

Overview of Nanotechnology and Other Technologies

Modern agriculture is developing an entire new toolbox of equipment and methodologies to improve and increase crop production. Margaret Smith, professor of plant breeding and genetics at Cornell University commented in an interview with Fox News, “We’re facing increasing stresses from more erratic weather and new and different pests that move in. I think in that regard we’re going to need every possible tool we can get to help make our crops as productive as they possibly can be.”¹ How and what tools are incorporated will impact the future of our food production. Just like other industries, agriculture will draw on biotechnology, chemistry, engineering and computer sciences to move ahead. Some examples have already been discussed in other Agriculture Update papers.

This section gives a brief overview of some of the latest technologies that are being incorporated into modern agriculture and food production.

Nanotechnology

What is Nanotechnology?

The definition provided by the Royal Society/Royal Academy of Engineering Working Group on the subject is:

- “Nanoscience is the study of phenomena and manipulation of materials at atomic, molecular and macromolecular scales, where properties differ significantly from those at larger scale.
- Nanotechnologies are the design, characterization, production and application of structures, devices and systems by controlling shape and size at nanometre (sic) scale.”²

Nanotechnology is a process that builds, controls and restructures materials that are the size of atoms and molecules. A nanometer (nm) is one-billionth of a meter. (In a more familiar frame of reference, a sheet of paper is about 100,000 nanometers thick; a human hair is approximately 80,000- 100,000 nanometers wide. See this chart http://www.engineeringtoolbox.com/particle-sizes-d_934.html to help in understanding the nanometer scale. One micron is 1,000 nanometers. Nanoparticles tend to be less than 100nm.³ The small size of the nanoparticles gives them a structure with a large surface area in proportion to size. The larger surface creates unique response characteristics (for example increased reactivity or intensified color or flavor).⁴

At present:

There is no “official” definition of “nanotechnology” at FDA:

FDA draft guidance document (June 2011): “Considering whether an FDA-regulated product involves the application of nanotechnology” identifies 2 criteria for assessing the use of nanotechnology in FDA-regulated products:

- 1. Whether an engineered material or end product has at least one dimension in the nanoscale range (approximately 1 nm to 100 nm); or*
- 2. Whether an engineered material or end product exhibits properties or phenomena, including physical or chemical properties or biological effects, that are attributable to its dimension(s), even if these dimensions fall outside the nanoscale range, up to one micrometer.⁵*

Uses of Nanotechnology

Nanoparticles have always existed in nature (examples include particulate clay and ash and biological nanoparticles such as exosomes), but their unique characteristics have only recently been studied and used in science and engineering. Researchers are now studying uses for existing nanoparticles and using technologies to produce new nanoparticles.⁶ “By 2020, the increasing integration of nanoscale science and engineering knowledge and of nanosystems promises mass applications of nanotechnology in industry, medicine, and computing, and in better comprehension and conservation of nature.”⁷

As of 2013, over 1600 commercially available products contain nanomaterials.^{8,9,10} Some examples of newly developed products include a stain repellent in clothing, material to extract toxics from water, sunscreens to absorb light, and a barrier in packaging such as beer bottles (producing a lighter weight bottle with longer shelf life.)¹¹

Research is underway for a variety of future uses in agriculture production such as 1) precision farming—acting as sensors that are distributed in the field and linked through GPS to detect soil conditions, insects or presence of disease; 2) smart delivery systems, delivering chemicals in a controlled, targeted manner, to address a problem such as disease, nutrient deficiency, or insects even before the farmer can visually detect a problem; and 3) water filtration.¹² Researchers report that “so-called multiwalled carbon nanotubes (MWCNTs)” can penetrate through the thick coatings on seeds, stimulate germination of the seeds and stimulate the growth of certain plants.¹³

Within the food industry, nanosensors incorporated into packaging can be used to detect spoilage or act as preservative (initial development is underway). In the future nanotechnology may be used to control release of color or nutrients in foods based on the consumer’s preference. In some instances, food additives in current use may contain nanoparticles in part as the result of varying sizes of powdered components, for example titanium dioxide, an approved coloring and anticaking additive frequently used in sugar products.^{14,15} With growing awareness of nanomaterials there is concern that the potential risks of nano titanium dioxide both in food and in the manufacturing plant need to be better evaluated.¹⁶ An excellent chart that summarizes the uses of nanotechnology in food and agriculture is found in the publication, “FAO/WHO Expert

meeting on the application of nanotechnologies in the food and agriculture sectors: potential food safety implications: Meeting report.”¹⁷

