Globalization and Traceability of Agricultural Production: The Role of Mechanization

by *Francis J. Pierce*

Director, Center for Precision Agricultural Systems
Washington State University
Irrigated Agriculture Research & Extension Center
24106 N. Bunn Road
Prosser, WA 99350
United States
Email: fjpierce@wsu.edu

and Ralph P. Cavalieri

Associate Dean/Director
Agricultural Research Center
Washington State University
P.O. Box 646240
Pullman, WA 99164-6240
United States
Email: cavalieri@wsu.edu

1. Introduction

The topic evolved from the belief that the new trend on traceability of products is related also to an appropriate mechanization and that each machine has to answer to the quality requirements of food needed by the market (Prof. Giuseppe Pellizzi, personal communication, 2002). In this paper, we address the topic of traceability in agriculture and what traceability means to the future of agricultural mechanization with particular reference to the state of agriculture in the U.S. Prof. Paolo De Castro addresses this topic with reference European conditions.

We approach this assignment with the following perspective. Our context will be production agriculture in the U.S., with special reference to irrigated agriculture of high value crops. We will briefly address the "state of agriculture" in the United States because there are many issues beyond traceability that are shaping the future of agriculture in the 21st century and that create new demands for technology and mechanization beyond that needed for traceability. It is our premise that U.S. agriculture in general must reduce the cost of production of the highest quality crop and food products if it is to be competitive in a global market with both global and localized demands on what is produced and how. We then discuss traceability and what that means to U.S. agriculture. Regardless of whether traceability is mandatory or voluntary, it appears that the U.S. must be able to deal with it because consumers will continue to demand it and because it is achievable with current if not emerging technology. We discuss three areas where mechanization can contribute to crop quality and traceability: Automation, quality detection, and tracking. We conclude with a belief that while technological advances to improve quality and traceability of crops and food products are feasible, the degree to which the U.S. can produce the needed advancements in these areas depends on the strength of its research programs in agricultural mechanization and technology development. At this point, the public capacity in the traditional agriculture research institutions in the U.S. is not adequate for the challenge due to lack of funding and national priorities in this area over the last few decades. Gearing up the research capacity for this effort should be a priority for the U.S.

One caveat before we proceed. Nowak (personal communication, 2002) suggests that there are two agricultural systems emerging in the U.S.: the large, commercial, highly mechanized producer and the small, niche market, green label producer often found in the urban fringe. Nowak suggests that the latter group will not need traceability since the market they serve does not demand it and accepts the food they sell because they are "local" or their market pitch sells "trust". Therefore, while our discussion may not pertain well to this agricultural system, it will have relevance if these producers engage in the broader marketplace, particularly the world export market.

2. The State of Agriculture in the United States

Any discussion about mechanization and traceability must begin with an appreciation of the economic environment in which U. S. agriculture must operate. Eastern Washington agriculture experienced a rash of difficulties during 2001 that exemplify the general state of agriculture in the United States. In January, 2001, potatoes were selling for US$ 0.022 per kg, well below the cost of production, largely due to a glut of potatoes on the market. In February, the anticipated drought from lack of snow pack in the mountain ranges of the Pacific Northwest and Southwest Canada caused water districts in Eastern Washington to reduce irrigation supplies to junior water right districts to about one-third of their normal allocation. In some areas of the Pacific Northwest, specifically Kalamath Falls, Oregon, water was completely shut off to hundreds of thousands of acres of irrigated land. Low water levels increased the competition for water resources due to priority water rights for fish in Eastern Washington rivers. The Western United States' electrical energy crisis hit, further reducing water availability and taking hundreds of thousands of acres out of production when the water rights for those lands were purchased by power companies like Bonneville Power Administration. In April and

