so that the data are interoperable with other supply chain and regulatory entities.

Some IT issues/concerns stem from non-IT sources. Lack of data or "garbage in, garbage out" becomes an IT issue when decisions are made regarding modeling and pesticide use, etc. Future data collection, modeling, and decision making need to be closely coordinated. Applications and decision-making requirements should drive the process, with data and modeling resources developed as necessary.

The ornamentals industry will always have different post-harvest issues compared to tree/fruit or other specialty crop sectors. Ornamentals are selling the plant, while other industries are selling a product off the plant. The ornamental industry must address APHIS regulatory concerns related to pest and disease transmission. It is also difficult for growers to differentiate their product from the products of other growers. Better supply chain management systems and better labeling could help growers do that.

Table 9. Engineering science and technology challenges for IT and decision aids

Issue/need/concern from Day 1	New knowledge/ technology/capability[a]	Urgency[b]
Crude, generalized models for diseases, insects, water management, plant/fruit growth; plant-based data collection is needed	Possible to adapt existing models; need calibration and assessment; need databases able to handle the quantity of data generated by plant-based sensing	3-6
	GIS mapping where you can overlay weather, soils, yield, inputs, product quality, moisture, etc.	0-3
	Create and evaluate field hardware	0-3
Date management and standardization of reporting	Customizable interfaces; affordability; appropriate user interfaces—bilingual or visual	0-3
	Data filters (ensure data quality); technology transfer education to use new products	0-3
	Management of technologies (timeframe for updating or calibration)	6+
	Affordable system architecture	3-6
Traceability and supply chain management	New data integration/sharing standards; integrated RFID	3-6
	Real-time data from packers & canners supplied;	0-3

[a] All were designated high (3) priority.
[b] Years: near term (0-3), medium term (3-6), long term (6+)

Product traceability will continue to become even more and more important; it is necessary to keep track of types of pesticides and other inputs used, etc. We can look to Europe for examples and precedents.

The group also felt that developments in this area need to focus on innovators, early adopters, and those willing to change to stay profitable. There will always be a group of producers that resist change and, that if catered to, could dampen the progress potential of evolving IT and decision tools.

III PRECISION AGRICULTURE

Precision agriculture (PA) refers to spatially and temporally precise culturing and management activities, including applications of water, nutrients, and chemicals, harvesting, yield monitoring, scouting, soil mapping, auto-guidance, etc. Sensing systems and information management tools (e.g., geographic information systems) are seminal components of these activities. The breakout group selected several issues from the first day's groups and identified some existing PA capabilities and associated barriers/limitations (Table 10).

Table 10. Existing capabilities and barriers related to precision agriculture.

Issue/need/concern from Day 1	Existing knowledge/ technology/capability	Barrier
Water management	Wireless sensor networks for irrigation (down to rows)	Knowledge base and integration insufficient for decision making
Chemical application technologies; how to get the material to the target; need variable flow applications	Four-fan overhead, directed air blast (grapes); electrostatic sprayer (nuts); air assist sprayer	Field operator education; technology transfer capability; information lacking on outbreaks and responses
Remote sensing; local sensing for plant physiology, canopy, and insects	Vegetation index; satellite imagery; vigor maps; modeling capability; IT	Compatibility of technology with existing systems; limited applications for sensor data
Product quality	Spectral sensing for post-harvest	
Labor management—the right person in the right place at the right time	Radio frequency identification (RFID)	Inventory control use of PA

In addition to the issues listed in Table 10 and Table 11, several unprioritized issues were also discussed by this breakout group. First, coordinated teams of government, university, and stakeholder participants need to coalesce to address issues of common interest, e.g., food safety, traceability, water management, environmental management. One of the barriers, however, is facilitating this coordination and organization. The group suggested that establishing special interest teams, organized around particular issues, might help seed and draw together a critical mass of researchers and practitioners. Second, the level of technology transfer of research results to grower communities is often much less than the value of research completed. There is a sense that too often research is isolated from the problems that drive it and the solutions needed by stakeholders. The above-mentioned issue teams could help with this effort, but well-established plans and processes for delivery of new knowledge and technology are needed. The existing Geospatial Extension Specialists program at CSREES was given as an example of how technology transfer could effectively translate research into field practice.

Table 11. Engineering science and technology challenges for precision agriculture.