Safety and Regulation of Nanotechnology

There is agreement that this technology may be important in the future; however, with the rapid expansion of research and development of new uses, questions as to safety and potential toxicity from these products need to be addressed as soon as possible. The risks include the ability of the particles to cross the blood-brain, dermal, placental and other barriers, potential impacts on biological systems and control and tracking of the particles.^{18,19,20} For example a recent study from the University of Missouri indicates that silver particles used as pesticide in treatment of pears, can be retained on the pear surface and penetrate into the pulp, and could potentially be taken into the human body. Whether or not these could be toxic is not yet known.²¹ Other concerns include effects in the environment on soil organisms and insects.²² Both industry and the public are seeking to have rules and guidance to address health and safety concerns.

The National Nanotechnology Initiative (NNI) is a collaborative, multi-agency, cross-cutting program among 25 federal agencies, 15 of which have specific nanotechnology budgets: R&D funds for research to advance understanding and control of matter at nanoscale with a goal of “national economic benefit, national and homeland security, improved quality of life.”^{23,24} The NNI’s 2010 research budget totaled an estimated \$1.78 billion. About 5% of that was devoted to environmental, health, and safety research, with the rest going toward things like basic research into nanomaterial behavior, research facilities, and developing nanoscale devices and systems.²⁵ Through this initiative governmental organizations have combined funding and are exchanging information.

The EPA is in the process of developing rules and guidance.^{26,27}

General rules and legislation with regard to the FDA oversight of technology are discussed in the Food and Drug Administration paper of this Agriculture Update. The FDA issued a draft Guidance for Industry in April 2012. The guidance, although not binding, at present outlines the following approaches to industry that will be consistent with FDA decision-making:²⁸

FDA is maintaining its product-focused, science-based regulatory policy.

FDA’s approach respects variations in legal standards for different product-classes.

- *Where premarket review authority exists, attention to nanomaterials is being incorporated into standing procedures.*
- *Where statutory authority does not provide for premarket review, consultation is encouraged to reduce the risk of unintended harm to human or animal health.*
- *FDA will continue post-market monitoring.*
 - *Industry remains responsible for ensuring that its products meet all applicable legal requirements, including safety standards.*

- *FDA will collaborate, as appropriate, with domestic and international counterparts on regulatory policy issues.*
- *Both for products that are not subject to premarket review and those that are, FDA will offer technical advice and guidance, as needed, to help industry meet its regulatory and statutory obligations.²⁹*

As of October 2013, a final United States regulatory policy on Nanotechnology had not been developed and both industry and the public are concerned. A Report to the European Commission looking at the need for strong public policy suggests:

It has been difficult to identify products manufactured with the use of nanotechnologies and, due to a lack of knowledge, it is also difficult to judge the current benefits of nanotechnologies. Policy instruments must be used to balance the two ends of the scale: economic value (potential benefits, the replacement of scarce raw materials, stakeholder interests, new job creation) balanced against 'acceptable' risks (hazard and exposure assessment, risk behaviour, uncertainties). However, a simple weighing up of the pros and cons is not possible. Taking the precautionary approach seriously is an essential but difficult task. Accepting precautionary measures (which are perhaps comparable with preventive measures) might be problematic for many companies. Initiatives such as voluntary codes of conduct may be helpful guides, but the view of trade unions and NGOs is that these types of voluntary systems cannot replace binding legislation.³⁰

Throughout the literature, those involved in studying nanotechnology and its impact have stressed the need for transparency in research, use and labeling and the need to provide public involvement and education.³¹

Other Technologies

There are many other evolving technologies that are having an impact on agriculture.

New More Efficient Agriculture Equipment

Modern tractors and harvesters are more fuel-efficient and emit less particulate matter and nitrous oxide and yet are more productive than equipment sold as recently as 2000. Planting equipment is improving, allowing for narrower rows and more selective seed planting, and less soil compaction. The number of required passes by machinery is reduced by planting equipment designed to penetrate crop residue. Reduced tillage means less soil erosion, improved soil tilth, conservation of water, reduced carbon emissions and lower costs for fuel and labor.³² The cost of these tools can be prohibitive to smaller farming operations.

