5 | RESEARCH PROGRAMS

In the early years of the ABE department, funds from the federal Hatch Act provided the support for most of the department research. In recent decades, however, the Hatch funding that was provided was less than the rate of inflation and Hatch funds gradually became insufficient to mount strong research programs. However, the need for research continued, not only to solve societal problems but also to support graduate students without whom the future would be bleak. In response to the diminishing Hatch funds, departmental faculty members took on a new responsibility in addition to teaching, advising graduate students and conducting research. That new responsibility was to write research proposals and submit them to funding agencies to garner the financial support needed for research. By 2010, virtually all of the ABE department research was being supported by such grant funds.

For many years, the ABE department has had technical interest areas in which students could specialize. In 2009, the five areas were BioEnvironmental Engineering (BEE), Biological Engineering (BioE), Food and BioProcess Engineering (FBE), Off-Road Equipment Engineering (OREE), and Soil and Water Engineering (S&W). Research results are reported below under the technical interest areas. In most cases, research by a faculty member is reported below under the area in which he or she is appointed. However, cooperation between divisions was encouraged. Thus, for example, although John Reid worked in the OREE area, he also used his machine vision expertise to solve problems in the FBE and the S&W areas and the results are reported under those areas. In addition, the reader will notice that many projects included participation by researchers from other departments on campus and even by researchers from other institutions. Also, there is a separate section below on nanotechnology. In 2009, this was a relatively new research area for the ABE department and a significant amount of nanotechnology research is reported below that was not necessarily a part of the research in the five technical areas.

Research – Soil and Water Resources

Soil and water, two of the basic natural resources that are important to agriculture, have been the focal point of investigations since agricultural research began. Research in the area of agricultural engineering has dealt with the conservation of these resources as well as with drainage and irrigation to improve the environment for plants, the movement of water across or through the soil, and the structures used to protect the soil or impound water. Recently studies have placed less emphasis on those subjects described in the previous history and more emphasis on water quality and amelioration of contaminants in surface and subsurface waters.

Erosion Control

Kent Mitchell, Michael Hirschi and Greg McIsaac continued research started in the 1980s and in 1996-1998 reported on the Control, Prediction, Economics, and Environmental Effects of Soil Erosion. Y. Zhao assisted in these efforts. The project was funded by the University of Illinois and the USDA. Dissolved phosphorus was measured in runoff from simulated rainfall applied to two soils and several tillage treatments used in an annual crop rotation of corn and soybeans. The average concentration and load of soluble P in the runoff were significantly greater from the no-till than from other tillage treatments. Only moldboard plowing after surface broadcasting of P fertilizer reduced the soluble P concentration below 0.05 mg-P/L. For the Catlin soil, a variety of tillage practices (disk, field cultivation, and strip-till) appeared to result in soluble P concentrations of approximately 0.14 mg-P/L. For the Tama soil, disk-harrow followed by field cultivation and harrow after fertilizer application appeared to reduce soluble concentration in the runoff to approximately 0.06 mg-P/L. Simulated rainfall was applied to several tillage systems on two soil types at slopes ranging from 1.6% to 10%. Soil profiles were measured using a pin-type rill meter. On Catlin soils, rills widened as erosion progressed. On Tama soils, rills deepened as erosion progressed. Elliott's (1988) equation was a better predictor of rill widths. For tillage systems with crop residue ranging from 15% to 54% in the Tama soil, both equations underestimated rill. The following year, soil losses from four Illinois soils under simulated rainfall were measured, along with variables affecting soil loss. These included soil moisture, bulk density, soil aggregations stability, raindrop fall velocity, and drop size distribution. Equations relating soil loss as a function of raindrop kinetic energy, and soil clay content and organic matter were developed for Tama, Catlin, Cisne and Plainfield soils.

Using funding from the U.S. Army Construction Engineering Research Laboratory, Prasanta Kalita and Michael Hirschi did an Evaluation of Range Design Relative to Combat Readiness and Environmental Risks from 2004 to 2008, assisted by N. G. Svendsen, B. R. Tadlock, and L. Schutte. Training and testing ranges on U.S. Army installations are essential for combat readiness of military personnel. A wide variety of range types are needed to provide realistic training conditions. Problems such as soil erosion, water quality degradation, air quality degraded by dust, wildfires, smoke, obscurants, and heavy metal accumulations from live fire activities were addressed at U.S. Army installations. The objective was to analyze training and testing range design with respect to mission, environmental degradation, regulatory noncompliance and long-term operations and maintenance requirements.

Drainage

Illinois C-FAR supported research from 1999-2002 by Richard Cooke, Michael Hirschi and Jay Davis, assisted by A. M. Garcia, W. J. Northcott and A. K. Verma, on Aerial Infrared Mapping of Subsurface Drainage Systems. The goal was to provide maps that show the layout of subsurface tile systems in the Lake Decatur watershed. Mapping relies on the soil over working tile lines drying faster than at other locations in the field, resulting in higher reflectance in the infrared region of the radiation spectrum.

Richard Cooke conducted a University of Illinois-funded project on Evaluating Preferential Flow Paths in Sludge-amended Soils in 1996-1997. The goal was to characterize the effects of preferential flow paths in sludge-amended soils. Drain flows from sludge-amended and non-amended plots were monitored to test the equivalence of infiltration rate, permeability and effluent water quality. Temporal variations in permeability of soil cores were evaluated when the cores were subjected to water quality variations covering the range of ionic strength of divalent cations measured in leachate from municipal sludge.

Richard Cooke and Kent Mitchell conducted a project from 1996-1999 on The Effect of Water Table Management on Productivity and Water Quality assisted by A. K. Verma and V. M. Kurian. The project was funded by the University of Illinois and the USDA. The primary objective was to optimize the performance of subsurface drainage systems by mapping existing drainage systems and estimating the regions of influence of tiles.

Richard Cooke, Greg McIsaac, and S. E. Walker, in work supported by the USDA, studied Evaluation of Water Quality From Alternative Cropping Systems Using a Multiple-Paired Design. The objective of this study in 1998-2000 was to quantify tile drain effluent under organic and conventional cropping practices in Illinois. Organic systems were paired with conventional systems with similar soils, crops, drainage system size and climate. Pairing eliminates major sources of external variability and allows broadening of the range of applicability of findings.

The Case Corporation funded research in 1998-2004 by Richard Cooke and Prasanta Kalita on Effect of Drainage System Layout on Yield, Yield Uniformity, and Water Quality. They were assisted by S. E. Walker, A. K. Verma, W. J. Northcott, C. Harbourt and K. Kim. The overall goal of this research was to improve the characterization of subsurface drainage processes in tile drained watersheds and to quantify the effect of several depth and spacing combinations on yield, yield uniformity, and water quality. In the long run, the results can be used to select subsurface drainage management practices that optimize yield, water quality, or both.

In 2005 to 2008 The Natural Resource Conservation Service and the ARS Soil Drainage Unit provided funding for Richard Cooke for an Illinois Conservation Drainage Research and Demonstration Watershed Project. The purpose was to provide a showcase watershed for drainage water management and other environmentally-friendly drainage practices; to conduct research on stream flow, water quality, controlled drainage and bioreactors; to collect data for modeling flow and transport in a tile-drained watershed; and to work with local stakeholders to promote conservation drainage.

Richard Cooke used University of Illinois funding in 2006 to 2008 to study Development of Conservation Drainage in Illinois assisted by A. Rodrigue, J Chun and D. Goswami. The goal was to test the hypothesis that differing drainage systems with equal drainage capacities may differ in their effect on water quality. Other goals were to determine design configurations that optimize crop production while minimizing environmental impacts and to involve producers, drainage contractors, educators and local conservation personnel in drainage research.

Illinois C-FAR supported research by Richard Cooke, Sharyl Walker and Michael Hirschi, assisted by W. J. Northcott, K. I. Christopher, J. K. Mitchell, and J. K. Zuercher, from 1999 to 2000 on Effectiveness of Controlled Drainage on Poorly Drained Soils in Illinois. The hypothesis was that use of controlled drainage systems on poorly drained soils will reduce the concentrations of nitrate in the effluent without reducing crop yield. Paired tile drains, one conventional and one with controlled drainage, were monitored. The tiles in each pair had similar soils, crops, size and climate.

Richard Cooke used funding in 2004 to2006 from the Natural Resources Conservation Service to study the Effect of Drainage Water Management on Tile Water Quality. The goal was to test the hypothesis that drainage water management will reduce the loadings of nitrates and phosphorous from tile drainage systems without reducing crop yield. Over a three-year period, effluent from a pair of fields was continuously monitored. The pair consisted of two 40-acre, side by side fields with similar soils, crops and climate. Pairing reduced external variability, thus reducing the time required to draw conclusions.

The USDA Agricultural Research Service funded research from 2004 to 2008 by Richard Cooke, assisted by T. A. Wildman and A. Rodrigue, on Amount, Timing and Quality of Water Coming from Managed (Controlled) and Unmanaged Drainage Systems in Illinois.

Flow was monitored and flow-weighted water quality samples were obtained from managed and free-drainage systems on a range of soil types in various locations in Illinois. Using the resulting data, management criteria were developed for drainage water management systems.

Hydraulics

In a project funded by the University of Illinois and the USDA, Michael Hirschi, Kent Mitchell and Richard Cooke studied the Impact of Agricultural Systems on Surface and Ground Water Quality in 1996-1997. N. Jiang studied two small-scale sediment-trapping controls, filter fabric (also called a silt fence) and a rock check dam were evaluated for their sediment trapping characteristics. A unified conceptual model, using orifice flow relationships, showed promise for describing both control structures. Hydraulic capacity determinations, based on design runoff events, lead to recommendations for contributing area limits based on structure size. Specifications for such control structures were needed by erosion control practitioners and were requested by soil conservation agency personnel.

Hydrology

Ron Bingner completed a study in 1999, supported by the Sedimentation Laboratory, ASR, USDA, that involved the development of a model to simulate, for long term analysis, runoff, sediment yield, and channel characteristics such as bed material or cross section changes, for complex, ungaged watersheds containing various crops, soil types, slopes, channel sizes, levels of conservation management and instream erosion control structures. Temporal and spatial variations of a rainfall event were also considered so the response of the watershed could be accurately modeled. Channel processes were incorporated into a comprehensive model to evaluate the effects of man-made and natural changes to the channel system. Data from the extensively instrumented Goodwin Creek Watershed in northern Mississippi were used to validate the model. The model was then used to simulate the response of the watershed to various conservation and instream erosion control management practices and the effect of these practices on the entire watershed system. The techniques used in the development of the database and modifications of the model can be used for understanding watershed management practices on other watersheds.

Prasanta Kalita, Richard Cooke, Michael Hirschi and R.J. Hudson, assisted by T. Wildman, J. Nelmelman, K. Kim, K. S. Lander, D. Dupre, A. Kaleita, and D. Goswami, conducted a project on Understanding Hydrologic and Water Quality Response of a Tiled Watershed from 2003 to 2008. The work was supported by the USDA and by the National Research Initiative Competitive Grants Program. Tile-drained watersheds contain much of the productive agricultural land in the north central United States, yet the hydrology of these watersheds is not well understood. This study initiated a new dimension for watershed management to improve water quality in tile-drained watersheds. Once the techniques and relationships were validated, an estimate of total maximum daily load (TMDL) to a surface water source was available through simple and accurate means. Overall, the results of this study will be utilized for better management of agricultural practices in east central Illinois and similar areas with tile drained watersheds.