May 2001, the Bush Administration proposed extending and broadening of the Andean Trade Preferences Act (ATPA), which expired at the end of that year and gives duty free or reduced-rate treatment to the products of Bolivia, Peru, Ecuador and Colombia. Agricultural products arriving from countries covered under earlier version of this Act, such as asparagus, reduced the market price to levels unsustainable to these U.S. industries. The year 2001 was the last year for farmers in select counties in Washington State to meeting strict water quality standards for irrigation in which water leaving a farm field has to be as clean or cleaner than irrigation water entering that field. The U.S. Environmental Protection Agency (EPA) continued their process of removing targeted groups of pesticides from the market, many of which have been essential to pest management in irrigated crops of Eastern Washington. These changes are part of a general move to what are referred to as "soft" crop protection chemicals that are much more selective and allow for the management of beneficial organisms. Finally, apple growers lost money for the third straight year in 2001, resulting in the consolidation of both growers and processors in the tree fruit industry. The year 2002 has the same problems perhaps with a different set of players. This year, drought plagues other regions of the U.S, such as Colorado, which is experiencing the drought of a century and widespread fires.

The long-term outlook for farmers and agribusiness has not been bright for these and many other reasons. Globalization, national policy, environmental accountability, competing uses for water and farmland, frequency and intensity of drought and floods, energy shortages, and overproduction all make farming tenuous. Add to that concerns over food quality and safety, and most recently, homeland security, and it becomes increasingly difficult to select the business model needed for sustainable food and fiber production. The relevant point is that any discussion about the effects of traceability on mechanization cannot ignore the other factors shaping agriculture in the United States.

Solutions proposed to reverse the downward trends in farm profitability in the U.S. take three general tracks: legislative, including farm subsidies and trade protection; increased marketing; and improved competitiveness. The recently passed Farm Bill is record setting in the dollars allocated to farm subsidies in the U.S.; thus, the legislative track is increasing in intensity, although arguably, there are winners and losers here. Increasing markets for farm and food products is generally the favorite of farmers because it fulfills the notion that anything they can produce can be sold. Many would like a return to the scenario that occurred in the early 1970's when grain prices quadrupled and farmers were encouraged to farm "fence row to fence row" [1]. Improving competitiveness involves a preference for our products over others. While very desirable, this is the most difficult track for agriculture largely because it involves improving quality while at the same time reducing the cost of production and requires strict attention to consumer preference, which is often illusive and constantly changing. Traceability is important here because product differentiation and branding foster competitiveness and require traceability and/or identity preservation. However, there is more to competitiveness than traceability.

Consider the apple industry in the United States which has declined in recent years due to issues discussed previously. Until the last two years, apple growers were not receiving direct payments from the Federal government that several commodities enjoy. While accepted by growers as short term aid, for the most part, apple growers do not want to take this track in the long-term. Marketing has been and will continue to be an integral part of the apple industry and is well supported by industry dollars. However, after three years of losing money, this industry has realized that marketing alone cannot sustain profitability. The fact is that globalization has made it possible for others in the world to produce apples at lower prices and levels of quality that are adequate to compete with U. S. apples. The U. S. apple industry now realizes that it must increase it's competitiveness in global and domestic markets by offering the highest quality apple at an affordable price. While simple in concept, this is difficult to achieve for two reasons. The cost of apple production has and continues to increase while retail price and total consumption remain flat; and, secondly, consumer preferences have changed more rapidly than the industry's products have changed.

To this the tree fruit industry in Washington has responded by developing a "Technology Roadmap for Tree Fruit Production" (www.treefruitresearch.com) which outlines the research and development program needed to attain their stated vision: "For the tree fruit industry in the Pacific Northwest to be globally competitive, it must reduce the cost of production of the highest quality fruit by 30% by 2010". The underlying notion here is that Washington apples can compete in the global market if they are of high quality and are affordable even if retail costs for their applies exceed the competition. This belief is held because, when done well, the unique growing conditions of apple growing areas produce fruit of exceptional quality found in few other places in the world. The details of the roadmap can be found in the documents available on the web site. What's important to this discussion is that the key to achieving the roadmap's vision is technological innovations that lead to automation in orchard and packing operations, highly efficient and effective orchard management systems, intensive and site-specific information systems from field to market (including identity preservation for market differentiation), and value-added throughout the production and packing operations. A major target here is worker productivity and safety, both large costs in apple production and packing. Of significant importance is optimizing orchard management since various management practices have direct impacts on product quality.