Modern technology is allowing farmers to use engineering design to develop methods of combating pesticide problems. In Australia, farmers have developed several systems for addressing a problem with rye grass weeds invading wheat fields. Machinery has been adapted to capture the seed and chaff at harvest and then burn the chaff after completing harvest. More

recently a mining crusher has been adapted to crush the captured seeds (early test show this to be 95% effective).³³

Light Resources

Agriculture is dependent on light for the photosynthesis process. Mediterranean and desert climates provide an ideal lighting situation with long days for growth. Unfortunately these climates also tend to be short on water. New greenhouse and vertical farming techniques are being developed using artificial light. The development of LED light sources allows a combination of light that encourages photosynthesis.³⁴ These methods are being applied to standard greenhouses and in urban vertical farming. Dutch engineers are growing plants using artificial light and carefully metered water. The controlled environment eliminates many disease, insect and weed problems. However, questions need to be answered about the nutrition quality and the required input of energy.³⁵

Biofactories

Biotech companies are now beginning to create new organisms that can be programmed with the capacity to manufacture chemicals that exactly duplicate ones that are now extracted from plant sources. The new methods use mostly GE yeast that can convert sugar to medicine, create biofuels and other products. A Swiss company Evolva has created a vanilla flavoring that duplicates the natural flavor extracted from farmed vanilla beans. The US Defense Advanced Research Project Agency (DARPA) has initiated a program called “Living Foundries” that has provided grants to encourage industrial research intended to design living organisms that (in a factory setting) synthesize materials we currently cannot manufacture.³⁶ In the future these new manufactured products may impact agriculture and food in many ways.

Energy Resources

“Twelve percent of global greenhouse gas emissions come from agriculture, and six to nine percent of farm expenses are energy related.”³⁷

Farmers have long used wind power to pump water and generate electricity. Recently farmers have added wind turbines to their farm and are using more energy from this source. Farmers are also taking advantage of solar power and biomass energy. These three techniques may reduce the energy costs of farming while allowing all types of farmers to more efficiently produce crops.³⁸

Biofuels are liquid transportation fuels that substitute for petroleum products such as gasoline or diesel. They include ethanol and biodiesel (from oil products). These products can provide an income stream for the farmer and can be used on site to save on energy costs.³⁹ However those produced from crops use acreage and energy that might otherwise be used to produce food.

Anaerobic manure digesters collect manure and convert it to methane that can be used as energy for farm operation or for sale. The added benefit is the protection of water from pollution that can occur as the result to overflow or leakage in manure from lagoons or runoff of field manure.⁴⁰

Use of Satellites, GPS and Computers

Modern agriculture takes advantage of all the latest communication tools. Satellites can be used to monitor field conditions, identifying the health and maturity of crops, and provide early warning of crop failure or famine. In combination with the Global Positioning System (GPS), satellites can provide detailed information on farm fields that can be used for more intense and efficient cultivation practices.⁴¹

Linked with GPS and satellites, computers can control field operation from monitoring irrigation tracking soil nutrients to forecasting weather conditions and predicting yields.

In Summary

Adopting new technologies is part of farm operations. Farmers make these decisions based on their specific circumstances. New technologies require an investment in both labor and capital. Farmers need to know the value of the investment. Obvious technologies that tend to provide small but sure gains at limited cost are adopted quickly. Less obvious technologies take time to be adopted because of many factors including education, costs, labor requirements, and a slower rate of return. Farmers need to evaluate technology based on what they can gain from it, and look at all ideas – even those that seem to be luxuries.⁴²

Recommended Readings

Nanotechnology

Charles W. Schmidt, “Nanotechnology-Related Environment, Health, and Safety Research: Examining the National Strategy,” *Environ Health Perspect.* 2009 April; 117(4): A158–A161. PMID: PMC2679627, *Environews Spheres of Influence*, <http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2679627/#>, accessed 11/17/13.

Jennifer Kuzma, Peter VerHage, *Nanotechnology in agriculture and Food Production: Anticipated Applications*, Woodrow Wilson International Center for Scholars, PEN 4, September 2006, <http://www.nanotechproject.org/search/?q=nanotech+in+food+and+agriculture+&x=0&y=0>, accessed 11/17/13.

Kent Pinkerton, Ph.D. Rona Sillva, B.S. Laurel Plummer, Ph.D. Amy Madl, Ph.D., DABT, **PowerPoint presentation**, “Using Nanotechnology in Agriculture”, Western Center for Agricultural Health and Safety Seminar Series, June 6, 2011 http://agcenter.ucdavis.edu/seminar/flyer/2011/Pinkerton_Using_Nanotechnology_in_Agriculture.pdf, accessed 11/17/13.

New Equipment

Brian Scott, “12 Most Advanced Agricultural Technologies,” Posted on Mar 12, 2012, <http://12most.com/2012/03/12/advanced-agricultural-technologies/>, accessed 11/17/13.

