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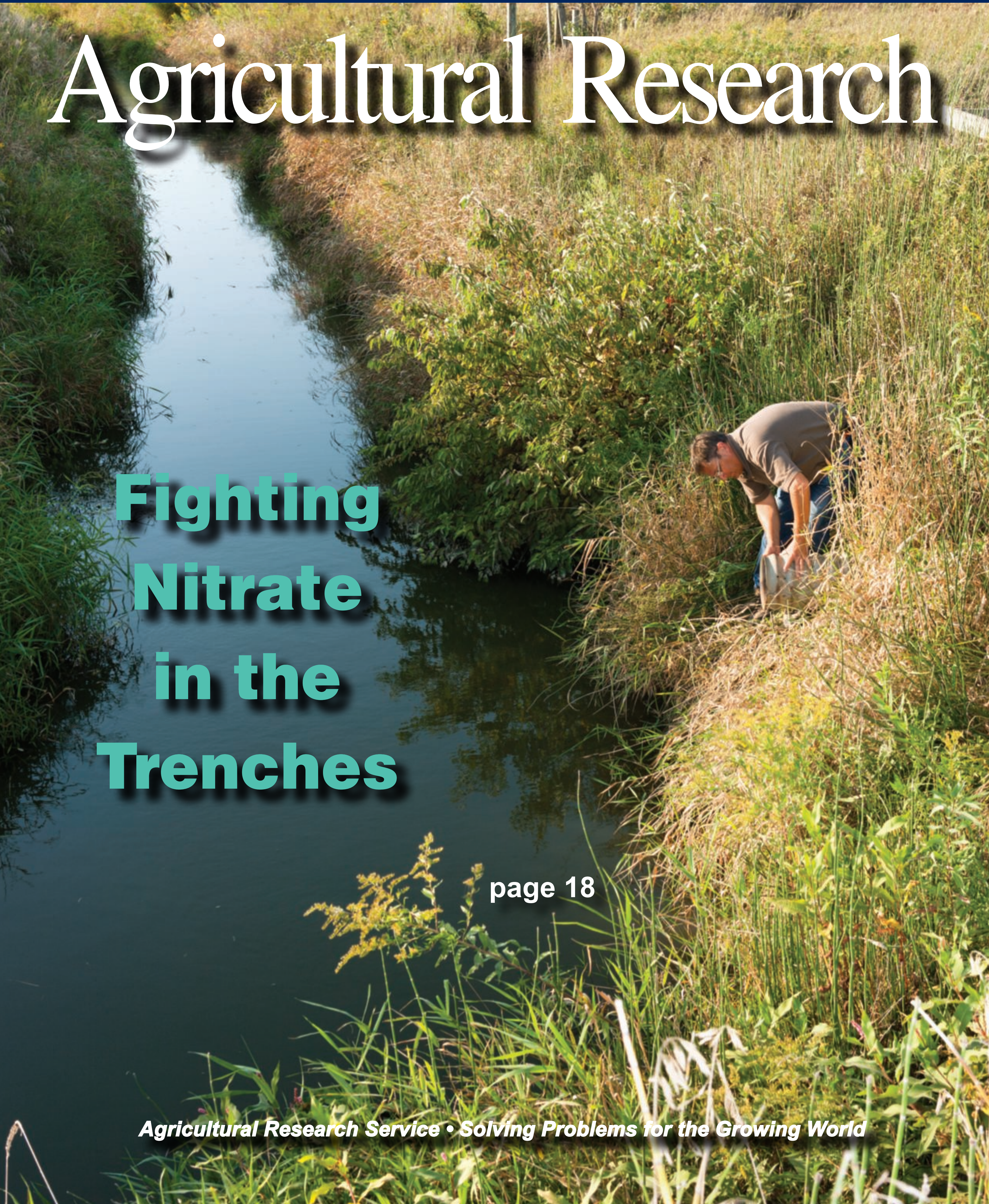

Fighting Nitrate in the Trenches

page 18

Agricultural Research Service • Solving Problems for the Growing World

FORUM

Satellite imagery shows average midday clear-sky evapotranspiration (ET) rates—a measure of water loss from the land—for August 2004. Story begins on page 4.

It Takes a Satellite To Feed the World

It's ironic that just when Earth-monitoring satellites are needed more than ever to address the food and freshwater demands of a burgeoning global human population, we face an impending gap in coverage by the Landsat program. A series of Landsat satellites has been continuously in orbit since 1972, collecting an invaluable time sequence of global imagery that records decades of land-use and land-cover changes. The recent decision by the U.S. Geological Survey (USGS) to provide Landsat imagery free of charge has led to an explosion in applications, enabling unprecedented study of global deforestation, changes in cropping systems and irrigation practices, and conversion of land from its natural state to managed or urban use.

Addition of a thermal infrared channel to the Landsat series in 1982, with Landsat 4, enabled monitoring of not just land use but also water use. Evaporation of water from the soil and transpiration by plants cool the land surface and generate a detectable thermal signal. Using thermal band satellite imagery, scientists have developed techniques for mapping evapotranspiration that are used throughout the world to monitor consumptive water use by irrigated and rain-fed crops. The collective archive of Landsat thermal data provides a nearly 30-year record of global water-use patterns, with enough detail to resolve individual agricultural fields.

Today, the continuity of this valuable historical record is under threat. At present, only Landsat 7 is still collecting data, but at degraded capacity due to a component failure in 2003. (Landsat 5 data collection was suspended on November 18, 2011, after a remarkable 27 years of operation.) Landsat 8 is scheduled for launch by the National Aeronautics and Space Administration (NASA) no earlier than January, 2013. Thus, much of the 2012 growing season will have limited coverage by Landsat imagery, a first since the early 1970s.

Support for continuing thermal imaging capabilities within the Landsat program has also been tenuous. As a cost-saving measure, a thermal sensor was initially omitted from the original Landsat 8 mission scope. An outcry from water managers and governors in the western states, who rely on Landsat thermal imagery for operational water management efforts, persuaded Congress to request that NASA add the Thermal InfraRed Sensor (TIRS) to the Landsat 8 instrument suite already under construction. However, due to time constraints related to the late addition, TIRS has a more limited design life and less internal component redundancy than previous thermal Landsat sensors have had.

Landsat's thermal and optical sensors provide invaluable high-resolution (30 to 120 meters) information for monitoring global production of food and fiber, crop health, available soil moisture, and early warning of drought. Many of these applications are summarized in the story on page 4, describing the research of Agricultural Research Service scientists Martha Anderson and Bill Kustas. But the temporal coverage provided by a single Landsat system—one snapshot every 16 days or longer, depending on cloud cover—is inadequate to meet the real-time needs of agricultural monitoring. Future agricultural satellite systems would ideally provide 1- to 4-day revisit intervals, achieved either by widening the swath of the imaging instruments or flying multiple platforms in staggered orbits.

Global interest in satellite-based crop and water-use mapping has exploded in recent years as demand for food and fresh water expands and increased climate variability imposes new challenges to agricultural communities worldwide. With crop and water-use information at sufficiently high resolution and with dependable, satellite-derived flood/drought early-warning products, the climate resilience of these communities may be significantly improved. Timely information of this type may have enabled earlier and better-targeted mobilization of relief efforts as the 2011 famine unfolded in the Horn of Africa. Satellites are vital to our pursuit of new ways to use science and technology to improve agricultural productivity to feed the world, the core mission of the U.S. Department of Agriculture.

Beyond Landsat 8, the future of the Landsat program and operational land imaging under the auspices of the USGS is uncertain. Initiation of satellite development during fiscal year 2012 appears doubtful, and thus we may not be able to launch the next satellite until sometime after the design life of Landsat 8 expires. We risk yet another gap in Landsat coverage.

The well-being of nations greatly depends on their having ample food and fresh water for the general population. The cost of satellites, their launches, and sensor development is high, but that has to be balanced against the global low-cost data they provide for years once in orbit—and against the value of their role in protecting the world's food and water supply.

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STEPHEN AUSMUS (D2443-1)

In western areas where some rangeland vegetation doesn't contain enough selenium for grazing animals, ewes that consume a natural high-selenium supplement in their food can pass the needed selenium to nursing offspring in their milk. Story begins on page 14.

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Cover: Preventing movement of nitrates from crop fields to streams is the focus of ARS soil microbiologist Tom Moorman's research. Story begins on page 18. Here, Moorman examines a farmer's subsurface drain pipe. Photo by Peggy Greb. (D2403-1)

A New Way To Map Drought and Water Use Worldwide

Physical scientist Martha Anderson and research leader Bill Kustas view a global scale map of evapotranspiration generated with the ALEXI model. Anderson and Kustas are collaborating with U.S. and international researchers from all the major continents in evaluating ALEXI output.

Every month, the National Oceanic and Atmospheric Administration's (NOAA) Center for Climate Prediction has a drought briefing by teleconference to identify the latest drought areas in North America.