A project on Modeling Flood Flows in Flat, Tile-Drained Watersheds was funded by the Illinois Groundwater Consortium and was conducted by Richard Cooke in 1997 to 1999, assisted by S. E. Walker, J. K. Mitchell, M. C. Hirschi, G. F. McIsaac and A. K. Verma. Most flood flow models do not have the capability of including subsurface drain flow. Drain flow models, on the other hand, are mainly field-scale models that are virtually impossible to apply at a watershed scale. This project addressed the development of a composite model in which a subsurface drainage model was subsumed into a flood flow model to achieve better prediction of flood peaks and of flood water quality.

Richard Cooke and William Northcott, assisted by A. K. Verma, S. E. Walker, J. K. Mitchell, S. M. Badiger, A. M. Garcia, K. I. Christopher, W. J. Northcott, K. S. Lander, J Nehmelman, J. Singh and R. J. Hudson, in work supported by a USDA National Needs Fellowship studied Incorporation of the Effect of Artificial Subsurface Drainage into Surface Water Quality Models in 1999 to 2004. In Illinois, subsurface drains provide alternate pathways for solute movement to rivers and streams. The goal was to incorporate the effects of such subsurface drains into watershed-scale flow and transport models.

NSF funding supported a project by Prasanta Kalita and Michael Hirschi, assisted by W. J. Northcott, S. E. Walker, J. Singh, K. Kim and K. I. Christopher, in 2001-2006 on DHARMA: Domain Specific Metaware for Hydrologic Applications. Many hydrologic models at the watershed scale are limited in resolution and scope by their computational demands. A goal of this project was to build a middleware layer to provide the resources for revolutionizing hydrologic modeling. The required resources ranged from local data to supercomputing power on the national computational grid. Researchers expanded the applicability of the Water Erosion Prediction Project model to large watersheds, specifically applying the extended model to the Lake Decatur Watershed in Illinois, and enabled the model for predicting erosion within the watershed by allowing significantly easier access to computational power and data acquisition capabilities.

The USDA-Foreign Agriculture Service, The National Association of State Universities and Land-Grant Colleges, the Government of India and the Agricultural Knowledge Initiative (AKI) Program provided funding for R.S. Kanwar, Prasanta Kalita, R. Mohtar, M. Walter and V. Singh in 2007 to 2008 to initiate an International Water Management Program. The purpose was to build expertise and human capacity in both priority areas, capacity building and water management, of the U.S.-India AKI Competitive Grants Program. The goals were to develop a consortium of U.S. and Indian Universities/Research Insitutes/NGOs; to develop MS and PhD sandwich degree programs in International Water Management; and to develop collaborative research programs on bio-drainage for salinity control and water harvesting techniques for groundwater recharge.

LVR: Hydrology, Drainage, Water Quality

The Little Vermilion River (LVR) Water Quality Project was begun in 1991 by Kent Mitchell, Michael Hirshi, and A. S. Felsot, and continued under various supporting programs until 2003; with evaluations and reporting continuing until 2006. The project titles supporting this work were 'Best Management Practices (BMPs) for Controlling Field-to-Stream Delivery of Agrochemicals Field Validation in the Little Vermilion River Watershed', 'Management Practice Effects on Nitrate-N Concentrations in the LVR', 'Modeling Agricultural Practices for Water Quality Improvement Using GIS', and 'Understanding and Modeling the Hydrology of Tile-Drained Watersheds'. All data were organized and stored by Kent Mitchell in 2007 and are available for further analyses. The project was supported by the UIUC/Illinois Agricultural Experiment Station; the USDA Hydrologic Unit Area – CES and NRCS; the Illinois Groundwater Consortium; a USDA – National Research Initiative; a USDA – Special Research Initiative; C-FAR – Projects 95-89-5 and 99I-021-5; the Illinois Council on Food and Agricultural Research; and the Champaign County Soil and Water Conservation District. Faculty members Prasanta Kalita, Richard Cooke, Ken Konyha, Greg McIsaac, Sheryl Walker, and Kazimierz Banasik contributed to the project as well as Graduate Assistants V. M. Kurien, S. Kim, K. Kim, W. J. Northcott, Paul Miller, Y. Yuan, Chris Harbourt, N. Jiang, J. Singh, K. P. Lander, R. H. Mohtar, and A. Algoazamy. The overall objective of the study was to develop strategies that mutually benefit both agriculture and water quality in regions where hydrology is strongly influenced by subsurface drainage. This was done by monitoring flow and water quality from subsurface tile drains in the Little Vermilion River Watershed in Illinois. Results from field observations have been used to develop fundamental relationships describing flow components to incorporate in computer simulation models.

The Little Vermilion River Watershed is 489 km2 located in East Central Illinois and is terminated by Georgetown Reservoir, which was a drinking water supply. The topography is flat and the watershed is characterized by dark prairie soils with poor internal drainage, classified as silt loam and silty clay loam. Approximately 90% of the watershed is used for row crop production, primarily corn rotated with soybeans and those areas have slopes of 1% or less. Seven sampling points were established along the Little Vermilion River, including Georgetown Lake. Flow stage was recorded and water samples were collected at intervals following rainfall events and during baseflow (one river station was continuous stage monitoring and pump sampling). Water was analyzed for nitrate, phosphate and nine pesticides. Eight small subsurface drainage systems were selected within the watershed for which the exact extent of drainage was known. Seven of the sites were in corn-soybean production in various combinations, while an eighth site was permanent meadow. Four surface runoff monitoring stations were also established in conjunction with four of the subsurface drainage monitoring stations, and surface flow monitoring and pump sampling was conducted. Tillage practices represented by the seven sites under production included no-till, reduced tillage and conventional tillage.

Sub-surface drainage (tile) flow was sampled bi-weekly and additional samples were taken during increased flow following major rainfall events. These samples were analyzed for nitrate as well as pesticides. The sub-surface outflow was monitored continuously with a flume and stage recorder. Records of agrichemical application to and tillage on the monitored fields were maintained. Soil sampling was performed to provide background and periodic concentration of agrichemicals in the field soil.

The use and loss of nitrogen data have shown that concentrations of nitrate differed little among specific sampling locations along the river, but they definitely followed a seasonal cycle. Nitrate concentrations from tile drains varied considerably between fields depending upon cropping management systems used, with concentrations varying seasonally as in the river. The effect of the application of broadcast, preplant nitrogen fertilizer is clearly shown in the nitrate-N concentrations from tile drains. The pre-plant anhydrous-N application systems with average nitrogen application of 100 kg/ha/yr. had a mean concentration of nitrate-N of 16.8 mg/L while the side-dress and manure application systems with average nitrogen application of 85 kg/ha/yr. had a mean concentration of nitrate-N of 9.8 mg/L. The mean concentration of nitrate-N from a permanent meadow field was 1.1 mg/L. Nitrate-N losses from cropped fields have ranged from 15 to 41 kg/ha/yr. depending upon the management system. Losses from the grassed system were 3.8 kg/ha/yr. and in the most upstream river station was 12 kg/ha/yr. of nitrate-N.

The DRAINMOD model was used with an optimization routine to determine the region of influence of random tile drains. The random tile drains in the agricultural fields on Drummer/Flanagan soils in Central Illinois have an effective region of influence of 328 ft. The GRASS GIS was used to explore relationships between watershed characteristics and watershed outlet response. A linear model, relating field tile flow and watershed soils to outlet flow, was particularly successful in predicting 1993 measurements. The Root Zone Water Quality Model (RZWQM) does an adequate job of simulating non-extreme tile flow events and provides a realistic estimate of crop yield (at least at typical fertilizer application rates). A physically based hydrology model to simulate the runoff response from rainfall was developed from the framework of TOPMODEL. The model can identify the portions of the hydrograph resulting from tile flow, subsurface flow and surface runoff. Perhaps the most common method for predicting storm runoff volume is the SCS curve number method. The potential for using watershed outlet base flow prior to an event as an alternative to five-day antecedent rainfall for evaluating the antecedent moisture condition of the watershed was studied. Watershed lag time (LAG) is an important factor in determining the time to peak and the peak value of the instantaneous unit hydrograph, IUH. In the procedure of predicting a sedimentgraph (suspended sediment load as a function of time) a similar parameter is the lag time for the sedimentgraph (LAGs).

Results of three-year water quality monitoring programs carried out in two small, lowland agricultural watersheds of various fertilization levels; the Upper Little Vermilion River (ULVR) located in Central Illinois and the Zagozdzonka River located in Central Poland, were analyzed. The watershed with intensive agricultural practice (ULVR) generates runoff with higher concentrations of nutrients. Nitrate-nitrogen losses amount to a significant part (about 15%) of applied total nitrogen fertilization in the ULVR. High concentration of P-P04 in runoff from Zagozdzonka watershed was also recorded.

Water Quality

John Reid and John O'Brien, in a study supported by the USDA National Needs Fellowship and the University of Illinois, studied Machine Vision as a Sensor for Microbial Contamination in Water in 1996 to 1999. The goal was to evaluate machine vision and image analysis as a means of identifying and enumerating pathogenic protozoans such as Giardia lambia and Cryptosporidium in water.

In a project supported by Illinois C-FAR, Prasanta Kalita, M.S. Kuhlenschmidt, R.D. Smith and Ted Funk, assisted by J. R. Trask, S. McLaughlin and M. K. Patel, in 2001 through 2005 studied An Integrated Approach to Reduce Pathogens and Nutrients in Runoff from Animal Production Systems. The goal was to limit the delivery of microbial pathogens and nutrients from animal production facilities on small and midsized farms. The fate of C. parvum and E. coli in surface and near-surface was investigated to develop management strategies to limit their transport.

The USDA National Research Initiative provided funding for M.

Kuhlenschmidt and Prasanta Kalita, assisted by P. C. Davidson, in 2007 and 2008 to study Control of Cryptosporidium and Rotavirus Contamination. The goal was to prevent microbial contamination of water resources and provide a safe and sustainable environment for animal production facilities. In order to design and implement field-applicable technology for prevention of microbial contamination, the processes of microbial transport in surface and near surface runoff need to be understood and quantified. The study aimed to indentify and characterize critical factors such as soil slope, composition, vegetation and rainfall that affect microbe transport and viability.

Using funding from the AWWA Research Foundation Project 4101, Lance Schideman, B.J. Marinas and D. H. Metz began an Evaluation of Granular Activated Carbon (GAC) Filter Caps for Control of Disinfection Byproducts and Emerging Trace Organic Contaminants in 2008. The feasibility was evaluated of using GAC for removal of contaminants including endocrine disrupting compounds, pharmaceutically active compounds, potential homeland security threats, pesticides and disinfection byproduct precursors. Industry treatment practices were surveyed and bench-scale testing was done to determine the level of removal for a broad range of potential water contaminants. Novel adsorbents, regeneration techniques, and predictive modeling tools were developed and tested.