Certainly, there are many new opportunities available now and forthcoming in niche and differentiated crops in the U.S. In some cases, there exist significant infrastructure limitations to what farmers can actually achieve. One such case is the opportunity for marketing wheat based on quality (e.g., protein content). Basically, certain markets, for example, Japan, are seeking wheat with specific protein ranges and will pay a premium for wheat with guaranteed quality. The problem for wheat growers is twofold: wheat proteins varies within fields and from year to year and there are constraints within the harvest operation to separate and segregate wheat in the combine and in segregation in grain storage and transport, at least at the local level. With current technologies, wheat farmers suggests that while the premium is desirable, they are unable to extract that premium given current equipment and infrastructure.

It appears that the forces acting on agriculture discussed above – globalization of markets, national trade policies, environmental quality concerns, climate change, and consumer preference (including traceability) – will continue to shape U. S. agriculture. Efforts to counterbalance these forces and fortify U. S. agriculture – farm subsidies, country of origin labeling, trade protection – will also continue. Some predict that this situation will inevitably lead to an even more dramatic decline in agricultural production in the U.S., with food production relegated to other nations that can produce food more cheaply than us. Blank [2], in his book entitled "The end of agriculture in the American portfolio", argues that technological innovations have made it possible for other less developed nations to compete globally. This new competition has reduced prices and created relatively low and static returns on investments in U.S. agriculture over the last quarter-century. Blank [3] states that the average real net return to assets in U.S. agriculture has been negative every year since 1994, was -3.8 percent in 1999 and that "farmers could do better just depositing their money in the bank". In reality, over the last 25 years, the retail cost index has remained relatively flat while the farm value index has fallen remarkably, leading Duffy [1] to conclude that it does not appear that in the United States the primary beneficiary of future technological change would quite likely be agribusiness firms. In Blank's [3] view, the fact is that prices are falling faster than are costs per unit of production and unless future technologies can reverse this trend, American producers will continue being forced to make the investment decision to leave commodity markets and, ultimately, the industry.

While Blank [3] portrays the end of agriculture in the American portfolio, he does leave open the possibility that future technologies might reverse this trend. Others take the view that technological innovation is in fact the way the U.S. can compete globally. While Friedman [4] agrees that technology created globalization, he believes that it is technology that will allow the U.S. to compete in a global market place. He postulates that there is no other country better poised to compete with technology than the U.S. In traceability issues, like non-GMO foods, rather than view this as another lost market, Friedman would view this as another opportunity for technological innovation and suggest that no one is better positioned than the U.S. While the situation for a given farmer or sector of U.S. agriculture may be closer to that postulated by Blank, we subscribe to the Friedman view that technological innovation provides the U.S. with what it needs to be globally competitive. We also subscribe to the general vision of the technology roadmap that to be globally competitive, U.S. agriculture must produce high quality food at an affordable price, recognizing that consumer preference, including the demand for traceability, largely defines food quality.

The general challenge for mechanization is to assist agriculture to manage and/or overcome constraints so that U.S. farmers and food processors are positioned and equipped to effectively compete in global markets. President Bush, in a speech delivered on November 28, 2001 to the national Farm Journal forum, called on Senate leaders to abandon efforts to resurrect old-fashioned crop subsidy programs and urged them to embrace the future by passing farm bill legislation that meets his goal of improving the ability of farmers to compete in a global marketplace. . . Bush suggested increased spending on agricultural research and extension programs to provide American farmers with the highest quality crops and most technologically advanced farm equipment and practices in the world [5]. The 2002 Farm Bill creates record subsidies but also proposes large increases in research and extension.

We draw from this discussion that the best response of U.S. agriculture to the issues facing it is to embrace technology and develop whatever is needed to be globally competitive. Such an effort is non-trivial and it suggests a significant role for mechanization. We next explore the issue of traceability to explore ways in which mechanization can contribute to a world of "traceability" in agriculture.

3. Traceability

Traceability is "the ability to track the history, deployment or location of an entity (for example a plant, animal or food-stuff) by means of recorded identifiers" [6]. Essentially, traceability systems are systematic record keeping systems and are used primarily to keep foods with different attributes separate from one another either by physical segregation or by identity preservation (IP) [7]. Thus, IP is a system of production and delivery in which the grain is segregated based on intrinsic characteristics (such as variety or production process) during all stages of production, storage and transportation [8]. Traceability is closely linked to product identity but IP can also relate to the origin of materials and parts, product processing history, and the distribution and location of the product after delivery [9]. The recordkeeping, segregation, and "all stages of production, storage, and transportation" dimensions of IP systems immediately suggest an important role of mechanization in traceability since they all involve mechanization to some extent.