ARS scientists Martha Anderson and Bill Kustas are hoping that in a year or so, data from their computer model/satellite package will give evapotranspiration (ET) maps a seat at that briefing. With funding from NOAA and the National Aeronautics and Space Administration (NASA), they have developed a modeling system that NOAA will use to generate ET estimates over the continental United States. NOAA will evaluate these ET products to see how well they work for operational hydrologic and meteorological modeling. One application of the remotely sensed ET maps will be to monitor drought over the United States from a satellite's perspective.

Anderson is a physical scientist and Kustas is a hydrologist; both are at the ARS Hydrology and Remote Sensing Laboratory in Beltsville, Maryland.

Next Year, North America; Someday, the World

Anderson and Kustas, along with NOAA colleagues Chris Hain and Xiwu Zhan, are also mapping ET over the entire globe at a coarser spatial resolution, working towards a day when the maps can be used worldwide for drought monitoring. The group has developed a website showing their drought-monitoring maps; the site will soon go public and be linked to the U.S. Drought Portal at www.drought.gov.

The work has advanced enough that the team wants to expand its drought monitoring to Mexico, Canada, and Central and South America. They are mapping parts of Africa—including the Horn of Africa region, where drought has caused famine in Somalia—with data from European Union meteorological satellites.

Anderson recently attended a conference in Ethiopia on soil moisture and drought monitoring to help subsistence farmers cope with increased weather variability. Scientists, Ethiopian government officials, and disaster-aid groups participated in the conference and showed great interest in the new water-use and drought-early-warning information that can be provided by satellite systems.

Use of ET for Drought Mapping

ET consists of the water evaporated from soil and plant surfaces and the water vapor that escapes, or transpires, through plant leaf pores (stomata) as the plants absorb carbon dioxide (CO_2) through photosynthesis.

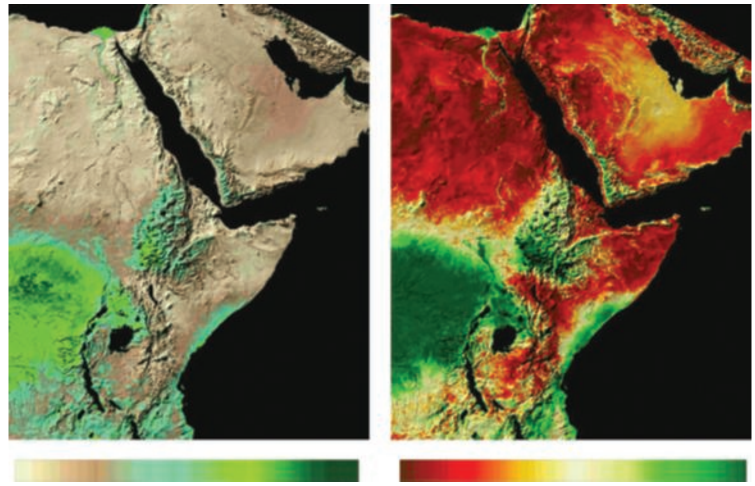
Anderson and Kustas and colleagues have simplified the estimation of ET by using measurements of land-surface temperature obtained from weather and research satellites. With this data, they can infer soil moisture without needing data on precipitation, soil characteristics, or anything else below the Earth's surface. Anderson says that, "generally speaking, a cooler land surface is an indicator that ET is higher. Evaporation cools surfaces, so lower surface temperatures are typically associated with wetter soil and greater ET rates. In contrast, stressed vegetation exhibits elevated leaf temperatures, which can also be detected from space."

Their ET maps can discriminate rivers, lakes, irrigated cropland, and wetlands based on the cooler surface temperatures. These maps are remarkably similar to those created by more complex hydrologic computer models requiring significantly more input data—which is often not readily available.

ALEXI Infers Soil Moisture

Anderson and Kustas feed the remotely sensed temperature data into their computer

MARTHA ANDERSON



Maps of northeast Africa and Saudi Peninsula for April through September 2009 showing average evapotranspiration (ET) and average ratio of ET to potential ET (PET). The ET/PET ratio is used to calculate the Evaporative Stress Index, a measure of how different the current ET is from normal. When ET equals PET, the ratio is 1, which indicates the soil is wet and has ample moisture for plants.

model, ALEXI (Atmosphere-Land Exchange Inverse), and it mathematically partitions the composite measurements into soil and plant temperatures. In turn, the equations use these component temperatures to make separate estimates of soil evaporation and plant transpiration. Soil evaporation estimates allow inferences about soil moisture in the first several inches of topsoil. Plant transpiration estimates do the same for soil moisture in the root zone, which can extend down to 3 feet or more, depending on plant type. Information about root-zone soil moisture is critical to farmers because it helps them decide how much and when to irrigate or how drought is likely to affect yields in dryland agricultural areas. These soil-moisture estimates can also be integrated into hydrological models to estimate total water losses and gains, accounting for factors such as runoff, drainage, and ground-water recharge.

Since 2000, ALEXI has been running daily, estimating ET over the continental United States. ALEXI's accuracy has been shown to be within about 10 percent of measurements by surface- and tower-based instruments.

Dry is Normal in the West

Anderson explains that drought is monitored by detecting anomalies—so she and colleagues want to add ET anomalies to the monitoring process.

"It is dry in the American West, so that's their normal, while greater moisture is the norm in the East," Anderson says. "We're looking for what is abnormal for a region, either drier or wetter than usual."

To do this, they created an Evaporative Stress Index (ESI) by computing anomalies in the ratio of the "actual ET" estimated by ALEXI to the "potential ET," which is the maximum ET that could be expected for a given region. This ratio gives a value from 0 to 1, with 0 indicating very dry conditions and 1 indicating wet or ample moisture for soil and plants. In a typical year, the ratio will be smaller in the West than in the East, but significant deviations from the typical ESI values in various regions provide a measure for detecting drought conditions.

"Drought detection is always in terms of percentage deviation from the norm in dryness or wetness for a region. In other words, will there be more or less rainfall than usual,"

At the OPE3 (Optimizing Production Inputs and Environmental Enhancement) study area in Beltsville, Maryland, hydrologist Bill Kustas checks the position of a water vapor/CO_2 sensor on a micrometeorological tower. In combination with the adjacent sonic anemometer, which measures horizontal and vertical wind, these instruments measure the turbulent exchange of water, energy, and CO_2 between the soil-plant system and the lower atmosphere and are used to evaluate the ALEXI computer model over different landscapes.

PEGGY GREB (D2423-1)

Kustas says. "This index tells us whether there is more or less ET than usual."

Cross-Checking Their Methods

The scientists use coarse-resolution data from geostationary satellites to screen for drought stress and then take a closer look at stressed areas with high-resolution data from other satellites. Geostationary satellites appear motionless because they orbit at 22,000 miles above Earth's equator. These satellites take snapshots of land-surface temperature conditions every 5 to 15 minutes.

Scientists at ARS, NASA, and Johns Hopkins University are testing the drought-mapping software side by side with traditional hydrologic mapping to see if the best parts of each method could be combined to improve regional water-budget estimates. Currently, they are comparing the two techniques to see how well each one estimates water usage along the full length of the Nile River.

"We want to see how closely the results from those two methods match, as a cross check," Anderson says. So far, maps drawn from the two methods look very similar, but the remote-sensing approach gives better spatial detail, and it highlights regions of enhanced ET in irrigated and wetland areas that hydrologic models miss.

The ALEXI model mainly uses data from meteorological satellites, but it also receives data on vegetation cover from NASA's Aqua and Terra satellites. ALEXI is coupled with a model that simulates the interactions of the lowest part of the atmosphere with Earth's surface. These interactions affect soil evaporation and plant transpiration. For example, if the lower atmosphere is dry and the land surface wet, ET will increase.

Two Sources are Better Than One

Anderson was a researcher at the University of Wisconsin-Madison (UW-M) in the 1990s, working with John Norman, a professor with expertise in soil-plant-atmosphere computer modeling and agricultural remote sensing. Anderson joined Norman in working with Kustas on developing ALEXI.

Kustas said that "at a time when the ability to estimate ET using remotely sensed surface temperature was being discredited, Norman came up with a new approach, a unique two-source modeling framework, that converted many skeptics." The two-source model estimates contributions of water, energy, and temperatures from both the soil and vegetation components of the land surface. ALEXI is built on this two-source framework, but extends its application to a regional scale.

Norman, Kustas, and colleagues worked for more than two decades to develop the surface temperature-based techniques for estimating ET. But, Kustas says, it is Anderson "who has carried ALEXI from a research tool to an operational system that can serve as a practical tool for ET and drought monitoring."

PEGGY GREB (D2422-1)

Bill Kustas and Martha Anderson check measurements from a micrometeorological station located at the OPE3 field research site in Beltsville, Maryland.

Evaluating ALEXI Model Formulations

Since 1987, there have been studies evaluating different modeling components used in ALEXI as part of large-scale remote-sensing field experiments throughout North America. These studies have yielded a vast reservoir of data across various landscapes, from desert to tall-grass prairie to crop fields, forests, and bare land.

Many of these campaigns focused on testing microwave sensors that detect Earth's natural microwave emissions from land for direct measurements of soil moisture. Wade Crow, an ARS physical scientist at Beltsville, is researching ways to blend microwave with thermal data currently used by Anderson and Kustas, looking to take advantage of the best features of each method.