Lance Schideman and M.C. White, in 2008, used funding from Camp, Dresser and McKee to study a Mem-brain Intelligent Infrastructure System for Real-Time Optimization of Membrane Treatment Systems. Genetic algorithms and expert systems were used to develop an automated optimization protocol that continually evaluates and updates operational setpoints in response to variable influent conditions and other dynamic factors typical of membrane systems used for water purification. The goal of the intelligent infrastructure was to reduce operating costs, increase reliability and extend equipment life.

The U.S. Army Corps of Engineers Construction Engineering Research Laboratory funded research by Lance Schideman and E. Morgenroth on Evaluation of the Performance of Hydrogen-Enhanced Reactor Treating Perchlorate and RDX was begun in 2008. The project compared a pilot-scale anaerobic membrane bioreactor with two other bioreactor technologies to treat munitions industry wastewater containing perchlorate, RDX and other explosives. The novel membrane bioreactor used hydrogen gas to stimulate autotrophic growth for higher degradation rates, lower residuals production and improved effluent quality. The goal was to facilitate water reuse in the industrial process to save money and reduce environmental impact.

Illinois C-FAR supported research in 2000 to 2003 by Richard Cooke and Michael Hirschi, assisted by T. Wildman and A. Doheny, on Passive Subsurface Bioreactors for Enhanced Edge-of-Field Treatment of Tile Outflow. The goal was to test the hypothesis that installation of passive subsurface bioreactors on tile outlets will reduce the levels of nutrients and pesticides in streams and rivers. A laboratory study determined the substrate (carbon source) that results in the highest removal efficiencies for nitrates and phosphorous. A pilot system was established for field validation and demonstration.

Using funding from the USDA and the Cooperative State Research, Education and Extension Service, Richard Cooke and Prasanta Kalita, assisted by A. Doheny, studied Development of Design Criteria for Watershed-Scale Subsurface Bioreactors in 2004 to 2006. The objectives were to demonstrate the efficacy of passive subsurface bioreactors in removing nitrates from the flow from small watersheds, evaluate the effectiveness of woodchips from softwoods and hardwoods as carbon sources in the bioreactors, and to develop design criteria for subsurface bioreactors.

Richard Cooke, assisted by J. A. Chun, used funding in 2005 to 2008 from the Sand County Foundation and the Agricultural Watershed Institute to study Combined Drainage Water Management/Bioreactor System for Improving the Quality of Tile Outflow. The goal was to evaluate the effectiveness and cost efficiency of bioreactors, either as stand-alone practices or in combination with drainage water management systems, in reducing nitrogen discharge from fields with tile drains. The results were needed in scaling up a regional initiative to reduce nitrogen discharges from agricultural lands while protecting income to landowners and rural communities.

Prasanta Kalita and Richard Cooke used funding from the USEPA to study An Innovative System for Bioremediation of Agricultural Chemicals for Environmental Sustainability in 2007 and 2008. The objective was to design, implement, and evaluate a renewable, naturally-available biofilter to minimize transport of chemicals from agricultural fields into surface water sources. A cost-effective design for minimizing chemical leaching was preferred over reductions in pesticide and chemical application. In addition, this design will allow for sustainable agricultural production and technology, while being environmentally beneficial to surrounding areas.

The USDA and the Iowa Cattlemen/s Association provided funding in 2007 to 2008 for Prasanta Kalita, Ted Funk and Xinlei Wang, assisted by R. Bhattarai and M. K. Patel, to study Vegetative Treatment System Technology. The performance evaluation of a vegetative treatment area (VTA) for beef feedlot runoff management was investigated. This is probably the southernmost site among all the other experimental sites in a multistate effort with significantly different climate, hydrologic, and soil conditions. The overall objective of this investigation was to evaluate through field monitoring the performance of nonbasin (non-containment) technologies for the treatment of open feedlot runoff in several beef operations in different midwestern states. Two nonbasin technologies under consideration were infiltration basin followed by a vegetative treatment area, and vegetative treatment area only.

OREE research

In the 1990's, the name of the Power and Machinery (P&M) area of the department was changed to Off-Road Equipment Engineering (OREE) to more accurately describe the activities of the area. The research sub areas described below are those that were carried out primarily by department faculty assigned to the OREE area, with help from students and, in some cases, help from cooperators from outside the department. In earlier years, USDA personnel housed in the ABE department were an important part of the departmental research staff. Some of the USDA personnel held courtesy appointments on the ABE faculty and participated actively in faculty activities, including advising graduate students. By 1997, the only such USDA employee remaining in the ABE department was John Hummel. Hummel's participation with the ABE faculty ended in 2000, when he was transferred to Columbia, Missouri.

Agricultural safety

In a study funded by USDA Hatch funds, Bob Aherin and Gerald Riskowski designed and tested a system for preventing falls and suffocation of persons who enter grain bins. The system, which can be incorporated into existing or new grain bins, allows workers to accomplish needed tasks while providing protection from falling through crusted-over grain. The grain storage industry was informed of the results.

The primary goal of a study supported by the USDA Agricultural Library was to identify current sensor technology capable of detecting toxic atmospheres within confined spaces on farms. Project participants were Bob Aherin, Les Christianson, Gerald Riskowski and Randy Fonner. The study included a world-wide literature review, contacting federal and private research laboratories and manufacturers of sensors. The final report, released by the USDA, identified sensors with the greatest potential in agricultural confined spaces.

A four-year study supported by the National Institute for Occupational Safety and Health and by the National Farm Medicine Center was aimed at reducing the fatality risk from livestock manure storage pits. The study, led by Bob Aherin and MS student Matt Robert, undertook to understand the interactions that lead to dangerous concentrations of manure pit gases, develop potential strategies to reduce such concentrations, and evaluate sensors capable of detecting the pit gases develop safety procedures for people working in or around manure pits. The researchers found that hydrogen sulfide (H2S) concentrations can exceed published health limits when the manure is agitated, but lowering the % TVS (Total Volatile Solids) in the manure reduced the H2S emissions. They found that high ventilation rates are needed during pit agitation to protect the health of workers and animals.

Bob Aherin was lead scientist in a study on the respiratory health of swine workers. The study was supported by the National Institute for Occupational Safety and Health; the National Farm Medicine Center and by Carle Foundation Hospital Center for Rural Health and Farm Safety. Swine workers were given a lung function test every three months for a year. Results indicated that, in swine facilities that are designed and managed properly, there is only minimal risk to the respiratory health of swine workers.

Bob Aherin, Ted Funk and Yuanhui Zhang participated with other cooperators on a study of Occupational Exposures and Health Outcomes in Swine Confinement Facilities. The study was supported by The National Institute for Occupational Safety and Health and by the University of Illinois School of Public Health. Worker exposures to airborne contaminants in a swine confinement facility were evaluated. Biological markers of inflammation were evaluated before and after work for two consecutive work days in winter. Worker blood samples, exhaled air samples and lung function were evaluated. Each worker wore an air-sampling device that measured contaminants collected during their work shift. Air samples were evaluated for particulates, CO, CO2, H2S, NH3 and O2. Preliminary results showed that workers exposed to the particulates and contaminant gases showed little to no adverse effects.

Agricultural Infotronics Systems

Qin Zhang conducted Research on Agricultural Infotronic Systems in a study supported by USDA Hatch funds. The goal was to create a system capable of providing farmers with actionable information while performing precision farming operations. The framework of the system included data collection, operation planning and automatic implementation modules. The data collection module included algorithms to classify, fuse and track attributes of crop production information. The system was validated in precision farming operations.

Qin Zhang and Shufeng Han worked with agronomists on In-Season, Site-Specific Nitrogen Management for Corn. The study was supported by the Illinois Council for Food and Agricultural Research (C-FAR). The goal was to develop an on-machine corn nitrogen stress sensor and evaluate its potential for real-time site-specific nitrogen management during side-dressing operations. A multispectral imaging sensor was developed to detect nitrogen deficiency during fertilizing applications. The research confirmed that it is technically feasible to reliably detect nitrogen stress.

Biofuels

In a study supported by the Illinois Department of Commerce and Community Affairs, Carroll Goering and MS students Curt Ritter and Ryan Parcell instrumented a Detroit Diesel two cycle bus engine to evaluate 190-proof ethanol as a potential fuel for bus engines. An engine controller was developed to operate the engine on the modified Chicago Transit Authority engine cycle for 454 hours. A 14% power reduction due to injector needle sticking was eliminated by installing new injectors. NOx, CO and HC emissions were less for the 190-proof ethanol than for anhydrous ethanol.

The USDA supported a study by Carroll Goering, Les Savage, and graduate students Anne Meyer, Barry Bliss and Tom Briggs to develop an accelerated evaluation of vegetable oil fuels. A Lister-Petter two cylinder diesel engine was modified to allow one cylinder to run on petroleum diesel while the other ran on a vegetable oil fuel to allow comparative testing under identical conditions. The engine was used to evaluate a variety of biofuels developed by the USDA Peoria laboratory. The effects of the biofuels on engine performance and durability were determined.

In work supported by the Illinois Department of Commerce and Community Affairs, Allen Hansen and Qin Zhang conducted a study to Evaluate E-diesel as an Alternative Fuel for Diesel Engines. E-diesel is a blend containing 10% ethanol and 90% diesel fuel, with a special additive used to keep the two well blended. The researchers conducted a 500-hour test using a procedure developed in cooperation with the International Engine and Truck Corporation. The results were sufficiently promising to merit field testing.

In a study supported by the Illinois Council on Food and Agricultural Research and the Great Lakes Regional Biomass Energy Program, Allen Hansen, Qin Zhang, Rob Hornbaker and MS student Todd Manke did an Evaluation of E-diesel as an Alternative Fuel in Agricultural Machinery. The Illinois Corn Marketing Board, Deere and Company, and Caterpillar, Inc., were industrial partners in the research. Participating farmers on two farms used two tractors and two combines. One tractor and combine on each farm ran on E-diesel while the other tractor and combine ran on petroleum diesel. A standard test procedure was developed for monitoring the performance and condition of the tractors and combines. The tractor and combine engines running on E-diesel showed no abnormal wear but consumed 2.8 to 5.6% more fuel because of the lower energy content of the E-diesel. In addition, ADM ran two Mack trucks on E-diesel for a total of 372,000 miles without any problems. Fifteen Chicago city buses accumulated over 273,000 mile on e-diesel without any problems. The Illinois Corn Growers Association ran a Ford F-250 truck on E-diesel with no problems after 3 months of running.

USDA Hatch funds supported Allen Hansen's research on Evaluation of Biomass-derived Alternative Fuels for Off-road Vehicles. Selected biomass-derived fuels were evaluated as to engine performance, durability and emissions. The laboratory tests were used to optimize engine parameters for minimum emissions and maximum performance. Tests of B2, B5 and B100 in a turbocharged diesel engine showed up to 12% increase in NOx emissions compared to petroleum diesel. However, addition of ethanol to the base fuel suppressed part of the increase in NOx emissions.

In research supported by the Campus Research Board, Allen Hansen studied the Impact of Soybean Oil Methyl Ester Composition on NOx Generation from Combustion. A negative aspect of ester fuels is that they tend to increase NOx emissions. Special emphasis was placed on accurately representing fuel properties. Experiments and 3-dimensional fluid dynamics were used to study the ester composition effects on NOx formation. Results showed that relatively small changes in ester composition can reduce NOx emissions to be equal to or less than those from petroleum diesel fuel.