Golan et al. [7] suggest that the purpose of IP is to guarantee that certain traits or qualities (the source and nature of the crop or food stuff) are maintained throughout the food supply chain for purposes of: (1) product differentiation and marketing of foods with undetectable or subtle quality attributes, (2) to ensure food safety and quality, and (3) to improve supply side management, for example, to improve management of production flows and tracking retail activities. The upside of traceability is the opportunity it presents for increased value at various places along the food chain - from genetics to crop production to food processing to marketing and to retail. For example, Tastemark™ is a unique marketing program designed to provide the consumer with the same recognizable taste guaranteed across all fruit and produce types (www.tastemark.com). The program is based on a technology developed by Taste Technologies Ltd in New Zealand that provides for high speed, non-invasive, online Brix (soluble solids) sorting system using near infrared spectroscopy. The guarantee is sweet fruit and the key is providing consumer value through the guarantee and the brand. The system has been in use for at least two years in a few fruit packing operations in the U.S. This trademark system, under the Tastemark™ brand, guarantees one aspect of fruit quality to the consumer for a premium price, adding value to both the packer and the grower. Labeling is increasingly used to meet consumer demand and is exemplified by the organic food industry in the U.S.

The downside of traceability is its use as a requirement to compete in the marketplace. The most notable example is the mandatory tracking of genetically engineered crops and food proposed by the European Union (EU) to distinguish them from conventional foods. There is considerable resistance in the U.S. regarding the mandatory tracking of genetically engineered crops and food, with Golan et al. [7] arguing that it "is *not* among the practical or efficient uses of traceability", proposing performance standards as a better solution. The United States government believes product tracing should be required, if at all, for food safety purposes only [9]. Regardless of whether traceability is mandatory or not, the demand for non-GMO product markets has grown at rapid rates such that certain markets, like Europe, require them. Thus, the willingness to provide non-GMO products has grown and adjustments are being made to meet traceability requirements. Take for example the efforts at identity preservation in soybean production and processing as reported by Wijeratne's [10] who writes:

> *"The need and opportunity for identity preservation in oilseed processing" derives from the fact that "the conventional technology for vegetable oil production . . . . . evolved on the basis that refined vegetable oils from different sources become similar in appearance, smell and taste. The advantage is that they can be blended at will to derive desired functional characteristics in food applications. The disadvantage is that oils lose their identity upon refining and blending. The structure of the traditional oil extraction and refining industry does not lend itself to identity preservation in processing. . . . . . The Industry has responded to the economic opportunity of identity preservation during oilseed processing by developing a non-solvent system for oil extraction" that "can be decentralized and operated on a relatively small scale" and is "complimented by small scale oil refineries that match the extraction rates of the small non-solvent systems. . . . . . This concept has provided a total value adding opportunity to soybean with a relatively simple technology that can be practiced at the rural level."*

This new method of extraction (called the ExPress® System) had been established in 60 installations in the Mid Western United States at the time of Wijeratne's [10] assessment.

The previous example demonstrates that innovation can be key to implementing traceability. There are, however, more subtle issues associated with traceability. In reality, what may have emerged as a product differentiation opportunity producing added value to farmers, processors, and wholesalers, can evolve over time into an industry standard, and as such, become a requirement rather than a premium as originally envision. The expectation is that the Tastemark™ system may change the market permanently and no fruit will sell without it or some equivalent consumer guarantee. Those who innovate can pay for the conversion costs with the premiums received early in the adoption of the new technology; those who delay until the technology is required must absorb those costs as part of their capital budget outlay. This evolution is to be expected and clearly illustrates the dynamic nature of traceability issues.