In more recent field studies, they tested their thermal technique over cotton fields in the Texas Panhandle. They have also applied it in the Everglades of southern Florida, working with the South Florida Water Management District. Both regions are examples of areas where water managers and farmers urgently need the type of daily high-resolution ET and soil moisture availability estimates the ALEXI-satellite package promises to deliver.

For the Texas remote-sensing campaign, Kustas and Anderson worked with Paul Colaizzi, Prasanna Gowda, and Steve Evett to evaluate and refine major remote-sensing-based ET models for arid and semi-arid regions. Colaizzi and Gowda are agricultural engineers, and Evett is a soil scientist in the ARS Soil and Water Management Research Unit in Bushland, Texas. The experiment, led by Evett and Kustas, involved four ARS labs and several universities.

Weighing lysimeters at Bushland measure crop water use through changes in the weight of 100-square-foot blocks of soil perched on underground scales. These measurements provide "ground truth" data for testing ET estimates from ALEXI and other models.

"The ALEXI model allowed us to scale these point measurements up to regional water-use estimates," Kustas says. Typically, regional ground-based networks of ET weather stations are too sparse to support operational decision making. Consequently, satellite imagery is likely to be the only viable source for routine ET estimates.

Evett sees many future uses for satellite remote sensing of ET, particularly for water-district management and policymaking on water issues.

Irrigation Scheduling from Space

In the long run, Anderson and Kustas hope to provide local ET data for use in irrigation scheduling, just as is currently done from field weather stations. But the data from satellites would be for individual farm fields, rather than from the nearest field station, so it would more accurately reflect local conditions. This will be especially helpful in places where there are no extensive networks of field weather stations, such as Africa.

Still, getting routine ET estimates for individual fields from satellites is laborious at this point, Anderson says. She and Kustas hope to streamline the process for operational use. And they're counting on new satellites with high-resolution thermal sensors to improve the timeliness of satellite imagery. The Thermal Infrared Sensor on the Landsat Data Continuity Mission, scheduled for launch by NASA in January 2013, will be critical to moving toward routine mapping of ET at field scale.

More and More Uses

Besides drought monitoring, water management, and irrigation scheduling, uses of the ALEXI/satellite package include crop yield prediction. "If crops suddenly show stress, we can ask whether that will affect yield, which will depend on the crop and whether it's in a critical growth stage when drought occurs," Anderson says.

Another use is in weather forecasting. Differences between land and air temperatures have major effects on weather, including spawning convection and thunderstorms. "With 5- to 15-minute readings from the geostationary satellites, we can monitor the changes in land and air temperatures as the sun rises. Since heat transfer from the land surface is largest around noon, late morning to early afternoon is when there is the greatest potential for turbulence caused by the temperature difference between land and air," Anderson says.

In addition, remotely sensed ET and soil moisture maps can also be assimilated into meteorological models, potentially improving short-range weather forecasts. John Mecikalski, with the Atmospheric Science Department of the University of Alabama at Huntsville, is using ALEXI heat-flux estimates to eventually forecast where thunderstorms may develop 1 to 6 hours in advance. This is likely to improve flood forecasts and the prediction of severe weather outbreaks, as well as have benefits for air travel. Previously with UW-M, Mecikalski was responsible for developing the prototype data infrastructure to implement ALEXI at continental scales.

Link to Carbon Cycle

Anderson says the next generation of ALEXI may also predict carbon fluxes, since there is a close link between Earth's carbon and water cycles. Both canopy transpiration and CO_2 uptake are jointly controlled by leaf stomata, and therefore carbon assimilation and water use by plants can be tightly coupled. By modeling both cycles together, rather than separately, Anderson thinks we can do better at monitoring the nation's carbon and water budgets. Satellite measurements of land-surface temperature will be a crucial model input, providing valuable spatial information on the health of the crops and other vegetation that regulate water and carbon exchange across the landscape.—By **Don Comis,** ARS.

This research supports the USDA priorities of responding to climate change and promoting international food security and is part of Water Availability and Watershed Management (#211) and Climate Change, Soils, and Emissions (#212), two ARS national programs described at www.nps.ars.usda.gov.

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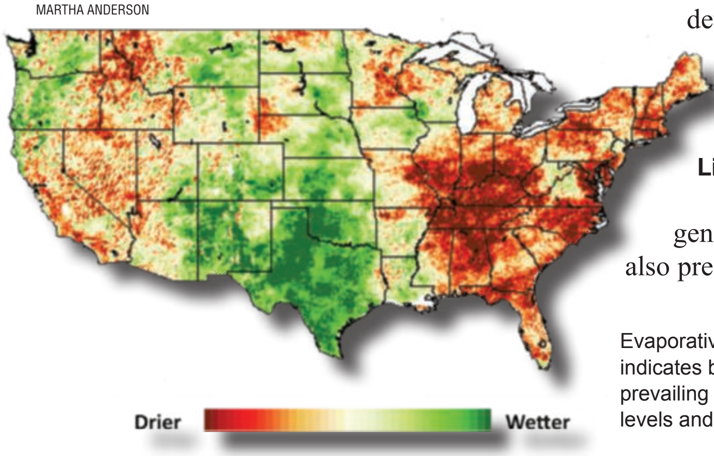
NASA (D2442-1)

Artist's rendition of the Landsat Data Continuity Mission satellite, scheduled for launch in January 2013. This satellite provides thermal infrared images at the high spatial resolutions critical for many agricultural applications.

MARTHA ANDERSON



Evaporative Stress Index map for the 2007 growing season (April through September). Red indicates below-average evapotranspiration. This map shows the extreme drought conditions prevailing in the eastern United States during 2007, which reduced crop yields and reservoir levels and caused conflicts between southeastern states over regional water supplies.

Multi-Pronged Fight Against Zebra Chip Disease in Potatoes

A potato plant showing typical zebra chip symptoms, including rolling up and stunting of the top leaves and purple discoloration.

Thanks to the investigations of scientists-turned-detectives, potato growers in the western United States and abroad now know the identities of the pathogen and insect responsible for outbreaks of the costly tuber disease known as "zebra chip."

So named for the dark stripes it forms inside afflicted tubers when cut and fried to make chips or cooked at high temperatures for other dishes, zebra chip has caused millions of dollars in production and processing losses since its first reported U.S. occurrence in potato fields near McAllen and Pearsall, Texas, in 2000. The disease, whose above-ground symptoms include necrosis and purplish, upward-curling leaves, among others, has since been reported in several other states (California, Nevada, Kansas, Nebraska, New Mexico, Colorado, Wyoming, Washington, Oregon, and Idaho), Mexico, parts of Central America, and New Zealand.

Intensive collaborative research by university, industry, and government scientists, including teams from three ARS laboratories—the Yakima Agricultural Research Laboratory (YARL) in Wapato, Washington; the Vegetable and Forage Crops Research Laboratory (VFCRL) in Prosser, Washington; and the Beneficial Insects Research Unit (BIRU) in Weslaco, Texas—narrowed the list of likely suspects to a fastidious (nonculturable) bacterium, *Candidatus* Liberibacter solanacearum, and the potato psyllid, *Bactericera cockerelli,* as its insect accomplice or "vector." (See "Bacterium Identified as Prime Suspect in Zebra Chip Case," *Agricultural Research,* October 2009, p. 22.)

The discovery is helping growers in affected regions improve their timing and use of insecticide sprays to prevent psyllids from feeding on and infecting potato crops with the zebra chip bacterium (hereafter "Liberibacter"). Longer term, researchers aim to recommend alternative controls for use in integrated approaches to managing the disease-spreading pest. Besides savings on insecticide use, other benefits of integrated pest management (IPM) include preservation of beneficial insects, prevention of secondary pests, and decreased risk of insecticide resistance developing in psyllid populations. Genetic resistance in plants to the pathogen or host is yet another benefit.

Research associates Godfrey Miles, ARS, (left) and Venkatesan Sengoda, Washington State University, evaluate symptoms in fried chips made from potatoes infected with zebra chip.

The "A-Team" Responds

Zebra chip is here to stay, so providing growers with IPM tools that will fit into their production systems over the long haul is of paramount importance, says YARL entomologist Joe Munyaneza. Since 2005, he's served on a multidisciplinary team of zebra chip investigators that includes VFCRL plant pathologist Jim Crosslin; BIRU entomologist John Goolsby; and experts from Washington State University-Pullman, the University of California-Riverside (UCR), Texas AgriLife Research-Weslaco, Northwest A&F University-Yangling, China (NAFU), and MAF BioSecurity New Zealand, among others.

Even as basic lab research on the psyllid-Liberibacter association continues, scientists are hard at work in the field evaluating biobased products for potential use in devising IPM strategies to minimize the incidence of zebra chip. Other fieldwork includes close monitoring of psyllid populations for the presence of Liberibacter.

"John Goolsby and I have started the third year of weekly testing of psyllids collected in Texas, Nebraska, and Kansas for the bacterium," says Crosslin. "This is to see if the incidence of the bacterium in psyllids moving into a potato-growing area can be used to predict the potential for development of zebra chip disease in the crop."