USDA Hatch funds were used to support Allen Hansen's research on Impact of Biofuels on Emissions Reducing Technologies for Off-road Diesel Engines. The purpose was to evaluate the impact of biofuels on both present and emerging emissions reducing technologies. The strategy of using exhaust gas recirculation to reduce NOx emissions was more effective with biodiesel than with petroleum diesel. Under high loads, EGR rates of 5 to 5.5% were sufficient to reduce NOx emissions to equal those of petroleum diesel. The biodiesel used was the methyl ester of soybean oil.

The US Department of Energy supported work by C.F. Lee, Allen Hansen and D. Kyritis on Graduate Automotive Education (GATE) Center of Excellence: Advanced Automotive Bio-fuel Combustion Engines. The objective of the Center of Excellence is to create an educational and research program to provide automotive engineers with knowledge and skills to develop future engines to run on biofuels such as ethanol and biodiesel.

In work supported by the US Department of Energy, C.F. Lee and Allen Hansen did an Investigation of Biodiesel-Fueled Engines Under Low Temperature Combustion Strategies. Laser diagnostics and multidimensional modeling were used to investigate a novel low-temperature combustion (LTC) strategy with biodiesel. The aim of the LTC strategy is to reduce NOx and particulate emissions while achieving high combustion efficiency. The large differences in properties between petroleum diesel and biodiesel did not affect the outcome of combustion simulations. The simulations predicted that, compared to petroleum diesel, biodiesel generated higher in-cylinder pressures and temperatures and less soot.

A project on Engineering Solutions for Biomass Feedstock Production was supported by the BP funded Energy Biosciences Institute of the University of California-Berkeley, partnering with the Lawrence Berkeley National Laboratory and the University of Illinois. ABE Participants were K.C. Ting, Allen Hansen, Qin Zhang, Tony Grift, Lei Tian, Steve Eckhoff and Lius Rodriguez. Seven postdoctoral students were also hired to assist with the research. BP funded the program to further the development of cellulose-based ethanol fuel. The five interrelated tasks in the program were pre-harvest crop production; harvesting; transportation; storage; and systems informatics and analysis. The research steps were to evaluate existing technologies; characterize task features; identify information needs and researchable questions; develop prototypes and computer models; conduct experiments and computer simulations; analyze experimental data and simulation output; and deliver results in the forms of operational machinery design/prototype and decision support information/tools. To grow micanthus and other feedstocks, 340 acres of UIUC farmland were set aside. The research was initiated in 2007 and was on going at time of writing.

Robotics

In research supported by a C-FAR Sentinel grant, Tony Grift, M. Bohn, Lius Rogriguez and A. Hager studied Development and Evaluation of High Efficiency Flexible Intelligent Farming tools – Phase I, Autonomous Weed Control. They worked on developing a flexible weeding system capable of identifying weeds and treating them based on their response to glyphosate (Roundup). Weeds responsive to glyphosate were treated chemically while resistant weeds were treated mechanically. The operations were carried out by autonomous robots having wireless Internet connectivity for access to a weed image data base and for remote monitoring of robot performance. The work was on going at time of writing.

With support from the Japanese Society for the Promotion of Sciences, Tony Grift and Y. Nagasaka worked on Development of Autonomous Robots for Biosystems Applications. An autonomous robot (Ag Tracker) was developed as a sensor carrier for crop scouting. Several walking robots were developed to demonstrate the potential of robots for crop scouting. A robot was developed as a carrier for a soil-sampling device that was developed at the University of Nebraska.

Mechatronics

At the request of a hydraulic components manufacturer, Carroll Goering and MS student C. Chou investigated the accuracy of the orifice equation in predicting pressure losses. A new model was developed to calculate more accurate values for the orifice flow coefficient as a function of Reynolds number.

Carroll Goering, Qin Zhang and PhD student Ruth Book developed a prototype mechatronics valve. Computer software permitted the generic valve to perform the functions of many specialized valves and also permitted implementation of control strategies previously not achievable. A disclosure was filed with the University's intellectual property office but, by the time they filed a patent application, Caterpillar Inc. had filed an application for a similar valve a few months earlier.

With support provided by Caterpillar, Inc., Qin Zhang and D. He researched a Wavelet-based Fault Diagnosis for Pump Health Assessment. The goal was to identify healthy, worn and damaged pumps based on feature extraction from pressure wavelets. The researchers found that wavelet analysis can improve the capability of diagnosing piston pump health and identify types of pump defects. The results were brought the attention of industry via publication in a national journal.

The National Fluid Power Association supported work by Qin Zhang on Maintenance and Fault Diagnosis Tools for Hydraulic Pumps. The goal of the on going program is to give undergraduate and graduate students a better understanding of fluid power through participation in research on pump maintenance and fault diagnosis, enabling them to evaluate the health and maintenance requirements of a fluid power system.

Qin Zhang's Study of Control Methods on Electrohydraulic System Performance was supported by the National Fluid Power Association.

The influences of variable delays, such as sensor delay and loop-time delay, were studied using a hardware-in-the-loop simulator to evaluate their effect on overall system performance. For example, the simulator was used to develop a successful electrohydraulic steering controller for automatic guidance. The simulator was also useful as a laboratory module in teaching undergraduate and graduate courses on electrohydraulics.

Automatic guidance

John Reid worked on Vision-based Guidance and Control of Field Machinery. The systems he developed based automatic guidance on pathways defined by crops, rows and artificial markers. An algorithm was developed to extract the guidance directrix based on machine vision images of crop rows.

Qin Zhang conducted research on Intelligent Navigation Control for Off-Highway Equipment with Automatic Guidance. Objectives were to develop an interactive electrohydraulic steering simulator with steering load control for reproducing load spectrums on various terrains and to develop advanced algorithms for electrohydraulic steering control. The simulator and algorithms that were developed were later used in research sponsored by Deere and Company on Automatic Tuning and Adaptive Control Technologies for Intelligent Vehicle Path Tracking.

USDA Hatch funds supported a study by Qin Zhang and John Reid on Fuzzy Controls for Mechatonized Off-Road Equipment. The goal was to develop an automated guidance system based on the hypothesis that an intelligent control system can use experience, common sense and intelligence similar to that used by human drivers in maneuvering equipment. The automated guidance system included technologies for redundant guidance sensing, vehicle path planning, sensor fusion and fuzzy controls for electrohydraulic steering control. The guidance system was developed and implemented on an agricultural tractor.

In January, 2001, John Reid left the department to accept a position with Deere and Company. A while later, Deere and Company began offering their Auto-Trac automatic guidance option for their tractors. Also, Deere and Company began supporting related research in the ABE department.

With support provided by Deere and Company, Shufeng Han and Qin Zhang initiated a project on Dynamic Performance Evaluation of GPS Receivers and GPS Guidance Systems. The project was to develop a procedure for performance evaluation of commercial DGPS receivers and to provide an independent evaluation of such receivers. The researchers developed a method to evaluate the GPS dynamic position accuracy of eight commercially available DGPS receivers under linear parallel-tracking applications. The dynamic performance of a receiver was extremely variable from test to test. The cumulative frequency distribution of the pass-to-pass average error provided a good statistical measure of the GPS dynamic accuracy. The results were reported in an article in a national journal.

Qin Zhang, with support provided by Deere and Company, investigated Vision Guidance for Wheel-Type Agricultural Tractors. The aim was to develop a vision-based system capable of detecting crop rows or crop edges in typical farming operations. A search algorithm was developed to use posture sensors to determine the current tractor position and a tractor dynamics model to estimate the future tractor position. The posture sensors included a real-time kinematic global positioning system (RTK-GPS) receiver and a fiber-optic gyroscope (FOG). The outputs from the dynamic path search algorithm were tractor lateral deviation and the desired yaw angle. Based on these outputs, an intelligent navigator created appropriate steering angles to guide the tractor along the desired path. The results verified that this dynamic path search algorithm could navigate an autonomous tractor in accurately tracking the desired path to perform agricultural operations.

Using support provided by Deere and Company, Qin Zhang did an Investigation on Automatic Tuning and Adaptive Control Technologies for Intelligent Vehicle Path Tracking. Representative controllers, such as PID, feed-forward PID, fuzzy, sliding mode and LQR controllers were implemented on a laboratory scale, hardware in the loop control system simulator to provide preliminary validation of the controllers. Strengths and weaknesses of each candidate controller were identified.

Qin Zhang, with support from Deere and Company, studied 3-D Density and Density Maps for Stereo—Based Navigation. Stereovision cameras potentially provide a 3-D format for detecting objects in the path of autonomous vehicles. The research goal was to develop the concept of using 3-D density and a density map to represent the detected objects in profile and location with sufficient accuracy and reliability needed for safe operations. Field tests with a standing person as the obstacle indicated that the system could reliably detect the obstacle and its motion in the path of an agricultural vehicle. The accuracy decreased as the distance between the obstacle and the vehicle increased. The results were reported in an article in a national journal.

Deere and Company provided support for Qin Zhang's project on Sensor Fusion Development for Auto Trac Guidance Systems. The primary focus was on integration of a low-cost IMU sensor with GPS to provide an accurate, robust navigation input for Auto Trac guidance systems. The integrated sensor system was tested in multiple farm fields.

Site-Specific (Precision) Agriculture

In a C-FAR supported study, Carroll Goering, John Hummel, Rob Hornbaker and PhD student Jing Liu developed an artificial neural network (ANN) to set spatially referenced maize yields on the basis of soil, weather and management factors. Setting realistic yield goals in each part of a field is an important first step in site-specific agriculture. Thirty years of data from the Morrill Plots were used to train the neural network. The ANN was able to account for about 80% of the yield variation in the plots.

In a study supported by C-FAR, Lei Tian, John Reid and PhD student Brian Steward worked on a Low-Input and Nonchemical Weed Control System. The goal was to integrate a machine-vision sensing system with a herbicide sprayer to create a mapping system for weed control. A system was developed to characterize plant features necessary for crop and weed identification. The neural network-based, pattern-recognition algorithm was able to separate broad leaf weed images from grass weeds based on texture differences. The results were reported in a national journal article.

Lei Tian and John Hummel worked on Development of a Precision Herbicide Application System. The goal was to develop a robotic system for applying herbicide only to target weeds during soybean and maize production. Specific tasks were to identify the current state of the technology, develop a working prototype and evaluate it in normal farming operations. A "smart sprayer" was developed. It used a sprayer-mounted machine vision system to identify weeds and turned on the appropriate individual nozzles on the spray boom to apply herbicide to the weeds.

With support from C-FAR, Lei Tian and John Reid developed a "Smart Sprayer" Expert System for Site-Specific Weed Management. The goal of the research was to use the smart sprayer as a research platform to establish a data base on weed distributions, i.e., the "patchiness" of weeds and to further optimize the smart sprayer to bring it closer to commercialization. Results showed that weeds are not uniformly distributed in fields, but grow in patches with up to 90% of the field being weed free.

The Sentinel program of C-FAR supported research by Lei Tian, Don Bullock and J. Westervelt on Developing an Agricultural Remote Sensing Program at the University of Illinois. The program aims were to assess the needs of farmers for remote sensing, develop key technologies needed NASA remote sensing applications in precision agriculture, and foster cooperation among scientists working in precision agriculture and remote sensing. The Illinois Laboratory for Agricultural Remote Sensing was created in the ABE department.