One additional aspect of traceability that further complicates its implementation is that often the quality attributes of importance to the consumer are qualitative in that attribute testing is not possible. Golan et al. [7] refer to these attributes as credence attributes and offer some insights into their properties and how they affect traceability as follows. When quality attributes are easily detected, like specific colors and shapes, traceability is not required to evaluate food quality. However, quality differences that involve credence attributes, ones that are difficult to discern even after consumption of the product, generally require IP and traceability systems to establish market credibility. Credence attributes involve either a change in the content of the product which is difficult for the consumer to discern (e.g., a change in nutrient content) or involve a characteristic of the production process which cannot be discerned by the consumer or by specialized testing equipment (e.g., organically grown). With credence attributes, product differentiation must be achieved by segregation of production lines, by intensive tracking and/or through the services of third party entities (ISO, ANSI, government agencies) that provide such things as standards, testing, quality assurance, certification and inspection. Products with credence attributes as their source of differentiation must establish market credibility either by making it or buying it from third parties.

Whether traceability is economical depends on many factors but is certain to involve consumer preference and their willingness to pay for value added beyond conventional foods. Traceability and IP may be necessary to create new market opportunities or to even sell in markets where traceability is mandated as is proposed by the European Union. A traceability system will likely add to the costs of food products and must produce benefits that justify them if they are to be of value to agricultural producers and affordable to the consumer. For farmers and food processors, the value in traceability is found in areas where consumers are willing to pay, particularly differentiated products and improved food quality and safety, and where traceability improves supply side management, the three motives for traceability suggested by Golan et al. [7]. Of great importance is the issue of how the desired quality attributes for traceability are created, acquired, recorded, and, perhaps most importantly, assured. Furthermore, it is critical to the economics of traceability to find ways to minimize traceability costs while maximizing the benefits of achieving it. The situation gets even better if traceability offers collateral benefits to other aspects of food production.

Given the nature of traceability systems and the fact that segregation and identity preservation involve "all stages of production, storage and transportation" the role of mechanization in traceability seems intuitive. We believe that mechanization is critical to the success of traceability and is essential to the future of agricultural production relative to the issues facing U.S. agriculture outlined above.

3. Food Quality, Traceability and Mechanization

We envision three major areas where mechanization can contribute to quality and traceability in crop production, handling, and processing: Automation, quality detection, and tracking. We will couch this discussion in terms of tree fruit production and packing but the general principles discussed here apply broadly to production and processing of crops and food products.

3.1. Automation

Labor alone will not be able to achieve crop quality and traceability standards needed for U.S. agriculture to be globally competitive. Many U.S. industries have turned to automation as a means to achieve global competitiveness. The automobile and steel industries are good examples of U.S. business sectors that needed to improve product quality and achieve it at an affordable price in order to compete globally. These industries turned to automation because it offered a means to control the manufacturing process to ensure product quality while at the same time reduce labor costs that were higher than their competitors and continually increasing. The situation is much the same for agriculture today but the major issues – labor (shortage of willing and qualified workers, worker productivity, and worker health and safety) and product quality and safety, including traceability – may be more intense for agriculture than it was for other industries who dealt with these issues decades ago. Of significance here is the U.S. domestic policy in place since 1979 that excluded federal funding of any research that reduced the labor force in agriculture. The result of that policy was the demise of public research and development in mechanization particularly in such areas as mechanical harvesting. While that national policy was recently (February 2001) reversed, it will take a considerable effort to gear up government sponsored research in mechanization to return to the needed level of effort.

What's needed are machines that (1) reduce labor costs by either replacing labor or by increasing the productivity of the workforce by assisting workers to improve their efficiency, remove workers from harmful or repetitive tasks, and reduce worker exposure to undesirable materials; and (2) are capable of doing things to enhance crop quality that were not previously possible. Labor is the orchardist's greatest cost and improving labor productivity, health, and safety represents a major opportunity for reducing fruit production and processing costs. Furthermore, quality improvement in fruit production will require a better trained workforce that may not be available to meet the labor needs in the orchard. Envisioned here are robotic tractors for mowing, spraying, thinning, pruning, etc., all tasks that now require extensive labor, machines capable of assessing crop and soil conditions and adding inputs accordingly, and machines that can harvest and process fruit based on quality attributes desired by consumers.