Issue/need/concern from Day 1	New knowledge/ technology/capability	Priority[a]
Water management	Plant level water mgmt: soil moisture, plant water use, water balance modeling	3
Chemical application technologies; how to get the material to the target; need variable flow applications	Automatic identification of hot spots and pests; alternative to high-volume air mass sprayer; interface between biology and application technology	3
Remote sensing; local sensing for plant physiology, canopy, and insects	Want: 24-hour coverage; remote imagery around 1m that is real time, reasonable cost; ability to purchase from global vendor	3
Product quality	Develop quality maps by tracking fruit to form a decision support system aimed at optimization; genotype/phenotype expression interacting w/environmental factors	2.5
Labor management—the right person in the right place at the right time	Develop system to use RFID technology downstream; trace back to individual box	2

[a] High (3) to low (1)

There is a broad need to move toward individual plant monitoring and management rather than block or row management, just as precision agriculture has taken traditional row cropping systems from field-level to zone-level management (and in some case plant-level management). Under such a scenario, production and management information must have a much finer resolution, be collected with greater time frequency, and be available in near real time. This is reflected in the first three issues in Table 11. Irrigation management systems are probably farthest along, in this regard, but still only operate at the row level and monitor soil moisture, rather than plant water stress. With the current labor shortages, it is critical that available labor is better managed; it would be useful if precision ag could help with that aspect of production. Some technologies, e.g. RFID, do exist, but they need to be augmented (e.g., with IT systems) and commercialized before they become useful, e.g. inventory control.

IV MECHANIZATION, AUTOMATION, ROBOTICS (MECHATRONICS)

The marriage of mechanical devices with electrical and computational systems is often referred to as *mechatronics* or electromechanical systems. We will adopt that terminology here. Both the reliability and capabilities of mechanical systems are improved by this collaboration. One key aspect of the control architecture inherent in mechatronic systems is the use of sensors to relay information about the machine operating environment in addition to task-based sensors. Production-related mechatronic applications might involve inspecting fruit on a packing line and sorting them based on infrared spectral signature, or autonomously moving through a vineyard to target and spray insect colonies, involving dozens of locomotion, imaging, and chemical sensors. It will be important as new technologies are developed that collaborative research employs the expertise of engineering scientists, horticulturalists, economists, producers, and manufacturers. The complexities of crop production systems for the various specialty crops may eventually require that multi-disciplinary teams work together to co-design the plant and machine system.

Because this breakout group dealt primarily with the mechanization and automation of cultural practices, issues identified in Table 12 and Table 13 include only those operations (except for the last item). Barriers listed in Table 12 are issue-specific in some cases, and generic to automation and technology adoption in other cases. Some of the barriers identified by the group include: crises-driven technology advances, rather than visionary; many technologies are expensive or too unreliable for commercialization; too much crop-specific dependency in current technology advances; and fruit maturity is poorly characterized at present. Not mentioned in Table 12 is the idea that designing/developing the “orchard” is the last bastion of grower “independence,” so making big changes in cropping architectures may be as much ideological or emotional as it is an economic decision.

Table 12. Existing capabilities and barriers related to mechatronics.

Issue/need/concern from Day 1	Existing knowledge/ technology/capability	Barrier
Crop thinning/pruning	Non-selective: hedge pruning, mechanical shaking, chemical thinning;	Short-term planning & technology adoption; crisis-driven industries; complex plant environment (access, light)
Crop operations (other)	Electrostatic and shroud sprayers	Accuracy and cost of new sprayer sensors; “row” architecture is a proven technology
Crop harvesting	Impact and mechanical shakers; aerial survey of crop	Picking vs. extraction harvesting; maturity poorly defined; robotic system complexity & maintenance
Crop monitoring	Airborne and satellite imagery	Applications software; coordination among biologists, engineers & producers
Post-harvest operations	Specialized fruit sorters	Labor is available

A significant challenge faces technology providers as they develop high-risk and low sales-volume mechatronic systems with limited information about expected production efficiency, systems cost, and market potential. When applying advanced technologies to agriculture, where profit margins are tight, it will be important to evaluate the economic potential for both producers and manufacturers. Economic viability is a must for all concerned entities and, in most cases, the simpler and more robust a system is, the better.