Kaolin Combat

Over the past year, for example, an ARS-university team has conducted lab and field tests of a commercially available technology known as "kaolin particle film." Kaolin is a nontoxic, reflective clay-based powder that can be mixed with water and sprayed onto plant leaves. Upon drying, it forms a protective coat, or barrier, that disrupts feeding and egg laying by certain insects, as well as infection by some pathogens. The technology has also been shown to reduce moisture loss, heat stress, and sunburn damage to treated fruits, such as apples. (See "Whitewashing Agriculture," *Agricultural Research,* November 2004, pages 14-17.)

Though kaolin is effective against mites, citrus root weevils, pear psyllids, and other sap-sucking insect pests, until now it hasn't been tried on potato psyllids, note Munyaneza and colleagues in a paper published in 2011 in *Pest Management Science.*

To evaluate the particle film, the team conducted a series of choice/no-choice lab and field experiments using special insect cages. For free-choice experiments, adult psyllids were allowed to choose between treated and untreated tomato plants. For no-choice experiments, they had no alternative but to land on treated plants. With this experimental design, the researchers could observe the pest's responses and collect data on what effect the kaolin had on feeding and egg laying.

Of particular interest was the treatment's repellency upon contact, since potato psyllids can transmit Liberibacter within an hour of probing host plants for sap. Indeed, it only takes one feeding psyllid to infect a plant with the disease, notes Munyaneza.

While the psyllids did in fact land on kaolin-treated plants (when given no choice but to do so), they spent less time feeding, and females deposited fewer eggs, than did the psyllids that were allowed to visit untreated plants.

"Our data indicate potential for kaolin particle film as a repellent for landing and a barrier to oviposition [egg laying] and may prove to be an economically viable and environmentally sound component of an integrated approach for control of potato psyllids and related pests," write Munyaneza and coauthors Tong-Xian Liu (NAFU), Linian Peng (Plant Protection Station of Sichuan, China), and John Trumble (UCR).

Building a Biobased Arsenal

In another project, the team, joined by two other NAFU scientists—Xiangbing Yang and Yong-Mei Zhang—compared the repellency of four commercial biorational insecticides, whose active ingredients ranged from natural plant extracts to plant-essential oils and mineral oil.

As with the kaolin study, the researchers conducted choice/no-choice experiments to assess what effect the biorational insecticides had on psyllid feeding and egg laying. The results, reported in the journal *Crop Protection,* show that all four products were repellent to the pests. Three of the products—SunSpray, BugOil, and Requiem—repelled 77-94 percent of psyllids when sprayed onto plants leaves. The fourth treatment, MOI-201, deterred 47 percent of them.

SunSpray, containing mineral oil, was the most repellent, deterring 94 percent of psyllids. Additionally, no psyllid eggs were found on SunSpray-treated plants. BugOil, which contained plant essential oils, had the longest residual activity, repelling 50 percent after 7 days, the scientists report.

JOSEPH MUNYANEZA (D2395-1)

Tubers infected with zebra chip disease show dark, stripelike symptoms in the tissue. The damage becomes even more pronounced when the potatoes are made into chips or fries.

Calling on Friendly Fungi

On another front, a team led by YARL entomologist Lerry Lacey (retired) evaluated commercial biopesticide formulations containing spores of the insect-killing fungi *Metarhizium anisopliae* strain F52 and *Isaria fumosorosea* (PFR-97).

In 2009 and 2010 field trials in Weslaco, Texas, applications of F52 reduced the number of psyllid eggs and nymphs (an immature stage) by 45-67 percent, rates comparable to those for the insecticide abamectin (63 percent). Similar reductions were observed with PFR-97. The fungal treatments also reduced damage to treated plants and diminished the severity of zebra chip symptoms in tubers.

Lacey and coinvestigators Munyaneza, Liu, Goolsby, David Horton (YARL), and Jeremy Buchman (formerly ARS) published a paper on the work in the journal *Biological Control* in 2011.

Resistance: A Cornerstone Defense

The foundation of IPM programs is genetic resistance, and an intensive search is under way to locate the trait in currently produced potato varieties, including collections maintained by ARS's Small Grains and Potato Germplasm Research Unit in Aberdeen, Idaho. There, ARS scientists Rich Novy and Jonathan Whitworth, along with Juan Manuel Alvarez (University of Idaho), identified several potato breeding clones with resistances to aphids, Colorado potato beetle, and wireworm.

"The many insect resistances in this germplasm made it a good candidate for potential psyllid resistance as well," explains Novy. UCR collaborators John Trumble and Casey Butler screened the germplasm and observed that resistance was present and was expressed as reduced occurrence and duration of psyllid probing (feeding) and decreased resting.

Use of a procedure known as "Taqman-based real-time polymerase chain reaction" confirmed reduced levels of Liberibacter in the germplasm after feeding by Liberibacter-infected psyllids. While several psyllid-resistant potato clones showed reduced Liberibacter infection, one appeared resistant to the bacterium despite having no apparent psyllid resistance. "This observation suggests that resistance to Liberibacter, and not just to the psyllid vector, may also be contributing to reduced Liberibacter infection," says Novy.

Scientists caution that further research and replication of results are needed before grower recommendations can be made. But the studies thus far have revealed promising leads towards waging a war that could turn the tables on the tuber disease and its insect accomplice.—By **Jan Suszkiw,** ARS.

This research is part of Crop Protection and Quarantine, an ARS national program (#304) described at www.nps.ars.usda.gov.

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Step-by-Step Strategies for Restoring Western Rangelands

ARS ecologist Roger Sheley teaches the EBIPM decision process to attendees of the annual EBIPM Field School in 2010 in Boise, Idaho.

Invasive plants exploit every environmental angle in their favor. So restoring damaged rangelands in the western United States involves a lot more than just getting rid of bad plants and bringing in good plants.

Since 1990, Agricultural Research Service ecologist Roger Sheley has been refining a process for identifying factors that give the undesirable space invaders their territorial edge—and figuring out strategies for restoring a healthy mix of native vegetation for rangelands in need of remediation.

"Killing a weed is like treating a symptom," says Sheley, who is co-located at Oregon State University's Eastern Oregon Agricultural Research Center in Burns, Oregon. "So our research has been focused on trying to understand the reason why plants are able to invade and dominate some landscapes and not able to succeed in others. We want to find the cause and then deal with the cause—what has changed in the ecology of the system and how can we change it back?"

Sheley used a range of findings in the literature and years of field research at Burns to develop a decision-making model called "Ecologically Based Invasive-Plant Management" (EBIPM). The process is a mix of longstanding theories of plant establishment and succession, new ecological principles, identification of variables that contribute to invasive plant management, and actions that can help native plants regain territory lost to invasive vegetation.

Using EBIPM, Sheley was able to increase the chance of restoration success by 66 percent over traditional approaches to invasive weed management. That could be a boon to land managers in the western rangelands, where invasive plants like cheatgrass are fueling wildfires and limiting livestock grazing options.

"Another term for our work is 'augmentative restoration,'" Sheley says. "In rangeland restoration, not everything needs to be done everywhere. It's much more effective to change restoration procedures based on what we observe as we move across the landscape."

Plant Succession—Not So Simple

Ecologists have often assumed that plant communities almost always follow a succession trajectory mainly determined by climate and unpredictably affected by management activities. For instance, a site would initially be colonized by mosses and lichens, which would help create conditions favorable for the growth of forbs, grasses, and shrubs.

Sheley and his colleagues based their work on another approach that proposed three general causes of plant succession: site availability, species availability, and species performance. This model held that site-specific ecological processes strongly influence plant succession dynamics and that these processes in turn are modified by natural and management-imposed factors that affect plant establishment and long-term vegetation change. Once these factors have been identified, successional management decisions can be used to coordinate activities that fine-tune the mechanisms and processes influencing plant succession—all of which helps rout invasive plants and restore native grasses and forbs.

Sheley and his colleagues tested their model in Montana's Kicking Horse Wildlife Mitigation Area at three sites that had varying degrees and types of damage from invasive plants. The first site had been overrun with spotted knapweed, sulphur cinquefoil, and cheatgrass. In addition, meadow voles had disturbed the soil by digging numerous tunnels, which increased the amount of bare ground ripe for infestation.

The second site didn't have meadow voles or a lot of bare ground, and it did have a substantial native plant population that could help support restoration. But the native plants were already competing with the invasive plants that had moved in.

The third site was wetter, which provided good condition for the establishment of desirable plants. But it didn't have a significant native plant population that could help jump-start restoration.

One Step at a Time

The first step in the EBIPM process was to assess each site using the Rangeland Health Assessment protocol, a system already used by many federal land managers for evaluating rangeland conditions, and identify the ecological processes that needed to be repaired. For instance, at the first site, the team decided that the major succession dynamic facilitating invasive success was "site availability." This was the result of several factors—including bare ground, soil surface loss, dry soils, and the lack of a native plant population—all of which also blocked the development of a healthy native plant community.

But at the second site, the team determined that "species performance" was the successional process dominating plant establishment and survival, since the native plants at the site were outnumbered by their invasive neighbors. So at this site, management activity needed to promote the success of the native plants over the invasive vegetation.