Considerable progress has been made recently on robotic and auto-guidance/control tractors. John Deere publicly presented its driverless orchard tractor in 2001 that can safely apply chemicals without operator assistance but it is not clear when these will be available for commercial use. Auto-guidance systems are available from Bee Line of Australia and Trimble of the U.S. that provide very precise positioning and tractor guidance and research continues [11]. An operator is still required with these guidance systems but applications are being developed that allow a single operator to utilize more than one vehicle simultaneously using automatic following vehicle systems [12]. Reid and Niebuhr [13] report that automated vehicle navigation may be the next revolution in agricultural production; however, machine safety and machine function sensing (e.g., edge detection, locating and dealing with obstacles) continue to pose barriers for implementing autonomous technologies and therefore remains a research priority.

Even without automated vehicles, there are many opportunities for automation of production and processing practices, including tree specific fertility and pesticide applications based on real-time sensing of tree condition [14]. An important area of mechanization for tree fruit is mechanical harvesting, although the needs are different for fruit grown for processing than that grown for fresh market. Tree fruit is still picked primarily by hand and, with labor shortages and increasing wages, at increasingly greater cost. Mechanical harvesting is generally available only for tree fruit harvested for processing (e.g., citrus grown for juice) and generally consists of shake and catch systems which are limited in use for fresh fruit because of excessive damage to the fruit [15]. Fruit picked for fresh market can be harvested using a shake and catch system, but systems such as the new cherry harvester developed by Peterson and Wolford [16] requires new approaches to marketing. The cherry harvester requires the use of an abscission-promoting chemical to reduce the fruit retention force of mature cherries to enable removal without stems and damage. However, a market for stemless cherries did not exist until efforts focused on making stemless cherries acceptable to consumers. Robotics makes pick and place harvest systems possible and while progress is being made [17], no economical systems are available commercially.

While mechanical harvesting is desired because of reduced labor costs, harvest automation is also desirable because it offers the opportunity to value add during the harvest operation. One opportunity is the exclusion of cull fruit from harvest bins sent to the packing house. The industry average for percent culls (fruit that does not meet fresh market quality standards) is approximately 25% (David Allen, personal communication, 2001). Cull fruit is removed from packing and processed mostly for juice. The bottom line is that the cost of cull fruit in the packing house exceeds its market value and that cost is charged to the grower creating a negative to cash flow to them. The point is that anything done in the field to assure that only quality fruit is placed into bins that are sent to the packing house (the notion of selective harvest) increases the profitability of the grower and the packer. Machinery that automate tasks in the orchard can, along with detection, separation, and tracking functions discussed below, improve fruit quality, assure it, and reduce costs, thereby achieving the goal to be globally competitive. Thus, the smart mechanization of selective harvesting will lead to improved quality. Compare this with the mechanized harvesting of tomatoes which required the development of a uniformly ripening tomato that could stand up to the rigors of mechanized harvesting.

The mechanical and electronic systems of those days were not capable of making the selection necessary to take advantage of multiple pass harvesting – of course, for salsa and other processed tomato products, there probably isn't the price premium for doing other than they are currently doing.

3.2 Quality Detection

The appeal of quality detection as part of mechanization is that a machine has access to the crop or food product at a time when a management decision can be made that either affects quality or leads to the segregation of the crop or food product in a timely and efficient manner. In a cereal grain crop, for example, knowing early in its life cycle that the crop is short of nitrogen creates the opportunity to add fertilizer to optimize grain protein. Knowing at harvest that the grain passing through the combine varies in quality, such as the presence of a toxin, protein content, or test weight, makes it possible to separate the grain according to grain quality and is desirable if doing so increases its value. Fruit is often thinned to ensure a given size or quality. If quality attributes of immature fruit could be detected, then automated thinning machines could remove the fruit with the poorest potential thereby optimizing fruit quality. At harvest, the ability to detect soluble solid content (Brix), skin defects, or internal disorders, would allow growers to separate cull fruit and send only quality fruit to the packing house. Quality detection and sorting is performed in the packing house but is not currently done in the orchard.