The NASA CRSP Ag20/20 Initiative provided funding for a study by Lei Tian, Lloyd Wax, C. Sprague and MS student Kelly Thorp on Variable Rate Herbicide Applications Using Remotely Sensed Imagery. The goal was to evaluate the effectiveness of variable-rate sprayer technology based on remote sensing in terms of cost savings, effectiveness in eliminating weeds and ability to maintain crop yields compared to traditional methods of herbicide application. In a continuation of the study, the North Central Soybean Research Program sponsored research by Lei Tian and Don Bullock on Using Remotely Sensed Data to Diagnose Soybean Yield Limiting Factors. The objective was to develop sensor-based, within-field maps of weeds, disease and nutrient deficiencies and evaluate their contribution to yield variation. Such data help crop consultants, producers and researchers interpret yield maps and allow appropriate site-specific management options for a field. The spatial quality of the raw hyperspectral data were quite variable and variable soil reflectance was a problem that was overcome be data processing. A successful variable-rate sprayer was developed to apply herbicides based on maps generated from remote sensing imagery. The sprayer was able to achieve a 21% reduction in herbicide use with no significant loss in weed control.

With support of the USDA, Lei Tian, John Hummel, Bob Wolf, Loren Bode and Scott Bretthauer worked on Precise Application of Agricultural Chemicals. Equipment and techniques were developed to improve the application efficiency of agricultural chemicals. Drop size spectra from various atomizers were measured and field-evaluated as to coverage and minimization of spray drift. Sensors and automatic control systems were developed to apply pest control substances as a function of soil organic matter, travel speed and other input variables. Findings from the study were delivered to farmers and professional pesticide applicators through extension meetings and an annual Spray School.

CEMAGREF provided funding for a study by Tony Grift, G. Kweon, E. Piron and F. Rioual on Development of a Smart Spreader System. The goal was to develop a Smart Spreader in which both rate and uniformity are controlled. The study included an investigation of the fundamental flow of particles during spreading. A technique was developed for measuring the Coulomb friction coefficient of sliding particles.

Support from the Citrus Research and Education Center, University of Florida, was used by Tony Grift, M.R. Ehsani and K. Nishiwaki to work on Development of a Yield Monitor for Citrus Fruits. A yield monitor became necessary when traditional fruit bins were replaced by continuous mechanical harvesting machines. A yield monitoring system was developed at the University of Illinois to give yields on a per-tree basis. The system was implemented at the Research and Education Center at the University of Florida.

Other OREE projects

Carroll Goering, PhD student Tim Stombaugh and undergraduate student Corey Neumann developed a total engine performance monitor. The project began as Neumann's undergraduate research thesis. The timing pattern of a needle lift transducer provided data used to calculate engine speed and diesel fuel consumption of the engine in real time. Also in real time, a mathematical model calculated engine torque as a function of engine speed and fuel consumption. Then engine power and specific fuel consumption were calculated. The monitor was brought to the attention of the engine industry via a publication in a national journal.

John Siemens conducted a project on Farm Machinery Selection and Management. A computer program was developed to determine the optimum sizes of a set of farm machines for any given farm. The program schedules field operations for different machinery sets and selects the set that minimizes cost, including cost of lost crop due to untimely operations. The program was brought to the attention of farmers via Simen's extension program.

John Siemens, John Hummel, and E.D. Nafziger conducted research on Tillage Systems. A variety of tillage systems ranging from moldboard plowing to no till were evaluated at five University of Illinois Research Demonstration Centers. Factors studied included crop establishment, growth, yield and weed control under various soil conditions. Results were transmitted to producers via Siemen's extension program.

John Siemens studied Soil Compaction Caused by Wheel Traffic. Treatments included no extra traffic, extra traffic on every other row and traffic over the entire plot before planting. Crop yields decreased due to soil compaction in some years, especially in years when compaction caused inadequate drainage.

Deere and Company supported research by Alan Hansen and Robert Hornbaker on Simulation of In-Field Grain Handling Systems. They fitted combines, grain wagons and semi trucks with data loggers to track their movement and transfer of grain between vehicles. The data were used to verify a model of grain movement and transfer during wheat and corn harvesting. The researchers found that optimization of the combine harvesting pattern can increase efficiency substantially.

Research by Alan Hansen, Robert Hornbaker and Qin Zhang on Real-Time Decision Support System for In-Field Agricultural Operations was supported by Deere and Company. The goal was to develop a decision support system for inter-vehicle, real-time data communication to optimize in-field grain handling by combines, grain wagons, road transport and grain elevators. Wireless communication protocols were established and preliminary field tests of a prototype were successfully completed in the United States and Australia.

Pioneer HI-Bred International, Inc., provided funding for a study by Tony Grift, M. Bohn and J. Novais on Corn Root Evaluation System. The researchers developed a system for efficiently imaging a large number of corn roots. The images were stored and characterized using fractal dimension and entropy to distinguish among corn genotypes.

Another use was to identify genetic markers that have distinct effect on room development under varying soil conditions. A database was developed containing root morphology images for a wide spectrum of corn genotypes grown under diverse field conditions.

Alan Hansen, with support from the Campus Research Board, worked on Development of Portable Tools with Optimum Configuration for Cutting Sugarcane. The goal was to design, build and test portable tools for cutting sugarcane based on engineering and ergonomic principles to maximize productivity and quality while minimizing stress on the human cutter. A platform was developed to measure sugarcane cutting forces and blade acceleration to use as inputs to a biomechanics model.

BEE Research

Research scope and activities in the Bioenvironmental Engineering (BEE) Section underwent noticeable change in 1990s and then growth in the first decade of 21st century.

The change was manifested in 1994 by changing the section name from Structures and Environment (SE) Section to BioEnvironmental Engineering (BEE) Section. Donald L. Day, SE Section Leader, a 32 year veteran of the faculty in ABE at UIUC, retired in 1994. Gerald L. Riskowski, succeeded Day as the Section Leader. The name change to BEE Section reflected the evolving research scope among the faculty, which has been gradually shifted from a more structures oriented program to a more bioenvironmental focused program. Two new faculty members, were added. In 1992, Ted L. Funk filled up the Extension position of Arthur Muehling who retired in 1992; and, in 1996, Yuanhui Zhang filled the teaching and research position of Donald L. Day.

Bioenvironmental engineering is defined as the engineering of environmental systems immediately surrounding the living things – animals, human plants and organisms. Research activities in the 1990's include the following highlights:

Laboratory animal environment: Motivated by biomedical research needs, laboratory animal living environment, in rooms or cages, became a key concern due to animal health and medical research validity. Several research projects were funded by NASA and NIH to BEE faculty (Christianson and Riskowski) to study the living environment in the laboratory animal rooms and cages including measurement and control strategies for ammonia, carbon dioxide and particulate matter concentrations, ventilation rates and thermal conditions.

The indoor air quality program includes swine odor measurement and abatement technologies. Animal building air quality research includes lagoon covers, oil sprinkling, catalytic conversion of swine odor and ammonia. Particulate matter research includes the development of an aerodynamic air cleaning technology (aero-deduster) to remove dust particles from air flow. The aero-deduster research was later expanded to the area of off-road machinery cooling-air cleaning and other civil and military applications funded by US Army, Navy, Deere and Caterpillar. Yuanhui Zhang developed a new senior/graduate level textbook entitled "Indoor Air Quality Engineering".

The Bioenvironmental Structural Systems (BESS) Laboratory was established in 1990 focused on agricultural fan and ventilation equipment testing. By the end of 1990s, the BESS Lab became a nationally and internationally known facility, and publishes an annual report on agricultural fan performance. Approximately 95% brands of agricultural fans manufactured in North America were tested in the BESS Lab. It is estimated the testing results helped to improve fan energy efficiencies 20%.

Non-intrusive, full scale, quantitative and instantaneous measurement techniques for airflow in entire airspaces (versus single point measurements) were needed, especially in the area of developing CFD models. The BEE group investigated the measurement technology of 3-dimensional, volumetric particle tracking velocimetry (VPTV) to measure and model large volume fluid flows such as room air. Using this technology, BEE researchers successfully measured the cabin flow field and pollutants distribution in a full scale Boeing 767 aircraft cabin section containing 35 mannequins. This project was funded by CDC and Boeing.

Since 1996, BEE researchers have pioneered research on a Thermo-Chemical Conversion (TCC) of swine manure into crude oil. Zhang's group mimics the crude oil formation process in nature – biomass buried underneath the earth subjected to high temperature and pressure and then formed into crude oil over millions of years – and successfully converted swine manure into crude oil for the first time in 1999. They continued work with feedstocks including human and food processing waste, and biomass including algae and lignocellulose. The specific technology is called the hydrothermal process (HTP) and directly converts the mixture of biomass and water into a bio-oil. The technology was later licensed to industry which has since developed pilot and commercial plants.

The impact of BEE research also resulted in a noticeable impact on the professional communities. Data, testing procedures and research results are included in the Handbooks of ASABE and ASHRAE.

The first decade of the 2000s was a time of growth. In January 2002, Gerald Riskowski left the department to become Head of Agricultural and Biological Engineering Department at Texas A&M. Yuanhui Zhang succeeded Riskowski as the BEE Section Leader. Xinlei Wang joined the BEE faculty in December 2002 to work on air quality and renewable energy systems. Lance Schideman filled the position of Leslie L. Christianson who retired in 2007. Schideman's area was water quality control processes and wastewater bioenergy systems. Angela Green joined the BEE in February 2008 to work on animal wellbeing and production systems. Richard S. Gates was recruited in August 2008 as the first 'Faculty of Excellence' hire in the Agricultural and Biological Engineering Department. His area was building environmental control. The expansion of faculty substantially extended the research portfolio in BEE and cross linked to other sections and disciplines, notably:

Engine emission control – Xinlei Wang extended his indoor air quality research to engine emission control. His research attracted funding from USEPA, and industry including Deere and Company and International Trucks and Engines Corporation. Diesel engine powered agricultural equipment and highway vehicles were a significant source of air pollution, which posed a significant challenge to the engine manufacturers. Wang's research was to develop after-treatment technologies to clean the exhausted air, including system simulation and a model-based control strategy to control the emissions from diesel engines. He also partnered with the USEPA, Cummins Inc. and the local mass transit district to reduce emissions from city buses.

Water purification and bioenergy production by growing algae – A major theme of Schideman's research program was the combination of environmental benefits with bioenergy production. One example was the use of algae for biological treatment of wastewaters and subsequent harvest and conversion of algal biomass to produce various liquid biofuels. This work was synergistically linked with the ongoing TCC work in Zhang's group to produce algal biocrude oil and provide post-treatment and reuse of TCC process wastewaters. This research showed how these bioreactor systems could be used alone or in combination with other membrane and adsorption treatment technologies to yield valuable energy resources and removing excess nutrients, pesticides, residual pharmaceuticals and endocrine disrupting compounds, which reduces overall environmental pollutant loads and facilitates water reuse applications.