This breakout group generated a fairly lengthy list of possible new knowledge, technology, and capability challenges. In the end, they focused their attention and priority setting on a smaller subset, appearing in Table 13. The primary thrust coming from this group is that we need to develop multi-purpose robotic platforms that can be configured with a variety of plug-and-play operational technologies, e.g., thinning, picking (which may be identical to thinning, except for the effector arm), spraying, etc. Such robotic platforms will require a variety of vision, navigation, obstacle avoidance, path planning, and locomotion technologies. More traditional mechanization technologies can also be developed to improve and augment worker productivity; in the short and medium term, these may ultimately be more economically viable. Other, non-autonomous systems are needed for improved chemical applications and for post-harvest handing. The latter could borrow some ideas or technologies from automation in the ornamental industry.

Table 13. Engineering science and technology challenges for mechatronics.

Issue/need/concern from Day 1	New knowledge/ technology/capability	Priority[a]
Crop thinning/pruning	Vision-based sorter with blast nozzle to expel buds, flowers, fruit	3
	Autonomous scout to thin and path plan for spraying or harvesting	3
Crop operations (other)	Automated pheromone application	3
	Crop-specific end effectors	3
	Vision systems for complex biological environments	3
	Simpler processes that use labor-efficient, more optimal orchards	3
	Sensor-directed chemical applications	2
Crop harvesting	Shared robotic platform for pruning, thinning, harvesting; systemic commonality for cultural operations with specific actions/modules to match specific operational objectives	3
Crop monitoring	Remote sensing to identify disease, etc.	2.5
	Autonomous "state of the crop" UAV or ground-based robots	2
Post-harvest operations	Apply ornamental automation systems to processing side of field crops	2

[a] High (3) to low (1)

V SOCIO-ECONOMIC AND ENTERPRISE

This group focused on the human and social dimensions of engineering solutions for specialty crops, specifically Social, Economic, and Enterprise issues. The group synthesized a great deal of both disparate and complementary information identified the preceding day by different segments of the specialty crop industry. This information ranged from the human and social dimensions of product quality, pest management, business management, and the management of natural resources, to the need for decision support tools for investment, production, response to regulations, market identification, and response to consumer demands and preferences. Quality, safety, and traceability, as well as barriers and resistance to standards and standardization were identified, along with the lack of baseline data and the need for benchmarking in many aspects of production, processing, and marketing. Furthermore, the information highlighted such ethical dilemmas as shortages of migrant labor, the impacts on rural communities of transient labor and replacing labor with automation, and the use of controversial production technologies, as well as the challenges to sustainability of ever increasing resource and energy demands.

The group distilled these myriad issues into a number of broad categories, four of which encompassed their highest priorities: 1) the relationship between labor and rural community vitality, 2) stewardship of national resources and the environment, 3) enterprise management, and 4) the human and social dimensions of technology.

Labor and Rural Community

Agricultural systems are labor intensive and specialty crops especially rely on migrant labor, all at a time when international migration of labor is constricted and the labor pool is purportedly shrinking. Labor costs and availability are primary concerns. By what means can producers gain greater efficiencies through their workforce? What policies and incentives can provide better access to willing and skilled labor? How can specialty crop producers invest in their local communities through wise decisions on workforce recruitment and retention? Conversely, what are the ethical and development implications for rural communities of replacing low-skill jobs with automation?

Stewardship of Natural Resources and the Environment

The future of specialty crops, and agriculture in general, depends on sustainable management of natural resources and environmental stewardship. What are the good agricultural practices that protect the quality and quantity of scarce water resources, soil fertility and health, and air quality? What conservation policies, incentives, and practices ensure wise stewardship of natural resources and the environment? What are the implications of, and mitigation strategies for, lands threatened by development?

Enterprise Management

In an era of international competition, what market information and global decision support tools are available and how can these best be used? What business models are most effective for specialty crop producers of different size or scale? What business models best support rural quality of life and economic viability of the specialty crop industry? What risk management models work best to reduce the vulnerability of specialty crop producers? How can federal investments and/or financial instruments be designed to best suit the needs of specialty crop producers? What incentives could be introduced for capital growth and reinvestment or to encourage succession plans and new grower entry? What strategies or tools are available to reduce the disconnect between producers and processors and producers and consumers throughout the supply chain? Which technologies are most appropriate to maximize revenue, improve efficiencies in the supply/value chain, and optimize operations? How can land-grant extension services best be supported to ensure their education and outreach role for specialty crops?