At the third site, native plant populations were low, which had given invasive plants the opportunity to become established. The researchers decided that both "species availability" and "site availability" were the successional issues that needed to be addressed.

Then the team developed strategies that targeted the ecological processes contributing to the successional dynamics at each site. At the first site, they seeded the bare sites with a mix of native plant species and watered them. At the second site they killed the invasive species with herbicides and disked the soil, both of which opened up space for the existing native plants to expand their range. They also lightly disked parts of the third site and then seeded it with a mix of native plants. This site was next to a wetland, so there was sufficient water available to support the emergence and growth of seedlings.

Sheley and his partners found that seeding and watering at the first site produced the highest native grass and forb density, while at the third site, tillage was key to the establishment and survival of native grasses and forbs. Using herbicides at the second site did not appear to have any significant benefits for the establishment and survival of the native plants.

Still, Sheley thinks that two out of three is a noteworthy success rate for EBIPM.

JAEPIL CHO (D2416-1)

Characteristic sagebrush steppe rangeland where cheatgrass has invaded and choked out most of the desirable grasses and forbs and caused a fire hazard.

TONY SVEJCAR (D2417-1)

A diverse, functioning rangeland ecosystem with desirable shrubs, perennial grasses, and forbs can help prevent invasive plants from becoming established and taking over.

"When we pick and choose how to support site-specific succession processes by repairing or replacing those processes, we can significantly enhance traditional successional restoration," Sheley says. "It can save land managers time and money, and it also helps lower the risk of unintentionally harming the ecosystem processes when we decide to intervene. This system allows us to integrate what we're actually seeing—what works, and what doesn't work—in sustainable invasive-plant management and restoration programs to create predictable and valuable vegetation changes."—By **Ann Perry,** ARS.

This research is part of Crop Protection and Quarantine, an ARS national program (#304) described at www.nps.ars.usda.gov.

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Battling Problem

Japanese beetle trap modified to coat beetles with *Metarhizium* spores in the Azores. Inset: Close-up of the trap's interior showing the dish of fungus spores and a newly dusted adult beetle.

Sandy beaches, blue water, warm weather, and—invasive insects? One of these things certainly doesn't belong. When we think of island paradise, invasive insects don't usually come to mind. But these pesky pests are a problem for countries all over the world.

In two separate projects, Agricultural Research Service scientists are working with their Azorean and French Polynesian counterparts to help control invasive insects there. Since these pests are also invasive in the United States, these collaborations may have mutual benefit. So far, the results have been promising.

An Infestation in the Azores

Off the coast of Portugal lies an archipelago of nine volcanic islands known as the Azores. The islands are rising in popularity as a vacation destination as people flock there to take in the lush, garden scenery, the blue and green lagoons, and the laid-back island lifestyle.

But in the early 1970s, an unwelcome traveler made its way to the islands. The Japanese beetle *(Popillia japonica)* was accidentally introduced onto the island of Terceira, marking the start of the insect's invasion. Over the next 40 years, beetle populations increased exponentially, causing major agricultural damage and threatening exports of Terceira products. And because of frequent inter-island travel, the beetle has now spread throughout most of the other islands in the archipelago.

Work on biological control of the beetle was initially started by entomologist Lerry Lacey, now retired from ARS. Over a 2-year period in 1989-1990, he conducted research on development of the fungus *Metarhizium anisopliae,* a bacterium, entomopathogenic nematodes, and parasitic insects to manage the Japanese beetle. His work laid the foundation for current efforts.

Entomologist Stefan Jaronski, with the Northern Plains Agricultural Research Laboratory in Sidney, Montana, is currently helping the Azoreans to further develop the fungus to control the Japanese beetle. His work is part of the Azores Cooperative Initiatives Program between the United States and the Azores. The program is funded by the U.S. Department of Defense's European Command.

To help provide an alternative to pesticides, Jaronski and the Azores Plant Protection Service are further developing the fungus in an intensive biocontrol program to help reduce Japanese beetle populations.

In 2008, Jaronski traveled to the Azores to teach the Azorean scientists how to mass produce spores of *M. anisopliae*. The fungus is one of two principal biocontrol agents—the other being entomopathogenic nematodes—recommended for use on the islands. He has since been back three times to continue helping with the project.

Lacey had previously designed a modified Japanese beetle trap so spores of the *Metarhizium* fungus could be better dispersed within beetle populations in a process called "autodissemination." Beetles caught in the traps "dust" themselves with the spores and then carry them to infect other beetles during mating and contaminate egg-laying sites. The Azorean scientists are also applying the spores directly to the beetle's breeding sites.

"The *Metarhizium* fungus is like fatal athlete's foot in insects," explains Jaronski. The fungus infects insects by penetrating through their cuticle, often via the feet, thus the analogy, but in the case of the Japanese beetle, all over its body. "Once a beetle is infected, the fungus grows inside it. Over the course of a week, the

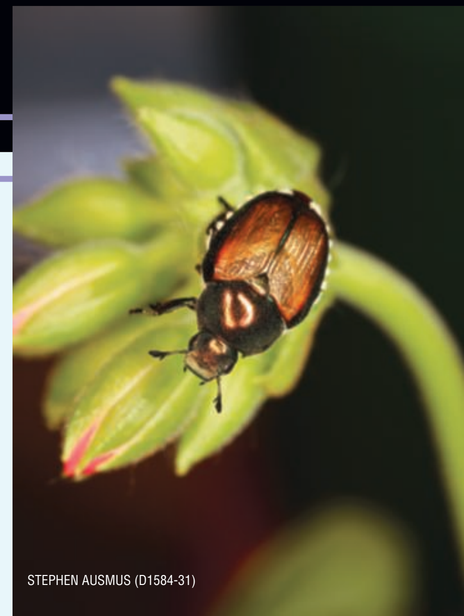
As part of the Hawaii areawide pest management program for the oriental fruit fly, center director Dennis Gonsalves (left) and entomologist Roger Vargas expose fly-infested guavas to parasitic wasps.

Pests in Paradise

SCOTT BAUER (K9578-1)

Opposite page: ARS scientists are helping French Polynesia manage its Oriental fruit fly outbreak. Here, a female Oriental fruit fly, *Bactrocera dorsalis,* lays eggs by inserting her ovipositor in the skin of a papaya.

Left: The parasitic wasp *Fopius arisanus* is an effective predator of the Oriental fruit fly.



STEPHEN AUSMUS (D1584-31)

ARS scientists are helping the Azores, islands off the coast of Portugal, control the Japanese beetle *(Popillia japonica)* with the *Metarhizium* fungus.

insect dies, and if conditions are right, it becomes covered by the fungus, which produces more spores, giving the cadaver a fuzzy, green appearance. In turn, these spores spread to other beetles, continuing the process."

The results so far show promise, with anecdotal evidence showing that beetle populations are decreasing on the one island, São Miguel, where the fungus has been used for the past 2 years. Jaronski plans to make another trip in the coming year to help fine-tune the fungus's delivery system. With his help, the Azoreans may soon have their Japanese beetle population under control.

STEPHEN AUSMUS (K11008-1)

Fruit Fly Problems in French Polynesia

Meanwhile, on the other side of the world, French Polynesia—another archipelago consisting of six island groups and considered by many as a tropical paradise—is battling an economically devastating insect of its own.

The Oriental fruit fly *(Bactrocera dorsalis)* is a pest well known in the United States and is causing severe damage to French Polynesian agriculture, a major industry with exports of several tropical fruits and vegetables.

Large-scale eradication programs were conducted on Tahiti and Moorea Islands in 1997, and eradication was almost achieved. But by 2001, the Oriental fruit fly population rebounded and became more abundant, spreading to many more islands.

Hawaii is no stranger to fruit fly outbreaks, with ARS scientists leading the way in coming up with solutions. That's why entomologist Roger Vargas, with the U.S. Pacific Basin Agricultural Research Center in Hilo, Hawaii, was tasked with helping the Tahitians manage their Oriental fruit fly outbreak. Funded by a USDA Foreign Agricultural Service grant and working from his experience with many successful fruit fly biocontrol programs in Hawaii, Vargas and his Hawaiian and Tahitian colleagues sought to have the same level of success in French Polynesia.

In 2003, Vargas introduced to the islands the parasitic wasp *Fopius arisanus*, a natural enemy of the Oriental fruit fly that has proven highly successful in the Hawaii biocontrol program. The wasp attacks the fruit fly by laying its eggs inside the fruit fly egg, where it continues to develop during the fruit fly larval and pupal stages. Before the fruit fly adult can emerge, the wasp emerges, killing the fruit fly.

"We established a small laboratory in Tahiti and continued to introduce populations of *F. arisanus* to the infested islands over the next 3 years," says Vargas. "To evaluate the wasp's effectiveness, we compared fruit samples before and after releases on Tahiti Island. We found a significant decline in numbers of fruit flies emerging from fruits." Details about this study have been published in the *Journal of Economic Entomology*.