Animal well-being and animal production facilities – Angela Green added a new dimension and bridge with animal sciences, combining principles of engineering a controlled environment with a better understanding of the occupant, including physiological and behavioral responses to environmental conditions and housing systems. One key aspect of Green's work involved preference testing, a way to get direct feedback from an animal about its perceptions. Other important research included development and refinement of technologies for measuring animal feedback, and quantification of real-world environmental conditions in commercial animal production. Green approached each animal housing analysis from a systematic perspective, considering not only animal welfare, but additionally aspects of management, environmental impacts, and economical components. Green and Gates were responsible for the Animal Welfare and Environmental Systems Laboratory (AWES Lab).

Controlled building environmental program – the interaction between building systems and their occupants, whether plants, animals or people, had long been a core strength of the BEE program. In 2008, Rich Gates joined the group, bringing ongoing projects on agricultural air quality focused on livestock and poultry emissions from production facilities, mitigation techniques including biofilters and dietary manipulation for egg laying hens. He began initiating new efforts in controlled environment plant production and cooperative efforts with the VPTV group (focusing on CFD model validation) and with Green on animal preference testing. He initiated two international student exchange programs, one with two Brazilian universities and another with four European universities, both focused on the further development and definition of biological engineering within the context of agricultural and biological engineering.

Food and Bio Process Engineering Research

J. Bruce Litchfield joined the Agricultural and Biological Engineering Department in 1986 to teach food engineering courses and conduct research related to food engineering. He used magnetic resonance imaging (MRI) to measure physical properties of food materials with Shelly J. Schmidt (Foods and Nutrition) and Paul C. Lauterbur (Medical Information Sci.) They measured water diffusivity, thermal conductivity, and thermal diffusivity, and physical structure during processing of grains, seeds, and model foods. They were able to map temperature profiles of flowing food particles which for the first time enabled researchers to non-invasively measure temperatures of particulates in aseptically processed foods. Measurement of temperatures at the coldest spot in food particles enabled verification of effective sterilization of thermally processed foods. In 1994, J. Litchfield, J. Reid, and C. Harper (FDA) investigated MRI and other technologies for detection of defective seals in flexible food packages.

In 1992, Litchfield, J. Bentsman, and N. Miller (Mech & Industrial Engr.) developed a knowledge-based adaptive, fuzzy logic, and neural control system for providing optimal drying conditions for dried food products. In 1992, Drs. Litchfield and Eckhoff developed a 3-dimensional model for moisture movement within a corn kernel during steeping. The model was verified using MRI.

In 1997, Litchfield and K.M. Ghiron developed a magnetic thermometry process to measure temperatures in particles of multiphase foods during aseptic processing. The system utilized magnetic sensor beads, pick-up coils, and a magnetic sensor.

Litchfield, Eckhoff and Mike E. Tumbleson developed alternative separation techniques to recover biosolids from a food processing facility using various biological or food materials instead of commercial flocculants. Recovered biosolids that did not use commercial polymer flocculants could then eventually be used as an animal feed supplement. In 2001, K. Rausch, S. Eckhoff, V. Singh, and M. Tumbleson investigated use of microfiltration of liquid streams from corn wet mills to recover protein and other nutrients as an alternative to using centrifugation, evaporation, and vacuum belt filtration to reduce capital and energy costs.

Litchfield and John F. Reid used in situ image processing with a microscope to monitor cell growth during a fermentation process. Their system used an automatic sampler to deliver microliter-sized samples from a fermentor to a microscope stage. Image features enabled decision making related to environmental conditions in the fermentor.

In the fall of 1997-98, Litchfield started work as a half-time rotating Assistant Dean for the College of Engineering and later became an Assistant Dean in the College of Engineering.

Steven R. Eckhoff joined the Agricultural Engineering Department in 1987 to conduct "value added" research related to corn wet milling. He and his graduate student, L. Du, developed an innovative alkali wet milling process using sodium hydroxide to disrupt the endosperm protein matrix. After alkali debranning of the corn kernels, grinding, and steeping in dilute alkali, total process time was reduced to 1.5 hours with product yields comparable to conventional wet milling. Then Eckhoff and his graduate student, J.F. Lopes, developed an Intermittent Milling and Dynamic Steeping (IMDS) process in which the corn kernel is milled in stages followed by steeping, allowing fast hydration and diffusion of sulfite into the endosperm. This process enabled high starch recovery in only 5 hours compared to normal times of 32 to 56 hours. In conventional steeping of corn in a wet milling operation, the corn is soaked in a solution of sulfur dioxide so that the SO2 can break bonds holding a protein matrix tightly to starch granules. An increase in starch appeared to also come from having less starch left in the fiber fraction.

In another study, Eckhoff with J. McKinney, used gaseous SO2 to diffuse the SO2 into corn kernels 100 times faster than when a liquid solution is used. They found gaseous SO2 cut steep times to ¼ to ½ of normal steep times which would save about 8% of the capital costs of a wet mill. In 1992, Eckhoff and E.J. Fox steeped high lysine corn and found that soft corn such as high lysine requires much lower steep times than hard endosperm corn. In 1993, Eckhoff and K. Rausch developed a resistance/ capacitance method for determining ambient-dried corn from adversely dried corn.

In 1994, Eckhoff with S.K. Singh, K. Rausch, and Am Mistry developed a 100-g lab wet milling procedure which later became the standard reference test used for extractable starch through out the corn wet milling industry. That year Eckhoff, K. Yaptenco, and E.J. Fox developed a lab-scale countercurrent steepbank for simulating steeping operations in a corn wet mill.

In 1997, Eckhoff with P. Yang, and R. Denhart designed a lab-scale steep battery as a computer-controlled system. In 2000, Eckhoff with K. Rausch and P. Yang steeped corn at 50°C with SO2 levels of 1000, 2000, and 3000 ppm for 18, 24, 30 and 36 hours in their countercurrent steep battery. Starch yield was significantly increased by increasing S02 level or by longer steep times.

Eckhoff with graduate student, V. Singh, developed a "Quick Germ" process for ethanol production by removing the corn germ prior to fermentation. This was the beginning of a later patented process that became widely accepted in the dry-grind ethanol industry.

Kent Rausch joined the ABE faculty in 1997. Rausch received his Ph.D. in 1993 from ABE at UIUC with Eckhoff. Rausch spent a year in industry with Cerestar wet milling, followed by three years in Biological and Agricultural Engineering at Kansas State University.

In 2000, Eckhoff with Kent Rausch, Vijay Singh, and A. McAloon developed a "Quick Fiber" process that enabled recovery of pericarp fiber from degerminated corn used in a dry grind ethanol process. The fiber was recovered using hydrocyclones following germ recovery done by the "Quick Germ" process. At that time, this process was estimated to provide a $0.04 per gallon savings by providing increased fermentation capacity by removing fiber ahead of the fermentors. Eckhoff, V. Singh, and R. Moreau with USDA, also determined the best fraction of corn fiber to use for recovering ferulate esters, which have been shown to be good for lowering cholesterol in the blood stream.

In 2001, Eckhoff, D. Gupta, L. Dickey, K. Rausch, V. Singh, and M. Tumbleson developed a "Quick Protein" process to obtain a zein protein rich fraction obtained from corn after undergoing the "Quick Germ" and the "Quick Fiber" processes. In 2001, K. Rausch, S. Eckhoff, M. Paulsen, and M. Tumbleson studied compositional changes in coproduct streams, light gluten and light steepwater, from a corn wet milling plant. Since these streams become part of corn gluten meal and corn gluten feed coproducts, the compositional variability greatly impacts finished coproducts.

In 2006 and 2007, Eckhoff worked with water absorption rates (tempering) of corn and adjunct chemicals to more cleanly separate corn fractions as a preprocess for dry grind ethanol processing.

In 2007 and 2008, Eckhoff and L. Berger compared ruminant digestibility of corn stover at 35-40% moisture to stover at lower harvest moistures.

In 2001, Rausch with J. Faller and S. Eckhoff investigated effects of specific hybrids on dry milling, extrusion variability, and starch rapid visco analysis (RVA). This was the beginning of work on hybrid specific processing.

In 2004, Rausch with V. Singh and R. Belyea from University of Missouri characterized coproducts from dry-grind ethanol processing. They found phosphorous concentrates in the thin stillage stream which is then added to DDGS, distillers dried grains with solubles. Due to environmental concerns with phosphorous, DDGS value is enhanced if its phosphorous content can be reduced. Rausch with V. Singh and M. Tumbleson also investigated dewatering technologies and membrane filtration to recover water and remove nutrients from dilute bioprocess streams. In 2006, Rausch continued work to identity bioprocesses that dewater, dry, or convert solids into higher valued products. In 2008, Rausch, V. Singh, and R. Belyea (University of Missouri) determined membrane filtration and heat transfer fouling characteristics of thin stillage to identify the potential for increased water recycling and reduced energy requirements for a dry grind ethanol plant.

In 2006, Rausch with B. Dien (USDA-ARS) and V. Singh developed a small-scale 25-g dry-grind ethanol test procedure to determine expected ethanol yield from raw corn.

In 1985, S. Gunasekaran, M. Paulsen, and G. Shove developed a laser optical method for sorting corn kernels with stress cracks. In 1986, C. Weller, M. Paulsen and M. Steinberg measured stress cracking and breakage susceptibility of four hybrids dried at 49, 71, and 93°C.

In 1987, M. Paulsen, L.D. Hill, and G.C. Shove reported on the 1986 loading of a 57,000 metric tonne ocean vessel at New Orleans with corn that was shipped to Japan. Two holds were monitored with thermocouples to measure temperatures during the 35-day voyage. Corn within 1 meter of edges and headspace changed in temperature but corn remained uniformly cold within the center grain mass. Corn moisture contents did not change appreciably but breakage increased significantly during and after loading. Dr. Paulsen also started work using machine vision for detection of corn quality factors related to color and kernel breakage.

In 1989, K. Baker, M. Paulsen, and J. Van Zweden determined seed corn drying rates for three F-1 hybrids in thin-layer tests at 32, 40, 48, and 56°C. Warm and cold germination was reduced significantly at the higher drying temperatures.

In 1992, W. Casady, M. Paulsen, J. Reid, and J. Sinclair developed an image pattern classification system using machine vision using chromaticity coordinates to classify fungal damage in soybeans. In 1992, K. Liao, M. Paulsen, J. Reid, B. Ni, and E. Bonifacio developed a neural network classifier using machine vision to identify corn kernels for broken and whole kernels with about 92% accuracy.

In 1996, E. Bonifacio-Maghirang, M. Paulsen, L. Hill, and K. Bender determined single kernel moisture variation of 29% and 10% moisture blended corn. Moistures equilibrated to 18% by the third day.

In 1997, M. Paulsen with W. Xie used machine vision to determine degree of corn kernel respiration and damage based on tetrazolium color staining in pinkish red (healthy), purple (damaged cells), or white (totally dead cells). Kernels heated at 60 °C for 3 hours turned purple, and for 9 hours were dead while unheated check samples remained a healthy red color. In 1997, B. Ni, M. Paulsen and J. Reid developed an electronic corn kernel size grading system using machine vision. Accuracies averaged 74 to 90% based on pre-sized samples run through precision graders.