The Human and Social Dimensions of Technology

Specialty crop research and outreach will need to deal head-on with the issues and ethics of technology. Social acceptance of biotechnology, nanotechnology, ubiquitous sensors, mechanization, automation, and robotics will require educating society in general about the benefits and risks. Appropriate-scale technologies are needed to address the production needs of small and large specialty crop producers. Indeed the specialty crop industry will contribute new technologies for deployment throughout agriculture, and many small companies are already transforming technologies for the specialty crop industry, not just for production, but for transporting and storing, packaging and marketing. Furthermore, technology may be called upon to reestablish the connections lost between producers and consumers by helping the industry listen to customer needs and "talking their language."

VI EDUCATION AND WORKFORCE

Many Day 1 production issues also surfaced in Day 2 as the top educational challenges: How do you educate students to maintain environmental quality in their future professional employment? What classroom techniques will best convey a systems approach to production management?

Participants generally agreed most major academic institutions do a respectable job of providing rigorous academic instruction in most of the basic core competencies:

- Genetics, plant breeding and health
- Irrigation and waste water management
- Agronomy and crop management

However, less universally covered are topics surrounding personnel management, labor relations, and ergonomics and worker safety issues. These are business operations issues, separate from scientific disciplines that provide fundamental technical knowledge.

What most concerned workshop participants was the need to attract more scientists and engineers into the field and to provide more responsive, local training for the agricultural worker.

Following are some of the issues and barriers discussed to improve education and workforce capacity.

Issue/need/concern	**Priority[a]**	**Barriers**
Need to recruit & retain better educated: • agricultural researchers and engineers, • technicians and tech support, and • field-level workforce	3	Agriculture perceived as low-tech & low wage career Equipment & techniques becoming more sophisticated; requires more training Cultural/social stigma associated with some occupations
Dissemination of educational resources: What has been developed and for whom?	3	Academic institutions often do not share resources within regions; industry not 'one size fits all', no standardization among seminars, workshops, etc.
Cost of education & training	2	Formal education expense; quality training for small, fragmented industries not cost effective

[a] High (3) to low (1)

A two-tier educational system is needed. At the academic, degree-granting level, we need to better differentiate between the type of coursework provided to agricultural technicians and managers (associate-degree level) and agricultural researchers and scientists (baccalaureate and higher). At the field level, we need better training for the agricultural worker. This training needs to be multi-lingual, readily adaptable to changing, local issues, and responsive to specific industries.

VII PROMINENT THEMES

The technologies covered in these breakout sessions are converging in many ways. Sensors, as noted earlier, are necessary components of mechatronics and precision agriculture, and also serve as sources for much of the data used by IT and decision support systems. Autonomous (or controlled) mechatronic systems will provide the sophistication necessary to carry out precision agriculture operations, e.g., targeted delivery of chemicals. IT and decision aides will provide the intellectual glue that will make the other, engineered devices effective, either storing and analyzing collected data, or determining which operations to perform “where” and “when.” Steady advances in science and technology bring with them challenges for growers and processors as they try to keep pace with changing consumer, regulatory, and business demands. While there is much R&D that needs to be done to provide technologies for the industries’ long-term needs, there are many devices and capabilities that currently exist and that remain uncommercialized. In general, the economies of scale are unfavorable in agriculture. So, it may be necessary to apply more general-purpose technologies from other industries in some cases, or to redesign existing technologies for application to a variety of specialty crop industries’ needs, in other cases.

Greater sensor density in the production field, increased use of precision agriculture practices, and enhanced economic decision making will drive production operations from the block (or row) down to the plant level. However, growers will not be able to operate at this level with existing management tools, the volume of data and number of possible decision alternatives will be overwhelming. This burgeoning data stream will not only demand new IT tools, but will require changes in workforce skills, with concomitant changes in educational program offerings.

If the machines that operate in specialty crop production environments of the future will be changing from mechanical to mechatronic systems, it makes sense (and may require) that new cropping architectures and new machines co-evolve simultaneously. This will help ensure that there is a good match between machine and plant capabilities, thereby increasing the efficiency of cultural operations.

While labor issues provide much of the impetus for increased R&D investments, they are not the sole driver. Product quality, characteristics, maturity, and traceability were also mentioned by most of these breakout groups. A changing labor force and new product markets and consumer expectations together will impact how specialty crop industries re-invent themselves, their businesses, their operations, and their place in rural communities.