Satellites and IT

Agriculture and satellites, “Harvest moon, Artificial satellites are helping farmers boost crop yields,” *The Economist*, from the print edition, <http://www.economist.com/printedition/2009-11-07>, accessed 11/17/13.

¹ Fox News, “GMO’s Researchers Debate the Nature of Genetically Modified Foods,” Foxnews.com, 7/14/13, <http://www.foxnews.com/health/2013/07/14/gmos-researchers-debate-healthy-safety-genetically-modified-foods/>, accessed 11/17/13.

² Whatmore, Roger M. “Nanotechnology – What is it? Should we be worried?”, *Oxford Journals, Medicine, Occupational Medicine*, Vol. 56, Issue 5, pp 295-299, <http://ocmed.oxfordjournals.org/content/56/5/295.full>, accessed 11/17/13.

³ Pocket K No. 39: Nanotechnology in Agriculture, ISAAA, <http://www.isaaa.org/resources/publications/pocketk/39/default.asp>, accessed 11/17/13.

⁴ FAO/WHO Expert meeting on the application of nanotechnologies in the food and agriculture sectors: potential food safety implications, Meeting report, World health Organization, 2010, http://whqlibdoc.who.int/publications/2010/9789241563932_eng.pdf, accessed 11/17/13.

⁵ Sadrieh, Nakissa, “Overview of CDER Experience with Nanotechnology–related Drugs,” August 9, 2012, Advisory Committee for Pharmaceutical Science and Clinical Pharmacology, <http://www.fda.gov/downloads/AdvisoryCommittees/CommitteesMeetingMaterials/Drugs/AdvisoryCommitteeForPharmaceuticalScienceandClinicalPharmacology/UCM315773.pdf>, accessed 11/17/13.

⁶ Buzea, Cristina, Ivan I. Pacheco Blandino, and Kevin Robbie, “Nanomaterials and nanoparticles: source and toxicity,” *Biointerphases* vol. 2, issue 4 (2007) pages MR17 - MR172, <http://arxiv.org/ftp/arxiv/papers/0801/0801.3280.pdf>, accessed 11/17/13.

⁷ Roco, Mihail, “The long view of nanotechnology development: The National Nanotechnology Initiative in 10 years,” *J. Nanopart Res* (2011) 13:427-224, http://www.nsf.gov/crssprgm/nano/reports/MCR_11-0201_JNR13_NNI+at+10+years_11051_2010_192_print.pdf, accessed 11/17/13.

⁸ White, Jason C., “Nanotechnology Use in Agriculture: Benefits and Potential Risks”, 2013 APHL, Annual Meeting and 7th Government Environmental Laboratory Conference, June 2012, <http://www.aphl.org/conferences/proceedings/Documents/2013/2013-APHL-Annual-Meeting/42White%20J.pdf>, accessed 11/17/13.

⁹ The Project on Emerging Technologies, “Inventory finds Increase in consumer products containing nano materials,” Nano Technology Business News archive, <http://www.nanotechproject.org/news/archive/9242/>, accessed 11/17/13.

¹⁰ “The Project on Emerging Technologies,” Consumer Product, Inventory, Wilson Center, Virginia Tech, <http://www.nanotechproject.org/cpi/>, accessed 11/17/13.

¹¹ Nanotechnology Now, updated May 22, 2012 at <http://www.nanotech-now.com/current-uses.htm>, accessed 11/17/13.

¹² Tiju, Joseph and Mark Morrison, “Nanoforum Report: Nanotechnology in Agriculture and Food,” Nanoforum.org, April 2006, ftp://ftp.cordis.europa.eu/pub/nanotechnology/docs/nanotechnology_in_agriculture_and_food.pdf, accessed 11/17/13.

¹³ American Chemical Society, “Carbon Tubes can double growth of cell culture important in industry,” ACS News Service Weekly PressPac: Wed Apr 04 16:42:03 EDT 2012, <http://www.acs.org/content/acs/en/pressroom/presspacs/2012/acs-presspac-april-4-2012/carbon-nanotubes-can-double-growth-of-cell-cultures-important-in-industry.html>, accessed 11/17/13.

¹⁴ Tiju, Joseph and Mark Morrison, “Nanoforum Report: Nanotechnology in Agriculture and Food,” Nanoforum.org, April 2006, ftp://ftp.cordis.europa.eu/pub/nanotechnology/docs/nanotechnology_in_agriculture_and_food.pdf, accessed 11/17/13.