In 1997, Paulsen, Reid and Irfan Ahmad developed a machine vision to system use color, morphological and textural features to detect soybean seeds with fungal damage from healthy seeds. In 1997, J. Liu and Paulsen determined degree of whiteness of corn kernels using red, green and blue images which were converted to chromaticity coordinates. Machine vision inspections of corn maintained consistency and the same order as human-inspected samples.

In 1998, Paulsen and L. Pordesimo tested soft, medium and hard endosperm corn varieties, harvested at moistures of 30, 25, and 20% which were dried at temperatures of 25, 50, 60 and 70 °C for starch yield and a near-infrared spectroscopy calibration for starch yield was developed. In 1999, Paulsen and S. Mbuvi developed a corn extractable starch calibration for the NIRSystems 6500 spectrophotometer. In 2000, Paulsen and S. Mbuvi conducted high temperature drying at 90 to 110°C and found 0.9 to 16.0 % point reduction in extractable starch using a Foss Infratec 1229 near-infrared transmission calibration. Each % point gain in extractable starch was estimated to be valued at 4 to 6 cents per bu. In 2002, Paulsen, M. Singh, S. Mbuvi, and L. Pordesimo developed and an extractable starch calibration for corn wet milling and licensed it worldwide through Foss North America. In 2004, E. Newgard and M. Paulsen expanded the extractable starch calibration with more corn varieties and samples. In 2005, the extractable starch corn calibration was licensed to a major spectrometer company and became publicly available.

A project involving garlic bulblets in wheat was initiated with Eckhoff, Paulsen, E. Jones from Virginia Tech University and D. Eustace at Kansas State University. Helping on the project were L. Obaldo, B. Ye, and J. Liu. The relationship between garlic bulblet concentration and plugging of break rolls in flour mills causing economic loss was investigated, so that possible changes to USDA grading practices could be recommended. In 1999, kernel density and dimensional measurements of garlic bulblets and wheat kernels were determined to evaluate alternative sieving and cleaning methods. Garlic bulblets were found to have strong affinity for water and were usually found over a riddle sieve and larger sieves.

In 2004, Paulsen and S. Nimaiyar scanned ground soybeans and developed a Fourier transform near-infrared reflectance (FT-NIR) calibration for isoflavones in soybeans. In 2005 they developed FT-NIR calibrations for palmitic, stearic, oleic, linolenic, and linolenic fatty acids in ground soybean samples.

In 2006, Paulsen and S. Rathore used FT-NIR to identify and determine ethanol and total sugars in fermentation broths for a dry-grind ethanol process. In July 2006, Paulsen retired from the Agricultural and Biological Engineering Department after 31 years of service. In 2007, Paulsen with S. Rathore continued a project to develop a FT-NIR calibration to classify corn hybrids based on predicted ethanol yields. In 2008, Paulsen and S. Rathore developed a calibration and used FT-NIR to monitor a lab-scale liquefaction process to determine the effect of reaction time, initial enzyme dose, and corn hybrid on dextrose equivalent (DE) values.

Vijay Singh received his Ph.D. in 1998 from ABE at UIUC with Eckhoff. Singh joined the ABE faculty in 1998 as a Visiting Assistant Professor but was working at the Eastern Regional Research Center/ARS/USDA, at Wyndmoor, PA. While there he conducted research on developing enzymatic milling for the corn wet milling process and optimizing recovery of nutraceuticals from corn and other cereal grains. Later, in June 2002, Singh became an Assistant Professor at the University Illinois to teach and conduct research on process development and value added processing of corn for wet milling and dry grind ethanol processes.

Singh worked to develop novel corn fractionation technologies for corn dry grind ethanol and for corn wet milling processes. In the corn dry grind process approximately 70 percent of the fuel ethanol in the US is produced by the corn dry grind ethanol process. The dry grind process suffered from low coproduct value. Improving process efficiency and increasing the number of coproducts and their value reduces the cost of ethanol production and increases the viability of the ethanol industry. He and others developed several modified dry grind ethanol processes that allow cost-effective removal of germ, pericarp fiber and endosperm fiber as valuable coproducts at the beginning of the dry grind corn process. Additional benefits of these modifications are an increase in quality of coproducts and greater ethanol production per batch. He received two US patents and filed two more patent applications with United States Patent and Trademark Office. Two issued patents are being negotiated for licenses.

The conventional corn wet milling process currently uses sulfur dioxide to steep and process corn for starch. Sulfur dioxide is a health and environmental concern.

Dr. Singh and others developed an enzymatic corn wet milling process that reduces or eliminates sulfur dioxide requirements during steeping, which considerably reduces steep time and produces starch yields comparable to conventional corn wet-milling. Significant amounts of capital and energy savings are realized due to shorter steep times. He received another US Patent for this work and it has been licensed to a major US company. Singh and F. Taylor, ARS/USDA, received a patent in July 2003 entitled "Method for removing the hull from corn kernels."

In 2003, V. Singh and D. Johnston with ARS/USDA developed an enzymatic corn wet milling process that greatly reduces need for SO2 for steeping which would reduce environmental and health risks associated with use of SO2. In 2005, they found enzymatic milling reduced process time by 70% and maintained acceptable product yields and quality. In 2006 they evaluated enzymatic milling with corn wet milling processors. In 2008, they licensed the enzymatic milling technology to a major enzyme company and conducted commercial enzymatic milling trials with wet millers in Malaysia, India, and Turkey.

In 2003, Rausch and Tumbleson with M. Wilkins studied hybrid specific effects on starch modification. The work investigated reaction characteristics of starch samples obtained from single hybrids and found that initial (unmodified) starch characteristics were apparent following modification.

In 2005, V. Singh, L. Hoyer, D.B. Johnston and M. Tumbleson investigated strategies to control microbial growth in corn wet milling using enzymes in place of sulfites.

In 2005 and 2007, Rausch, L.M. Raskin (Civ Env Eng, now at U of Mich) and M.E. Tumbleson characterized processing streams in the corn wet milling process. This identified variability of process operation and identified opportunities for improved coproduct value in the wet milling process.

In 2004, V. Singh and J. Graeber with Syngenta Seeds investigated corn hybrid variability and planting location effects on ethanol yield. Singh and Rausch tested exogenous alpha amylase transgenic corn during liquefaction and fermentation as a means to use fewer enzymes during dry-grind liquefaction processes. In 2005 to 2008, Drs. Singh and Rausch worked with a major seed biotechnology company to determine liquefaction and fermentation properties of endogenous amylase corn for dry grind ethanol processing.

In 2005, Singh, Rausch, Tumbleson and G. Murthy simulated starch hydrolysis using a Monte Carlo simulation technique on a starch structure and combined it with a flux balance analysis (FBA) and cybernetic model for yeast metabolism to develop an optimal control of SSF. Optimal control of the dry grind SSF process resulted in reduced fermenter glucose concentrations, <2.0% w/v. Compared to the standard SSF process, use of the optimal controller resulted in 50% reduction in enzyme (glucoamylase) required for the SSF process under varying operating conditions. The optimal controller was tested in a commercial Midwestern dry grind ethanol plant and a 35% reduction in glucoamylase dose was observed compared to control treatment; final ethanol concentrations were similar for optimal controller and conventional treatments.

In 2006, Rausch, Singh and Tumbleson with M. Wilkins investigated the tendencies of thin stillage to foul evaporator surfaces. Thin stillage is a process stream from corn ethanol production and eventually becomes part of the distillers dried grains with solubles (DDGS) coproduct. They found that thin stillage fouled evaporator surfaces readily, but the rates were variable. Additional work in 2009 and 2010 with A. Arora determined that microfiltration membranes affected fouling rates and may be an effective method to reduce evaporator fouling. In 2003, Rausch, Singh and Tumbleson with R. Agbisit reported a similar effect when microfiltering steepwater from the corn wet milling process.

In 2006, V. Singh, K. Rausch, M. Tumbleson, E. Khullar and E. Sall from Monsanto investigated effect of corn genetics, planting population and post harvest conditions on modified dry grind processes for coproduct yields and fermentation profiles.

In 2007, V. Singh, K. Rausch, M. Tumbleson, B. Vidal and Jim Liu of Novozymes NA investigated use of granular starch and proteases in dry grind corn fractionation processes to improve rate of fermentation and increase ethanol yield.

In 2008, V. Singh, C. Parsons, J. Pettigrew, and K. Rausch developed a sieving and air separation process (called Elusieve) to separate fiber from DDGS. Since the Elusieve process removed fiber, feeding studies on roosters and hogs were conducted to determine total metabolized energy and true digestibility of amino acids in this low-fiber DDGS.

In 2008, Singh, Rausch, Tumbleson and J. Shihadeh developed simultaneous liquefaction, saccharification, fermentation and distillation (SLSFD) process for dry grind production: process that allows high solids (>32% w/w) fermentation. SLSFD process with 40% slurry solids was evaluated and compared it with the conventional process. The SLSFD process fermented slurry with negligible residual glucose content. However, with the conventional process residual sugar in beer started increasing at 20 hr and final residual sugar concentration of 5% (w/v) was observed. Ethanol productivity of the SLSFD process was 20 to 40% higher compared to the conventional process.

In 2007, Singh, Rausch, Tumbleson and V. Sharma, V evaluated the effect of different amylose and amylopectin ratios in starch that was processed through two different enzymatic techniques: commercial alpha and glucoamylases and raw starch hydrolyzing enzymes. In both processing techniques, the study shows that as the amount of amylose is increased in starch, the ethanol yield decreases.

In 2006, V. Singh, C. Batie, G. Aux, K. Rausch and C. Miller from Syngenta Biotechnology evaluated transgenic corn (amylase corn), containing alpha amylase in the corn kernel (endogenous enzyme) in a conventional dry grind ethanol process. With amylase corn no exogenous alpha amylase is required in the process. The study evaluated 3, 5 and 10% of the amylase corn with conventional yellow dent corn. No difference in final ethanol concentration was observed between the amylase corn treatments and the control treatment (in control treatment exogenous liquefaction enzyme was used).

In 2007, V. Singh, P. Wang, H. Xue, D. Johnston, K. Rausch and M. Tumbleson compared granular starch hydrolyzing (GSH) enzyme with conventional enzymes in dry grind ethanol process. Final ethanol yields with GSH enzymes are comparable to yields using conventional enzymes. However, glucose, maltose and maltotriose concentrations are consistently low with GSH enzymes throughout fermentation. Lower sugar concentrations during SSF helps yeast during fermentation and prevents bacterial infections. GSH enzymes work at the same temperature and pH conditions as conventional and can lower energy requirements in ethanol production.

Biological Engineering

Luis Rodriguez, Richard Cooke, Yuanhui Zhang, A. Kent and J. Zilles, assisted by J. M. Andrus, used NSF funding in 2008 to begin a Microbial Community Analysis of Denitrifying Biofilters. Biofilters developed at the University of Illinois have successfully removed 60% of nitrates on average in field trials, but little is known about the microbial community that mediates denitrification. Molecular DNA and RNA methods are available for characterizing microbial community composition and variation of several field biofilters. A time series was planned to link microbial community to biofilter performance.

In 2008 Luis Rodriguez, G. Menezes, A. Kent and M. Appleford used University of Illinois funding to begin the Development of a Framework to Model Microbial Communities in Humic Lakes. The goal was to model microbial communities and their dynamic response to meteorological, physical and chemical conditions using conventional and emerging molecular techniques and data from long-term ecological research stations such as North Temperate Lakes. Predictions from the models could help shape environmental policies and management decisions on ecosystem functions controlled by microbial processes.