WORKSHOP AGENDA

Tuesday, April 24

7:30 – 8:00am	Morning beverages
8:00 – 8:15	Welcome, housekeeping, introductions (Factotum)
8:15 – 8:45	Federal agency remarks (Dr. Ed Knipling, ARS Administrator; Dr. Colien Hefferan, CSREES Administrator; Mike Freilich, NASA; Dr. Eduardo Misawa, NSF Program Director)
8:45 (20m each)	Specialty Crop Research Team overview (Dr. Gabriele Ludwig, Almond Board of California)
	Industry introduction and needs: Tree fruits and nuts (Dr. Jim McFerson, WA Tree Fruit Research Commission)
	Industry introduction and needs: Wine and grape (Dr. Nick Dokoozlian, E&J Gallo)
	Industry introduction and needs: Ornamentals (K. Marc Teffeau, American Nursery & Landscape Association)
10:05 – 10:20	BREAK
10:20 (20m each)	Industry introduction and needs: Citrus and subtropical (Dr. Ted Batkin, Citrus Research Board)
	Industry introduction and needs: Berries and brambles (Randy Honcoop, Washington Red Raspberry Commission)
11:00 – 12:00	Breakout discussion by industry (5 groups, see prior industry session)
12:00 – 12:45pm	BOX LUNCH, sans box (sponsors: Almond Board of California, Citrus Research Board, Horticultural Research Institute/American Nursery and Landscape Association, Washington Tree Fruit Research Commission)
12:45 – 1:45	Breakout discussion by industry cont'd
1:45 – 2:45	Breakout reports & discussion (Factotum)
2:45 – 3:00	BREAK
3:00 (20m each)	Engineering capacity: Sensors and sensor networks (Dr. Bryan Chin, Auburn University)
	Engineering capacity: Precision agriculture (Dr. Shrini K. Upadhyaya, University of California-Davis)
	Engineering capacity: Information systems & decision aids (Dr. Edmund Schuster, Massachusetts Institute of Technology)
	Engineering capacity: Automation, robotics, & mechanization (Dr. William "Red" Whittaker, Carnegie Mellon Univ.)

	Engineering capacity: Human, economic, & social dimensions and enterprise (Dr. Robert Seem, Cornell University)
	Engineering capacity: Education and workforce (Dr. Karen Lewis, Washington State University)
5:00pm	ADJOURN

Wednesday, April 25

7:30 – 8:00am	Morning beverages
8:00 (20m each)	Vendor perspective: Derek Morikawa, Vision Robotics Corporation
	Vendor perspective: Dr. David Barrett, Olin College
8:40 – 11:45	Breakout discussion by engineering topic areas (6 groups, see prior day's afternoon plenary session) BREAK available @ 10:00.
11:45 – 1:00pm	BUFFET LUNCH (sponsor: E&J Gallo Winery) with remarks by Dr. Gale Buchanan, REE Undersecretary, and Bruce Knight, MRP Undersecretary
1:00 – 3:00	Breakout reports & discussion, followed by meeting wrap-up and next steps forward (Factotum)
3:00pm	ADJOURN

II CHARGE TO BREAKOUT SESSION ONE

For each of the following areas, what are the most pressing issues, concerns, or problems facing your industry now, or expected to be important in the next ten years? The four areas listed below are explicitly identified only to help stimulate and organize your thinking. Other need areas can be created, if it is helpful for the group. You may create a single list of issues/needs/concerns or organize your list around these need areas.

- Production efficiency
- Product quality
- Environmental footprint
- Post-harvest operations

And, for each of those issues that you list:

- How would you classify it, today, on a priority scale of 1 (lowest) to 3 (highest)?
- How would you label it as a short- (1-3 yr), medium- (3-6 yr), or long-term (6+ yr) issue?

Finally, for each identified issue, are there possible barriers that could impede its resolution? [If time permits]

III CHARGE TO BREAKOUT SESSION TWO

Given the engineering topic area of your breakout group and the industry needs/issues/concerns identified on Day 1, what technologies, knowledge, or capabilities already exist that can help with those identified needs/issues/concerns? [NB: each breakout's engineering topic will probably not be applicable to all Day 1 needs listed] Have there been barriers or limitations to their application, adoption, or use that may have reduced their impact?

Given the engineering topic area of your breakout group and the industry needs/issues/concerns identified on Day 1, what technologies, knowledge, or capabilities must be developed to help with the identified needs/issues/concerns or to fill gaps remaining from the existing capabilities identified in #1? Please classify those future R&D, education/outreach, or application activities on a priority scale of 1 (lowest) to 3 (highest).

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