More recently, a second species of beneficial parasite, *Diachasmimorpha longicaudata,* was introduced into Tahiti. The parasite program continues to be successful to this day in reducing not only Oriental fruit fly infestations, but also Queensland fruit fly *(Bactrocera tryoni)*.—By **Stephanie Yao,** formerly with ARS, and **Dennis O'Brien,** ARS.

This research is part of Crop Protection and Quarantine, an ARS national program (#304) described at www.nps.ars.usda.gov.

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A Dose of Selenium That Goes a Long Way

In western parts of the United States where some rugged ranges can only be reached by horseback, ranchers often find themselves saddling up weekly to deliver mineral supplements to livestock grazing in nutrient-deficient regions, especially areas scarce in selenium. The routine is not only time-consuming but also costly, and in some leased-land arrangements, such supplementation practices are prohibited.

Selenium, a trace mineral and component of important selenoprotein antioxidants, is essential for good health in livestock and humans. If the body cannot form these important antioxidant proteins, it predisposes the animal to sickness and eventually death at a young age.

Selenium deficiency in livestock affects more than 35 states and costs sheep, beef, and dairy producers an estimated $545 million in losses each year. Lack of adequate selenium in sheep reduces conception rates, increases neonatal mortality, and in some instances, causes white muscle disease—nutritional muscular dystrophy. Lambs that do survive suffer from increased disease, reduced weight gain, and impaired performance.

STEPHEN AUSMUS (D2211-8)

Animal scientist Bret Taylor (left) and technician Tonya Thelen collect milk samples from a ewe to measure milk production and selenium content.

Which Selenium Is Best?

In search of a more cost-effective and longer lasting supplement, scientists at the Agricultural Research Service's U.S. Sheep Experiment Station (USSES) near Dubois, Idaho, and at North Dakota State University (NDSU), in Fargo, isolated a selenium-rich coproduct of milling high-selenium wheat and studied its effects on ewes and their lambs.

The most common form of selenium supplement is sodium selenite, which is usually added to salt-based mineral mixes fed to grazing livestock. Sodium selenite is inexpensive, but it doesn't last long in the body, says USSES animal scientist Bret Taylor, so it must be provided frequently to animals living in selenium-deficient regions.

"To provide enough of these mineral mixes to a band of sheep—around 1,000 ewes and their lambs—grazing remote areas, it would take a lot of horses to carry the supplement and supplies," says Greg Lewis, USSES research leader. "That's because sheep can consume a lot during the week."

In a study by Taylor, the wheat coproduct, which is rich in a different form of selenium—selenomethionine, was included in the diets fed to some ewes during their last 40 to 50 days of pregnancy. The coproduct, derived from high-selenium wheat harvested in South Dakota, was fed at levels providing 10 times the daily selenium requirement.

Ewes passed the supplemental selenium to their fetuses during pregnancy and to their nursing offspring through their milk.

Because the coproduct was rich in longer-lasting selenomethionine, the selenium status of these ewes remained adequate 6 to 10 times longer than that of ewes fed supplemental sodium selenite during pregnancy, Taylor says. Ewes did not need any additional supplements until they returned for lambing the following year.

"All of the costs involved with delivering supplements on a frequent basis year round are eliminated with this type of feeding strategy," Lewis says. "We're really talking about only one time a year."

Two for the Price of One

Scientists discovered that the best time to feed ewes a diet rich in selenomethionine is when they are lactating. That's because lactating animals consume more feed, and thus, will consume more of the product, Taylor says. Furthermore, selenium consumed by the dam will pass to the nursing young through the milk.

In one of the experiments, ewes that had given birth to twin lambs were divided into two groups. Each ewe was housed with its lambs only. One group was fed a regular diet containing the standard sodium selenite at the recommended daily amount, and the other was fed a diet that included the selenium-rich coproduct providing selenium at nine times the daily requirement.

"What's unique is that during the first 19 days of their lives, the lambs were only allowed to consume milk from their dams," Taylor says. "Not only did the selenium-rich coproduct from wheat enhance the selenium status of the ewe, it enriched the milk with selenium, which was subsequently passed to the lamb."

Making the Most of Milk Production

In another study, colostrum and milk production were measured in ewes that were fed either a diet containing the selenium-rich coproduct or a basal diet supplying selenium requirements. Within each selenium treatment, ewes were fed either 60, 100, or 140 percent of their daily energy and protein requirements throughout pregnancy. At birth, treatments were stopped, lambs were raised separately from their mothers, and ewes were machine-milked twice daily for 20 days.

The selenium-coproduct group produced more milk, says Joel Caton, NDSU animal science professor. These ewes also produced more colostrum—a milklike substance produced by the dam right after she gives birth that provides antibodies to protect nursing lambs against bacteria, viruses, and other foreign elements.

"There was less butterfat in terms of percentage. But because ewes produced so much more colostrum, 540 grams vs. 390 grams, they were able to provide their offspring a lot more total grams of butterfat," Caton says. "The colostrum was more dilute, but because there was so much more of it, there were a lot more nutrients going to that offspring."

Scientists also addressed nutrient restrictions of rangeland sheep. They examined how limited nutrition and high levels of dietary selenium during pregnancy affect growth of adolescent ewes and their lambs.

Adding the selenium coproduct feed to diets of pregnant ewes appears to enhance weight gains and body composition, says Allison Meyer, a former NDSU doctoral student who is now an assistant professor of animal science at the University of Wyoming.

"The birth weight of lambs was reduced by low-nutrition diets. But when ewes were also fed the coproduct diet, their lambs had a greater birth weight," Meyer says.

Load and Go

Selenium deficiency is a soil issue, especially in the West where many of the soils are a little too acidic, Taylor says. Either selenium is not present or it exists in a form that the plants can't absorb.

"Because the selenium in the vegetation is so low, animals can't meet their daily selenium requirement," he adds. "They just can't eat enough plants in 24 hours to get what they really need."

"With the new program, sheep can be fed the selenium-rich coproduct diet before being released to graze selenium-deficient range," Taylor says. "We can load sheep with selenium from the natural coproduct feed before they go, and they'll have plenty in their system to meet their selenium needs."—By **Sandra Avant,** ARS.

This research is part of Food Animal Production (#101), an ARS national program described at www.nps.ars.usda.gov.

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In areas where soil and vegetation are low in selenium, ewes that consume a selenium-rich wheat coproduct in their feed pass the needed selenium to their nursing offspring. The adults can retain the selenium benefit for up to a year before they require more of the coproduct.

STEPHEN AUSMUS (D2343-2)

Gene Helps with Multiple Leaf Diseases in Corn

REGIS LEFEBURE (K5660-3)

Corn is one of the most widely grown crops in the United States, which produces 40 percent of the world crop. But as with all crops, diseases threaten corn production.

Three diseases, southern corn leaf blight, northern leaf blight, and gray leaf spot, all cause lesions on corn leaves. In the U.S. Midwest Corn Belt, northern leaf blight and gray leaf spot are significant problems.

Agricultural Research Service scientists and university colleagues found a specific gene in corn that seems to confer resistance to all three of these leaf diseases. This discovery, published in 2011 in the Proceedings of the National Academy of Sciences, could potentially help plant breeders build disease-resistance traits into future corn plants.

The researchers examined 300 corn varieties from around the world, making sure to have a genetically diverse representation. No corn variety has complete resistance to any of these diseases, but varieties differ in the severity of symptoms they exhibit.

"We set out to look for maize lines with resistance to these three leaf diseases. But what we really wanted to know is which genes underlie disease resistance," says ARS plant geneticist Peter Balint-Kurti, who is in the Plant Science Research Unit in Raleigh, North Carolina. Also on the research team were ARS plant geneticists Jim Holland and Matt Krakowsky and scientists with the University of Delaware, Cornell University, and Kansas State University.

When they tested the lines for resistance to these three diseases, they found that if a corn variety was resistant to one disease, chances were favorable that it was also resistant to the other two. So the search was on for the gene or genes responsible for that multiple disease resistance.

The researchers applied a statistical analysis technique called "association mapping" to identify regions of the genome associated with variation in disease resistance.

"We knew there was a strong correlation between resistance of one disease and the other two. So we postulated that some resistance genes conferred resistance to two or more different diseases," says Balint-Kurti.

"We identified a gene that seemed to confer multiple resistance," he says. "This gene, a GST (glutathione S-transferase), is part of a family of genes known for their roles in regulating oxidative stress and in detoxification. Both of these functions are consistent with a role in disease resistance."

"While we know the DNA sequence variation of the gene in all the different lines, the function of the genes tested is often unknown. But by putting together the information on which varieties carry specific sequence variations and also exhibit better resistance, we could identify a gene that appears related to multiple disease resistance," explains Holland.

This study represents a departure from the standard process of gene association mapping. "Usually, you are looking for something that causes the change in one trait. We modified the technique so that we can find gene variants that are associated with variation in multiple traits, such as resistance to multiple diseases," says Holland.—By **Sharon Durham,** ARS.

This research is part of Plant Genetic Resources, Genomics, and Genetic Improvement, an ARS national program (#301) described at www.nps.ars.usda.gov.

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Can a Prairie Teach Us About Agricultural Water Quality?