Luis Rodriguez, H. Jiang, S. Bell, K. Bhalerao, D. Kortenkamp, A.B.O. Soboyejo and K.C. Ting used NASA funding to do Coupled Analysis of Life Support Systems Reliability Modeling for Robustness and Cost. The research goal was to increase robustness of life support systems by applying the appropriate mix of people and software, develop model-based techniques for diagnosis, prognosis and control, and procedural techniques to support manual operations. Integrated models were developed to analyze a wide array of design architectures for inherent reliability and robustness. Reliability is a major issue in the design of long-term space missions. The research considered several preventive and corrective maintenance plans. Validation was sought through development of new theoretical models for reliability prediction.

Using NASA funding, Luis Rodriguez, H. Jiang, S. Bell and D. Kortenkamp did Validation of Life Support System Optimization. The focus was to demonstrate that application of heuristic tools on life support problems will find optima that are as useful as those identified using traditional analytical approaches. System complexity and the enormous search space create inherent challenges in identifying where the optima exist in the search space.

Luis Rodriguez and G. Menezes used University of Illinois funding to study Bottom-Up Models of the Photosynthesis from the Molecular Scale to Canopy Scale. The intention was to integrate molecular-scale models with existing leaf and canopy-scale models to improve simulation of crop biosystems at molecular, organelle, cellular, tissue, organism and community levels. The immediate challenge was to identify critical information that must be exchanged between different levels. The long term goal was to integrate within a large, complex model such as an agroecosystem model.

Luis Rodriguez, C. Li,, T. Lin, S. Eckhoff, M. Khanna and A. Spaulding used CFAR funding to develop Engineering-Economic System Models for Rural Ethanol Production Facilities. The explosion of small (35-70 million gallons per year) dry grind ethanol facilities suggested the need for extra care in the design and implementation of such facilities. The objective of the research was to develop a model of such facilities for use in decision making by corporate board members and legislatures considering tax incentives for handling of potential pollutants.

In a project funded by the University of Illinois, Grace Danao and her graduate students are working on Development of New Sensing Technologies. In addition to training graduate students, the goal is to develop new sensing technologies for monitoring the health and safety of animals, food systems and the environment. The researchers seek to take advantage of recent developments in the micro-fabrication and integration of biosensors into arrays capable of specific detection of multiple analytes. An example application would be detecting trace volatile compounds resulting from microbial activity in air, soil, water, crops and food samples and determining food quality and safety during storage and transport. A second interest involves using ultrasonic standing wave fields to manipulate and separate micron-sized particles suspended in a fluid medium to enhance the optical detection and quantification of the particles. A third area of study is the use of ionic liquids in gas-phase bio-catalysis. Ionic liquids are salt-like materials that are liquid at room temperature and exhibit unique properties that might be exploited in biosensors, biomass processing, protein stabilization and extraction and purification of natural products.

Multidisciplinary initiatives

In 2005 the Department hired two faculty members (Luis Rodriguez and Kaustubh Bhalerao) followed by the Department's first female faculty (Grace Danao) in 2007, to start the new Biological Engineering section. The goal of this section was to develop multidisciplinary research programs in diverse areas such as Biological Nanotechnology, Synthetic Biology, Biosensors, Ecosystems Engineering and Advanced Life Support Systems. All of these areas are multidisciplinary in nature and have allowed the Department to build bridged with other Departments and Researcher Centers on campus and led to increased visibility of the Department at the campus level. Since these programs are relatively recent and growing quickly, they represent ongoing projects.

Biological Nanotechnology

Kaustubh Bhalerao and his graduate student, Munima Haque, worked on characterizing the mechanism of corn protein aggregation in different solvent conditions. This waxy protein, called zein, constitutes the major fraction of distillers dry grains with solubles (DDGS), the byproduct of ethanol production from corn. DDGS is used to feed swine, but zein is not easily digested and ends up as excess nitrogen in the soil. Zein is resistant against digestive enzymes because of its insolubility in water. However, zein is soluble in a mixture of ethanol and water and is biodegradable in the long run. As a biopolymer, it has potential as a novel renewable resource for developing packaging materials for food or pharmaceutical purposes, and was used as a textile in the 1950s under the brand name Vicara® before synthetic polymers became economically competitive.

Zein's aggregation behavior is similar to behaviors seen in beta-amyloid proteins responsible for Alzheimer's disease as well as other protein aggregation diseases such as bovine serum encephalopathy (mad cow disease) and sickle cell anemia. Thus zein makes an excellent and simple model system from which to learn more about protein aggregation. One Ph.D. student, in collaborations with Civil and Environmental Engineering and the Department of Food Science and Human Nutrition, is studying zein aggregation.

In 2009, Bhalerao and Rashid Bashir (Electrical and Computer Engineering and Director of the Micro and Nanotechnology Laboratory) won an NSF grant to study the effect of aerosolized nanoparticles on cyanobacteria. Cyanobacteria are photosynthetic bacteria that form the lowest strata of our food chain. An imbalance at this level has the potential to transmit up the food chain with an increasing impact through accumulation of the particles in different species. The hypothesis behind this research was that aerosolization can significantly alter the uptake kinetics of the nanoparticles and has implications on the dispersal of particles in the environment. Two MS students, Sun Min Kim and Vaisak Parakett worked on the project. The former has a BS degree in Environmental Engineering, while the latter has a BS in Biotechnology, which highlights the different skill sets necessary to tackle such problems.

Nanotechnology

Introduction

Richard Feynman, in a December, 1959 talk to the American Physical Society at the California Institute of Technology, described molecular machines building with atomic precision, thus introducing what came to be known as nanotechnology. Feynman said that "the biological example of writing information on a small scale has inspired me to think of something that should be possible". The term, nanotechnology, was first used by Norio Taniguchi in a paper he presented in 1974 on an ion-sputtering machining. Nanotechnology can be described as technology in which the structure of matter is controlled at the scale of nanometers, i.e., 1 to 100 nanometers (A nanometer is one-billionth of a meter and a sheet of paper is about 100,000 nanometers thick), where unique phenomena enable novel applications. Nanotechnology involves imaging, measuring, modeling, and manipulating matter at this length scale. Unusual physical, chemical, and biological properties can emerge in materials at the nanoscale. These properties may differ in important ways from the properties of bulk materials and single atoms or molecules.

Theoretical studies in chemistry and physics led to predictions as to the kinds of systems that would eventually be possible as our ability to control the structure of matter at the nanoscale increased. While, in 2009, much of the promise of nanotechnology was still in the future, nanotechnology had already produced some useful products. Among them were antibacterial kitchen and tableware with nanosilver coating, which could also kill bacteria and microbes, and avoid disease. The global market for goods based on nanotechnology was predicted to grow from $147 billion in 2007 to $3.1 trillion in 2015, according to the research and advisory firm Lux Research.

Engineers previously built materials and devices using a top-down approach. By contrast, nanotechnology starts at the bottom, with the most fundamental structures of matter, and offers the possibility of engineering unimaginably tiny devices and systems. Nanotechnology made possible a total rethinking of how we could create faster, lighter, and stronger materials and devices. These ultra-small devices promised extraordinary energy saving features such as multi-functionality, portability, and inter-operability. As nanotechnology developed, it was important to avoid raising unrealistic expectations and anxieties. Nanotechnology was not going to solve all the major problems of the world, nor was it going to produce self-replicating nanorobots that take over the world. However, several of the U.N. Millennium Development Goals were possible by leveraging nanotechnology.

What follows is a snapshot of some of the agricultural, biological, and food applications that, in 2009, were under active research and development at the Department of Agricultural and Biological Engineering in association with the University of Illinois Center for Nanoscale Science and Technology (CNST) collaboratory, and the Micro and Nanotechnology Laboratory (MNTL).

Mechanobiology: Experimental evidence at the confluence of biology and engineering suggested that extracellular and intracellular mechanical forces have a profound influence on a wide range of cell behavior such as growth, differentiation, apoptosis, gene expression, adhesion and signal transduction. Advances in micro and nanotechnology offered unique opportunities for probing biological phenomena at a cellular and sub-cellular scale, which is likely to have major impact on the study of cell mechanics. Irfan Ahmad, Taher Saif of MechSE, and Hanafy Fouly and Henry Wilkinson of NRES worked on developing a nano-electro-mechanical system (NEMS) for pathogenesis of fungi, by studying Infectious hyphae invading cortical tissue for Gaeumannomyces graminis var. tritici , a fungus causing take-all of wheat. The NEMS could be adapted for studying food pathogens such as E.coli and Salmonella.

Nanoagriculture

Biosensors: Increases in the number and ferocity of the hurricanes hitting the U.S. coasts increased the risk of attack on the soybean crops by rust spores. Knowing whether to apply fungicides was a perplexing question. Two different fungal species, Phakopsora pachyrhizi and Phakopsora meibomiae, caused soybean rust with the potential to decimate soybean crops and cause huge economic losses. Therefore, timely detection of soybean rust spore detection was critical. Irfan Ahmad (ABE, CNST, and Micro and Nanotechnology Laboratory), Brian Cunningham (Electrical and Computer Engineering, MNTL), Glenn Hartman (United States Department of Agriculture), and Linda Kull (Soybean Disease Biotechnology Center) worked collaboratively in developing field-deployable biosensors for early detection of the spores.

Carbon Nanotubes for Enhanced Crop Germination and Growth

Carbon nanotubes (CNTs), are allotropes of carbon with a cylinderical nanostructure with novel properties. CNTs can penetrate plant cell walls and significantly influence biological activities by acting as smart delivery systems in plants. Irfan Ahmad at ABE and CNST, Linda Kull (Soybean Disease Biotechnology Center), Fabián Fernández (Crop Sciences), and John Rogers (Materials Science and Engineering) worked on using CNTs to produce for bigger and better soybean seeds.

Nanomedicine for Cancer Research. In 2009, over 70% of the developing world's population still depended on the complementary and alternative systems of medicine (CAM). Evidence-based CAM therapies showed remarkable success in healing acute as well as chronic diseases. Pakistan was among the eight leading exporters of medicinal plants. Kenneth Watkin, College of Applied Health Sciences, Irfan Ahmad, ABE, Brian Cunningham (ECE), University of Illinois, and Atiya Abbasi (Chemistry, University of Karachi) did CAMs research funded by the USAID and the Higher Education Commission of Pakistan. The overall objective was to develop partnerships and strengthen the nanomedicine infrastructure through synergistic integration of research, education, and training. Plant extracts such as curcumin (Curcuma longa) from the University of Karachi were tested using bionanophotonic crystal sensors from the University of Illinois to study their affect on breast cancer cells.

Societal Implications

Irfan Ahmad delivered lectures on societal implications of nanotechnology in biosensors classes at the College of Engineering. Semester-long courses were offered by Irfan Ahmad on Biomedical Applications of Nanotechnology jointly with Washington University Medical School, and were made available to the University of Missouri, and the University of Karachi, Pakistan. The lectures and courses were aimed at engaging the public on the societal issues and opportunities in nanotechnology research and development for agricultural, biological, food, environmental and energy applications.