¹⁵ Weir, Alex, Paul Westerhoff, Lars Fabricius, Kiril Hristovski, and Natalie von Goetz, “Titanium dioxide nanoparticles in food and personal care products,” *Environ. Sci. Technol.*, 2012, 46 (4), pp 2242–2250, Copyright © 2012 American Chemical Society, abstract available at <http://pubs.acs.org/doi/abs/10.1021/es204168d>, accessed 11/17/13.

¹⁶ Iavicoli, Ivo, Veruscka Leso and Antonio Bergamaschi, “Toxicologic Effects of Titanium Dioxide Nanoparticles: A Review of In Vivo Studies,” *Journal of Nanomaterials*, Volume 2012, Article ID 964281, <http://www.hindawi.com/journals/jnm/2012/964381/>, accessed 11/17/13.

¹⁷ FAO/WHO, “Expert meeting on the application of nanotechnologies in the food and agriculture sectors: potential food safety implications,” Meeting Report, Food and Agriculture Organization of the United Nations and World Health Organization Rome 2010, Appendix 4 page 99, accessed at http://whqlibdoc.who.int/publications/2010/9789241563932_eng.pdf, accessed 11/17/13.

¹⁸ Tran, C.L, K. Donaldson, V. Stone, R. Fernandez, A. Ford, N. Christofi, J. G. Ayres, M. Steiner, J. F. Hurley, R. J. Aitken, and A. Seaton, “A Scoping study to identify hazard data needs for addressing the risks presented by nanoparticles and nanotubes,” Research Report, December 2005, Institute of Occupational Medicine, University of Edinburgh, <http://www.nano.org.uk/members/MembersReports/IOM.doc>, accessed 10/20/13

¹⁹ Green, Carolyn J. and Sarah Ndegwa, Nanotechnology: A Review of Exposure, Health Risks and Recent Regulatory Developments, August 2011, National Collaboratory Center for Environmental Health, http://www.nceeh.ca/sites/default/files/Nanotechnology_Review_Aug_2011.pdf, accessed 11/17/13.

²⁰ Buzea, Cristina, Ivan I. Pacheco Blandino, and Kevin Robbie, “Nanomaterials and nanoparticles: source and toxicity,” *Biointerphases* vol. 2, issue 4 (2007) pages MR17 - MR172, <http://arxiv.org/ftp/arxiv/papers/0801/0801.3280.pdf>, accessed 11/17/13.

²¹ Basi, Christian, “Toxic Nanoparticles might be entering human food supply, MU study finds,” <http://munews.missouri.edu/news-releases/2013/0822-toxic-nanoparticles-might-be-entering-human-food-supply-mu-study-finds/>, accessed 11/17/13.

²² Zelladt, Nicholette, “Silver Beware: Antimicrobial Nanoparticles in Soil May Harm Plant Life,” *Scientific American*, 8/9/10, <http://www.scientificamerican.com/article.cfm?id=silver-beware-antimicrobial-nanoparticles-in-soil-may-harm-plant-life>, accessed 11/17/13.

²³ Peña, Carlos, “FDA Nanotechnology Regulatory Science Program Science Board Presentation August 2010,” FDA Nanotechnology Task Force, August 2013, News Bureau, University of Missouri, <http://www.fda.gov/downloads/AdvisoryCommittees/CommitteesMeetingMaterials/ScienceBoardtotheFoodandDrugAdministration/UCM222536.pdf>, accessed 11/17/13.

²⁴ Schug, Thaddeus T., A. F. Johnson, D. M. Balshaw, S. Garantziotis, N. J. Walker, C. Weis, S.S. Nadadur, and LS. Birnbaum, “ONE Nano: NIEHS’s Strategic Initiative on the Health and Safety Effects of Engineered Nanomaterials,” 2/12/13, <http://dx.doi.org/10.1289/ehp.1206091>, accessed 11/17/13.

²⁵ Kessler, Rebecca, “Engineered Nanoparticles in consumer Products: Understanding a New Ingredient,” *Environmental Health Perspectives*, 2011, <http://ehp.niehs.nih.gov/119-a120/>, accessed 11/17/13.

²⁶ Votaw, James G, “Nanotechnology Regulation – EPA Developing Rule to Regulate All New Uses of Engineered Nanoscale Materials,” *Environmental Leader*, July 25, 2013, <http://www.environmentalleader.com/2013/07/25/nanotechnology-regulation-epa-developing-rule-to-regulate-all-new-uses-of-engineered-nanoscale-materials/>, accessed 11/17/13.