One place to figure out how agricultural practices affect water quality is in a crop field that is being converted to native prairie vegetation. In Iowa, natural resource managers are conducting this type of landscape restoration at the Neal Smith National Wildlife Refuge near Prairie City. So this is where Agricultural Research Service soil scientists Mark Tomer and Cynthia Cambardella partnered with colleagues from Grinnell College, the U.S. Fish and Wildlife Service, and the Iowa Geological Survey Bureau (part of the Iowa Department of Natural Resources) to describe changes in water quality during prairie establishment.

The ARS researchers work at the National Laboratory for Agriculture and the Environment in Ames. Their group studied concentrations of nitrates and phosphorus in ground water in a 17-acre field while it was being converted from corn and soybean row-cropping to a reconstructed prairie. The researchers set up ground-water monitoring wells and collected water samples from 2002 through 2009.

After a final soybean harvest in 2003, the field was seeded with native grasses and forbs. As the prairie became established, nitrate concentrations declined and stabilized within 5 years. Initially, nitrate levels in ground-water wells higher up the slopes averaged 10.6 parts per million (ppm), levels that can fuel downstream development of the "dead zone" in the Gulf of Mexico.

But nitrate levels along ephemeral waterways averaged only 2.5 ppm, and after 2006, nitrates disappeared from the shallow ground water near the waterways. Further upslope, ground water still had measurable nitrate levels in 2006, but levels diminished to around 2 ppm after 2007.

"The rate of nitrate loss mostly came down to two things: how much available carbon was in the soil and the depth of the water table," Tomer notes. "Along the waterways, there was carbon available in the saturated soils. This provided an environment promoting denitrification that can decrease nitrate concentrations fairly rapidly—within one growing season. Upland soils were drier and had less available carbon, so nitrate loss occurred more slowly."

These results didn't surprise the researchers. But phosphorus measurements did, because unlike nitrate, phosphorus levels did not decline. Between 2006 and 2009, phosphorus concentrations averaged 0.14 ppm along the ephemeral waterways, while average upland concentrations were only around 0.02 ppm. The higher phosphorus concentrations were found in shallow ground water along the waterways—and if ground-water levels rose enough to produce overland flows that contribute to streamflow, the phosphorus concentrations were high enough to threaten local water quality.

"We learned that while conservation practices that plant grass along waterways and in riparian buffers can trap sediments from field runoff, the sediments contain phosphorus that can leach into the water," Tomer says. "Under certain conditions, legacy nutrients in soil might still pollute nearby waterways, even though eroded soil has been trapped." Legacy nutrients remain in the soil long after producers have stopped using them to fertilize crops.

Tomer wants to learn more about this tradeoff between phosphorus and nitrate in shallow ground water, how often it occurs, and what controls it. "We think studying this prairie has given us insight that can help farmers better manage water quality, from their fields right down to the Gulf of Mexico."—By **Ann Perry,** ARS.

This research is part of Water Availability and Watershed Management (#211) an ARS national program described at www.nps.ars.usda.gov.

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ARS researchers are studying how nitrates and phosphorus affect water quality in a crop field that has been converted to native prairie vegetation at the Neal Smith National Wildlife Refuge near Prairie City, Iowa.

JEFF COOK (D2415-1)

PEGGY GREB (D2404-1)

A farmer's subsurface drain pipe. Subsurface drainage may account for 50 percent of the stream flow in midwestern watersheds.

Nixing Nitrate Flow From the Farm

When early settlers arrived in the Midwest, they began constructing an underground network of tile drains to channel water away from the soggy prairies, which then became some of the most fertile crop fields in the country. But now when nitrate from soils and fertilizers leaches out of those flourishing fields, the subsoil engineering also facilitates the discharge of nitrates into nearby streams and rivers.

Because these local waterways are part of the vast Mississippi River Watershed, the nitrates are eventually transported into the Gulf of Mexico, where they can feed the development of oxygen-deficient "dead zones." But nitrate management isn't just an issue for the folks downstream. The U.S. Environmental Protection Agency has mandated that nitrate concentrations in drinking water—obtained either from surface water or ground water—cannot exceed 10 parts per million. Minimizing nitrate loss can also help producers obtain the greatest economic returns from the application of expensive fertilizers. So everyone benefits when nitrates are stopped from contaminating local water supplies.

Agricultural Research Service soil microbiologist Tom Moorman and others at the National Laboratory for Agriculture

PEGGY GREB (D2398-1)

Left: Technician Kent Heikens prepares a large core sampler to take a core sample of the wood chip bioreactor beneath a soybean field for lab analysis of denitrification rates and bacterial populations. Below: Kent Heikens and Ben Knutson examine a core sample from the bioreactor. The topsoil covering the wood chips is seen in the foreground.

PEGGY GREB (D2399-1)

Sample of wood chips taken from the bioreactor from beneath a soybean field.

PEGGY GREB (D2400-1)

and the Environment in Ames, Iowa, have spent the last decade studying whether underground trenches filled with wood chips could help stem this nitrate flow. Microorganisms that live in the wood use a process called "denitrification" to convert nitrates in the field leachate into nitrogen gas or nitrous oxide, which then diffuse into the atmosphere.

"Soils have some capacity to denitrify field leachate, but it generally decreases with soil depth," Moorman says. "So we wanted to see how well wood chip 'denitrification walls' could protect nearby waterways from the nitrates that leach out of the soil. We also wanted to see how quickly the wood breaks down in the subsoil."

Digging For Answers

Moorman and his team—technician Colin Greenan, microbiologist Timothy Parkin, plant physiologist Tom Kaspar, and soil scientist Dan Jaynes—set up experimental sites in a field north of Ames. They installed perforated plastic drainage pipes 4 feet below the soil surface and then dug trenches on either side of the pipe and filled the trenches with wood chips. They buried the trenches and the pipes, and then cropped the fields with a corn-soybean rotation for the next 9 years.

The researchers also filled mesh bags with wood chips and buried the bags at depths of 2 feet and 5 feet in a nearby trench that was also filled with wood chips. The fields above this trench were also cropped with a corn-soybean rotation. Establishing this extra trench allowed them to dig up wood chips to see how fast they decomposed without removing wood from the experimental trenches.

The team found that over the 9-year study period, the wood chip "bioreactors" consistently removed nitrates from the field leachate, with removal rates remaining steady in the last 5 years. From 2001 to 2008, annual nitrate loss in plots with conventional drainage averaged 48.6 pounds per acre, but losses dropped to 21.8 pounds per acre in plots with the denitrification walls.

The data also indicated that, compared to subsoil, the average denitrification potential of wood increased from 31-fold in 2003 to 4,000-fold in 2004. These findings supported an earlier laboratory study by Greenan that indicated denitrification by microbes is the main mechanism in wood chip bioreactors responsible for removing nitrate from leachate.

The scientists also found that the population of denitrifying microbes exceeded 454 million per pound of wood, compared to 45 million per pound of surface soil and 4.5 million per pound of subsurface soil—strong evidence that the wood chips provided a habitat that favored the denitrifying organisms.

Long-Lasting Success

The scientists periodically checked the bagged wood samples over the 9-year study period to see how quickly the wood was decomposing. They found that 50 percent of the wood buried between 35 and 39 inches deep had decomposed 5 years after it was buried, and 75 percent of the wood buried at this depth decomposed after 9 years.

However, less than 13 percent of the wood buried between 61 inches and 70 inches deep had decomposed after 9 years. The decreased decomposition rates at greater depths was probably due to lower oxygen levels in the subsoil, which was saturated with water for longer interludes than the subsoils at shallower depths. These findings can help in the design of denitrifying wood trenches, since wood decomposition rates will be needed to calculate the functional life expectancy of a denitrification wall after it is installed.

Denitrification also results in the production of the greenhouse gas nitrous oxide, and the team was concerned that the bioreactors might increase these emissions. But they found that overall nitrous oxide emission rates did not notably change with increasing denitrification in the bioreactor. This is partly because overall soil nitrate losses were reduced, which prevented nitrates from leaching out of the ground and into nearby waterways, where discharged nitrates are converted into nitrous oxide. "Until this study, very little work had been conducted on nitrous oxide loss from these bioreactors," Moorman says.

The results from this work were published in 2010 in a special issue of *Ecological Engineering*. In part because the benefits of using wood chip bioreactors for denitrification were so conclusive, Agriculture's Clean Water Alliance—a group of leading farm retailers in west-central Iowa—and the Iowa Soybean Association, in partnership with Wisconsin-based Sand County Foundation, are now encouraging farmers to install the denitrification walls to help mitigate the nitrate pollution associated with regional agricultural production.

"This study helped us confirm that using wood chips to build denitrification walls will result in a significant level of denitrification in field leachate," says Moorman. "We also understand much more about the different mechanics of denitrification itself, and now we have good numbers on how many denitrification bacteria live in wood and how long that wood can last in a trench under typical field conditions."—By **Ann Perry,** ARS.

This research is part of Water Availability and Watershed Management, an ARS national program (#211) described at www.nps.ars.usda.gov.

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PEGGY GREB (D2402-1)

Subsurface drainage water from individual field plots is routed to this sump where flow is measured and samples are prepared for nitrate testing. Here, soil microbiologist Tom Moorman takes a water sample for nitrate analysis.