Quality detection remains an important issue in post harvest research and these techniques offer potential applications in quality detection associated with agricultural machinery. In the future, crop quality tests will deal with physical quality attributes (color, texture, shape), internal (chemical) quality parameters (soluble solids, flavor components) and perhaps, nutritional parameters (nutraceutical content, vitamin contents). Testing may even get to the point where the DNA content is analyzed to verify such things as variety or GMO status. Incorporation of quality detection as part of an automated harvest system would be desirable if it could be done economically. The notion here is that whenever quality detection occurs in the field or as early as possible, the more likely quality can be assured and costs reduced.

Emerging technologies, like biosensors and nanotechnologies, offer new possibilities for quality detection. New biosensors are being developed that in principle consist of small computer chips designed to change properties when exposed to specific chemicals which can be detected remotely. For example, scientists at Sandia National Laboratories, Albuquerque, NM are developing a real-time sensor based on a chemiresistor [18]. The principles of this technology were reported as follows:

> *"a chemiresistor is an array of miniature, polymer-based sensors, each of which responds to a particular VOC (volatile organic compound). The*

> *sensors are made by mixing a commercial polymer, dissolved in a solvent, with conductive carbon particles. The fluid is deposited and dried on wire-like electrodes on a specially designed microfabricated circuit. . . . . In the presence of VOCs, the polymers absorb the chemicals and swell up. This swelling changes the electrical resistance in proportion to the chemical vapor concentration, which can thus be measured and recorded. When the chemical is removed, the polymers shrink and their resistance returns to its original state. The array can be used to identify different VOCs by comparing the resulting chemical signatures with those of known samples." [18].*

The appeal of biosensors in agriculture would be that they can be mass produced at sufficiently low cost that they can be spread throughout a crop. The function of machines may be to place, measure, and/or retrieve biosensors as part of their normal field operations.

Quality detection at specific points in the production and processing of crops will be critical to assuring quality and is a prerequisite to quality separation and tracking. Many quality sensors are available during post harvest but will need to be redesigned if they are to be economical for use in the field. Nanotechnologies and biosensors may be important if they can be produced at low costs. The access of machinery to the crop during production and post harvest makes it critical that machinery detection systems be incorporated into their design.

3.3 Tracking

Traceability involves physical segregation or the preservation of identity (IP) and requires intensive record keeping. Since machinery is involved in many phases of food production and processing, intelligent machines that can acquire, process, store and transmit data on operations will be required. The technologies and principles of precision agriculture are well suited to meet the needs of tracking for traceability [19,20]. However, agricultural technologies can be inadequate because they often are too expensive, unavailable in rural areas, too application specific, and/or difficult to implement. Therefore, affordability and interoperability are important considerations in any tracking system. Computer speed, storage capacity, and miniaturization are more than adequate for this task and continue to improve. Emerging technologies include high speed wireless internet, radio telemetry, and radio frequency tags (RFID) will make data acquisition and data management effortless. Wireless technologies are also advancing automation [21] and quality detection as discussed earlier. Read/write RFID technologies are capable of making supply chain and asset management seamless from field to the table. There appear to be few technological limitations for tracking crop and food quality. Costs and lack of standards for interoperability may limit progress unless these are considered in the design of tracking systems.

4.0 Summary and Conclusions

Many factors are shaping the future of agriculture in the U.S. and beyond and the effects of a single factor, like traceability, are difficult to assess alone. Given the state of agriculture, to be globally competitive, U.S. agriculture must produce the highest quality food at affordable prices, a task other business sectors have faced decades ago. Traceability, whether mandatory or voluntary, appears to be inevitable because consumers demand it and because it is possible to achieve. We believe that the appropriate response to these challenges is technological innovation that improves crop quality and reduces the cost of production. To achieve this, machinery of the future must be increasingly automated, capable of detecting crop quality at various points in the production and processing system, and fully equipped for tracking information about the crop from field to the table. Current efforts in agricultural automation - robotics, guidance, and mechanical harvest – are on the right track but are inadequate; they need more investment from government and private industry to make needed advancements. The public agricultural research programs in the U.S., consisting primarily of the USDA and Land-grant universities, no longer have the cadre of scientists and programs it once had working on mechanization. Either these public sector research programs have to be strengthened or the private sector has to fill in the gap if agriculture is to embrace technology as a primary means of attaining global competitiveness. Crop quality detection will benefit greatly from emerging nanotechnologies and biosensors but efforts to adapt current and future sensors to machines at affordable costs are critical. Equipping machines with tracking capabilities needed for traceability should be technologically feasible but efforts to make tracking systems affordable and interoperable will be the challenge. Smart machines with these capabilities will be increasingly important for U.S. agriculture to compete globally and to meet the needs of consumers for a safe and high quality food supply. However, to get there will require significant public and private sector investment in research and development that is not currently available.