Overview of Animal Management

- ²⁷ EPA, “EPA Proposes Policy on Nanoscale Materials in Pesticide Products,” press release, <http://yosemite.epa.gov/opa/admpress.nsf/0/05ff063e9205eb3c852578aa005aa0f8?OpenDocument>, accessed 11/17/13.
- ²⁸ FDA, Fact Sheet: Nanotechnology, April 2012, <http://www.fda.gov/Food/GuidanceRegulation/GuidanceDocumentsRegulatoryInformation/IngredientsAdditivesGRASPackaging/ucm300914.htm>, accessed 11/17/13.
- ²⁹ FDA, “FDA’s Approach to Regulation of Nanotechnology Products,” <http://www.fda.gov/ScienceResearch/SpecialTopics/Nanotechnology/ucm301114.htm>, accessed 11/17/13.
- ³⁰ von Schomber, Rene and Sarah Davies, “Understanding Public Debate on Nanotechnologies, Options for Framing Public Policy,” 2-1-, European Commission Services EUR 24169 EN, p. 108, http://www.nanotechproject.org/process/assets/files/8304/debate_nano_100203.pdf, accessed 11/17/13.
- ³¹ Ibid.
- ³² William C. Motes, “Modern Agriculture and Its Benefits- Trends, Implications and Outlook,” Global Harvest initiative Pre-publication draft, 3-16-10, <http://www.globalharvestinitiative.org/Documents/Motes%20-%20Modern%20Agriculture%20and%20Its%20Benefits.pdf>, accessed 11/17/13.
- ³³ Sroksrad, Eric, “The War against Weeds Down Under,” *Science*, Volume 341, August 2016, pp 734-736, summary at <http://www.sciencemag.org/content/341/6147/734.summary?sid=68aa56f8-032e-40b6-a0d3-83a80e488bb5>, accessed 11/17/13, not accessible online without a subscription.
- ³⁴ Cha, Ariana Enjug, “Companies rush to build ‘bio-factories’ for medicines, flavorings and fuels,” Washington Post, 10/24/13, http://www.washingtonpost.com/national/health-science/companies-rush-to-build-biofactories-for-medicines-flavorings-and-fuels/2013/10/24/f439dc3a-3032-11e3-8906-3daa2bcde110_story.html, accessed 11/17/13.
- ³⁵ Preston, Benjamin, “Growing Up: Water efficiency and Sunless Farming,” *State of the Planet*, 4/15/11, <http://blogs.ei.columbia.edu/2011/04/15/growing-up-water-efficiency-and-sunless-farming/>, accessed 11/17/13.
- ³⁶ Boyle, Rebecca, DARPA and Craig Venter, “Fire Up Bio-Factories For Quick, Streamlined Genetic Engineering,” 5/23/12, *Popular Science*, <http://www.popsci.com/science/article/2012-05/darpa-and-venter-fire-bio-assembly-lines-genetic-engineering>, accessed 11/17/13.
- ³⁷ Yates, Yesabel, “Eco-friendly Farming: Sowing the Seeds of Renewable Energy,” *Renewable Energy World.com*, 9/24/13, <http://www.renewableenergyworld.com/rea/news/article/2012/09/eco-friendly-farming-sowing-the-seeds-of-renewable-energy>, accessed 11/17/13.
- ³⁸ Union of Concerned Scientists, “Renewable Energy and Agriculture: A natural fit,” Fact Sheet, http://www.ucsusa.org/assets/documents/clean_energy/agfs_overview_2003.pdf, accessed 11/17/13.
- ³⁹ U.S Dept. of Energy, “Biofuels and Agriculture, A Factsheet for Farmers,” 2001 <http://plbrgen.cals.cornell.edu/cals/pbg/programs/departamental/forage/upload/Biofuels-and-Agriculture-a-factsheet-for-farmers.pdf>, accessed 11/17/13.
- ⁴⁰ Conservation Practices, “Minnesota Conservation funding Guide, Manure/methane Digester,” 2013 Minn. Dept. of Agr., <http://www.mda.state.mn.us/protecting/conservation/practices/digester.aspx>, accessed 11/17/13.
- ⁴¹ Earthnet Online, “Agriculture overview,” <https://earth.esa.int/web/guest/earth-topics/agriculture>, accessed 11/17/13.
- ⁴² Thilges, Michelle, “Adopting new Technologies,” Agriculture.com, 2011, http://www.agriculture.com/farm-management/technology/adopting-new-technologies_322-ar14644, accessed 11/17/13.