STEPHEN AUSMUS (D2408-9)

In Albany, California, research engineer Zhongli Pan (right) and food technologist Don Olson conduct almond pasteurization tests using infrared heating and a hot-air roaster.

Infrared Heating: Hot Idea for Keeping Almonds Safe To Eat

Crisp, crunchy almonds make a tasty and nutritious snack any time.

In Albany, California, investigators Zhongli Pan and Maria T. Brandl are collaborating in leading-edge studies that explore the use of a still-evolving technology, infrared heating, to help make sure almonds remain safe to eat.

The federal government, the U.S. almond industry, and food safety researchers are keeping an especially watchful eye on *Salmonella enterica.*

It's generally thought that almonds are not naturally contaminated with high levels of this pathogen. Nevertheless, all almonds processed for sale in the United States today have to be pasteurized in order to zap *Salmonella.* The pasteurization procedure has to be powerful enough to reduce *Salmonella* population levels by a 4-log minimum. That's a 10,000-fold decrease.

Nearly half a dozen methods already have federal approval for accomplishing this mandatory pasteurization. But many almond processors remain eager to learn about promising new options, including infrared heating. Pan, an engineer with ARS's Western Regional Research Center in Albany, says several processors have expressed an interest in the series of infrared heating studies that he and Brandl, a microbiologist at the center, began in 2006.

The Many Advantages of Infrared

Pan says that infrared heating "doesn't require use of any chemicals and offers a simple, safe, energy-efficient, and environmentally friendly way to kill *Salmonella* while almonds are still at the packinghouse."

Pan is confident that the laboratory procedures developed with Brandl will be easy to scale up for commercial use. The researchers' batch-based processes could, for example, be upgraded to a continuous-flow regime suited for the conveyor-belt-based processing that's standard at most almond packinghouses today. Most of those processing plants are located in California, where all of America's commercial almonds—a whopping 80 percent of the world's supply—are grown.

Some packinghouses already use infrared heating, but not for pasteurizing. Instead, it's part of a wet/dry process to remove almonds' paper-thin skin, or pellicle, for certain almond products.

Infrared has other food applications, as well. Infrared grills and ovens, for instance, can be found in professional and home kitchens alike.

The idea of using infrared heating to kill germs isn't new. But studies by the two California scientists are likely the most comprehensive investigations of the use of infrared heating to pasteurize almonds and knock down *Salmonella* populations to levels generally recognized as safe.

Pan says infrared heating offers the promise of fast, reliable, and relatively economical pasteurization. According to results from dozens of volunteer taste testers (sensory panelists) who participated in the studies, infrared heating doesn't detectably alter the mild taste, smooth texture, attractive appearance, or other characteristics that make almonds one of the country's most perennially popular tree nuts.

Infrared heating is, essentially, natural. "When you sit near your fireplace, the waves of heat that you feel are infrared energy," Pan says.

Electromagnetic and invisible, infrared waves are also "the same kind of radiant energy that we get from the sun." For their experiments, the scientists determined that infrared works well for killing *Salmonella* on either roasted or raw almonds.

In their studies with shelled, roasted almonds, for example, the team targeted a "medium roast," during which almonds' naturally light shade deepens somewhat.

The scientists compared the effectiveness of three approaches: conventional hot-air heating, infrared heating, or infrared heating followed by hot-air heating—a pairing that they dubbed "SIRHA" (sequential infrared and hot air).

Their evaluations showed that SIRHA was more energy efficient than either infrared or hot-air heating alone. Says Pan, "With the combined infrared and hot-air heating, we can produce a pasteurized product and significantly reduce roasting time. That should help processors save on their energy bills."

For this work and their newest study with raw almonds, the team used the bacterium *Enterococcus faecium* as a research model and substitute, or surrogate, for *S. enterica.* The microbe is "just as heat resistant as *S. enterica,*" according to Brandl.

The roasting studies showed, for instance, a more than 5.8-log reduction in *E. faecium* levels—exceeding the required 4-log minimum. That target was met handily by heating the almonds with infrared until they reached a surface temperature of 140˚C, then roasting them with hot air at the same temperature for about 11 minutes.

The infrared step took about 1 minute, using emitters—positioned above and below the almonds—that produced 5,000 watts of energy per square meter.

Infrared Works for Raw Almonds, Too

What about folks who prefer raw almonds?

Infrared meets that need too, with a three-step process that leaves shelled, infrared-treated nuts "virtually indistinguishable from those that haven't been treated," Pan reports.

"We expose the almonds to a quick burst of infrared heat, allow their surface temperature to drop, then keep them at that temperature until we reach the target kill rate," he says.

For example, the team achieved a 5.5-log kill rate by briefly using infrared to heat the almonds to 100˚C, then allowing the nuts' surface temperature to drop to 90˚C. After that, they kept the almonds in a warmed environment to sustain the 90˚C temperature until the 5.5-log kill rate was reached.

"We used a batch process, but it should be easy to replicate our kill rate in a continuous-flow system at the packinghouse," says Pan.

Salmonella can be a particularly problematical target because it is "quite heat tolerant" according to Brandl. "We had to find the right combinations of time and temperature that would overcome the tolerance and kill the pathogen."

Pan and Brandl collaborated in these studies with research leader and food technologist Tara H. McHugh, food technologists Gokhan Bingol and Donald A. Olson, and technician Steven Huynh—all at Albany; former University of California-Davis graduate students Jihong Yang and Yi Zhu; and Hua Wang, a professor at Northwest Agricultural and Forestry University, Yangling, Shaanxi, China.

Peer-reviewed articles published in the *Journal of Food Engineering* in 2010 and 2011 and in the *Journal of Food Protection* in 2008 document their findings.

Will Tomorrow's Packinghouses Opt for Infrared?

Infrared technology seems to pose few if any drawbacks. Of course, packinghouses would have to invest in infrared equipment and deal with the learning curve. But no license to own or use the equipment is

STEPHEN AUSMUS (D2409-1)

In tests of the effectiveness of sequential infrared heating and hot air (SIRHA) pasteurization, almonds were inoculated with bacteria and then treated with SIRHA. Here, microbiologist Maria Brandl places treated almonds into a washing device, and research associate Gokhan Bingol inspects the wash water for any surviving bacteria.

needed, and extensive training is not required, Pan notes.

Before this pasteurization process makes its way into the packinghouse, pilot-scale and in-the-packinghouse testing will be needed to gather the data necessary for federal review and approval. That might take anywhere from 1 to 2 years or more, Pan estimates.

Once that happens, perhaps infrared heating will become tomorrow's top-choice technology for pasteurizing America's almonds.—By **Marcia Wood,** ARS.

This research supports the USDA priority of ensuring food safety and is part of Food Safety (#108) and Quality and Utilization of Agricultural Products (#306), two ARS national programs described at www.nps.ars.usda.gov.

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Sliced almonds add flavor, crunch, and nutrients to this serving of hearty apple-maple oatmeal.

ALMOND BOARD OF CALIFORNIA (D2411-1)

ALMOND BOARD OF CALIFORNIA (D2410-1)

Almond Hulls: Harvest Leftover May Offer a Health Connection

Cross-section of an almond hull.

Besides yielding about $1 billion worth of healthful, orchard-fresh nuts, California's annual almond harvest also yields tons of leftover hulls. The hull is the tough, outermost layer that helps protect the shell—and the tasty nutmeat inside the shell—against attack by insects and disease.

Early studies by Agricultural Research Service chemist Gary R. Takeoka and colleagues have shown that hulls are a rich source of several interesting natural compounds that may have new applications for human health.

Using an array of sophisticated analytical techniques, including gas chromatography, high-performance liquid chromatography, nuclear magnetic resonance spectroscopy, and mass spectrometry, Takeoka's team provided new details about the identity and quantity of certain chemical compounds contained in the hulls. These included six kinds of acids (betulinic, chlorogenic, cryptochlorogenic, neochlorogenic, oleanolic, and ursolic) and two kinds of lipids (beta-sitosterol and stigmasterol).

Results from biomedical research that scientists elsewhere conducted—with laboratory animals or cell cultures as their research models—indicate that some of these compounds may have potential use in human health. For example, the medical research suggests that some of the chemicals may lower serum cholesterol, fight HIV and certain kinds of cancer, or suppress harmful internal inflammation—the kind associated with arthritis, for instance.

Takeoka's research about the compounds, published in peer-reviewed articles in 2000 and 2003 in the *Journal of Agricultural and Food Chemistry,* has led to commercial interest in the possibility of profitably extracting the chemicals. An international expert in natural products chemistry, Takeoka did the work with coinvestigators at the ARS Western Regional Research Center in Albany, California, near San Francisco. He's in the center's Processed Foods Research Unit.

Today, almond hulls are a low-value harvest leftover typically sold as a cattle-feed ingredient. Tomorrow, the hulls may prove to be a new and perhaps surprising source of health from America's almond orchards.—By **Marcia Wood,** ARS.

This research is part of Quality and Utilization of Agricultural Products, an ARS national program (#306) described at www.nps.ars.usda.gov.

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