5.0 References

[1] Duffy P.A., 2001. Casting bread upon the water: Comments on technology, globalization and agriculture. J. Agric. Appl. Econ **33**, 2, 341-247.

[2] Blank S.C., 1998. The end of agriculture in the American portfolio. Quorum Books, Westport, Conn.

[3] Blank S.C., 2001. Globalization, cropping choices and profitability in American Agriculture. J. Agric. Applied Econ. **33**,3, 315-326.

[4] Friedman T.L., 2000. The lexus and the olive tree. Anchor Books, New York.

[5] Merriman E., 2001. Bush, Veneman urge Senate leaders to get on track with farm bill, economic stimulus. Capital Press, Friday, November 20, 2001.

[6] ISO, 2002. ISO 8402. www.isocenter.com.

[7] Golan E., Barry K., Kuchler F., 2002. Traceability for food marketing & food safety: What's the next step. p. 21-25. Agricultural Outlook, January/February, 2002. Economic Research Service, USDA.

[8] Rial T , 1999. Containerized oil seed, grain, and grain co-products exports (An assessment for the shipper & exporter assistance program). Des Moines, IA (as cited by Reichert, H.,Vachal, K., 2000. Identity preserved grain: Logistics overview).

[9] Clapp S., 2002. A brief history of traceability. CRC Press/FCN Publishing. Washington, D.C Clapp S., 2002. A brief history of traceability. CRC Press/FCN Publishing. Washington, D.C.

[10] Wijeratne W. B., 2002. Identity Preservation in Soybean Production and Processing. www.insta-procom.

[11] Noguchi N., Reid J.F., Zhang Q., Will J.D., Ishii K., 2001. Development of robot tractor based on RTK-GPS and gyroscope. Paper number 011195, 2001 ASAE Annual Meeting.

[12] Matsuura, K., Iida M., Umeda M., Ono K., 2001. Automatic following vehicle system. Paper number 011164, 2001 ASAE Annual Meeting.

[13] Reid J. F., Niebuhr D. G., 2001. Driverless tractors: Automated vehicle navigation becomes reality for production agriculture. p. 7-8. Resource. September, 2001. ASAE, St. Joseph, MI.

[14] Whitney J.D., Miller W.M., Wheaton T.A., Salyani M., Schueller J.K., 1999. Precision farming applications in Florida citrus. Appl. Eng. Agr. **15**(5): 399-403.

[15] Sarig Y., 1993. Robotics of fruit harvesting: A state-of-the-art review. J. Agric Eng. Res., **54,** 265-280.

[16] Peterson D.L., Wolford S.D., 2001. Mechanical harvester for fresh market quality stemless sweet cherries. Transactions of the ASAE. Vol. **44**(3):481–485.

[17] Bulanon D.M., Kataoka T, Zhang S, Ota Y, Hiroma T., 2001. Optimal thresholding for the automatic recognition of apple fruits. Paper number 013133, 2001 ASAE Annual Meeting.

[18] Sensors, 2002. Soil and groundwater chemical sniffer may help protect nation's water supply. January, 2002. Vol. **19**, No. 1.

[19] NRC, 1997. Precision Agriculture in the 21st Century: Geospatial and Information Technologies in Crop Management". National Academy Press, Washington, D.C.

[20] Pierce F.J., Nowak P., 1999. Aspects of precision agriculture. Adv. in Agron. 67:1-85.

[21] Hirakawa A. R., Saraiva A. M. , Cugnasca C. E., 2002. Wireless robust robot for agricultural applications . p. 414-420. In: Proceedings of the World Congress of Computers in Agriculture and Natural Resources (13-15, March 2002, Iguacu Falls, Brazil.