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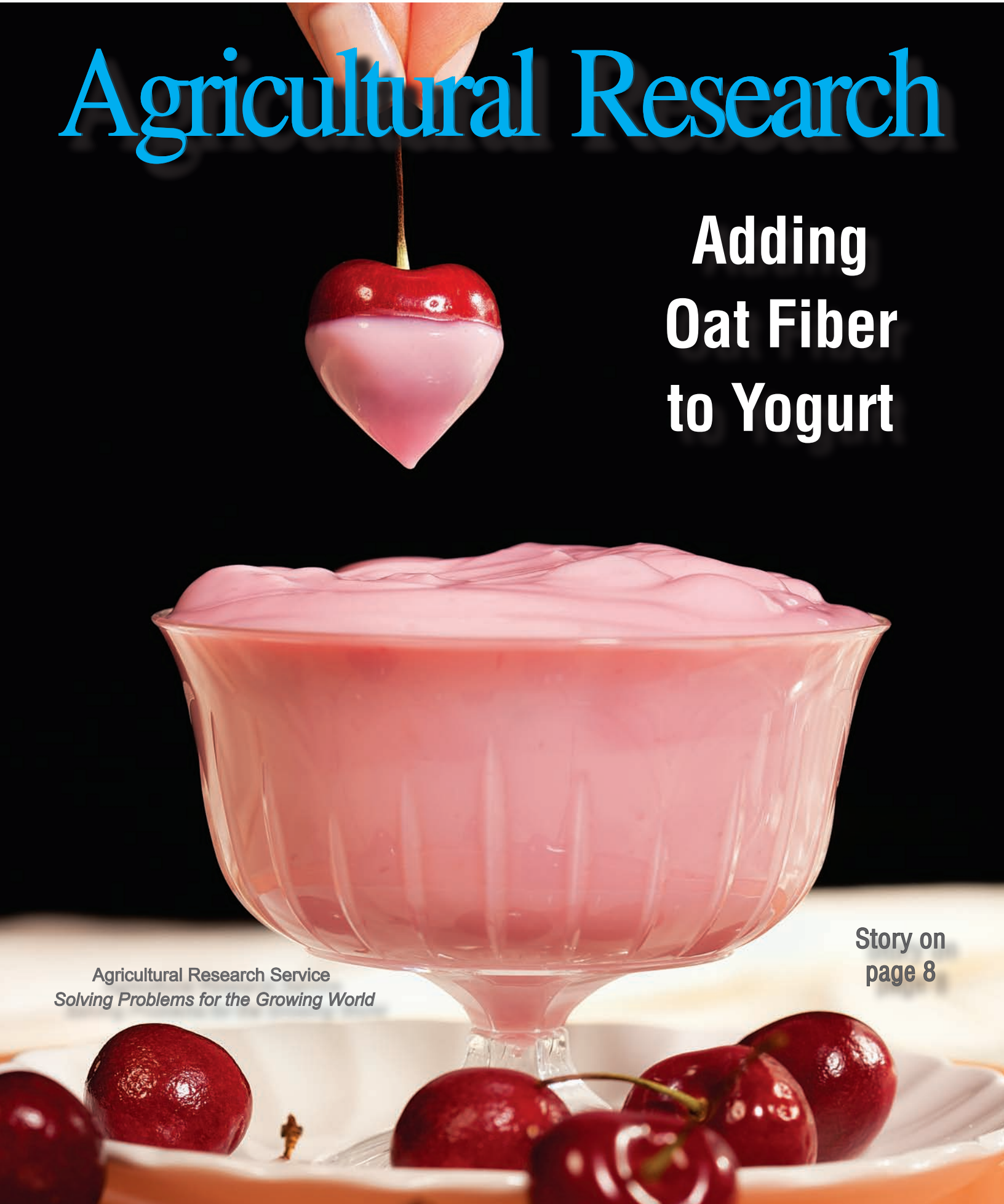
Agricultural Research



Adding Oat Fiber to Yogurt

Story on page 8

Agricultural Research Service
Solving Problems for the Growing World

FORUM

Wasted Food: What We Are Doing To Prevent Costly Losses

Like many other public and private organizations, the Agricultural Research Service is very concerned about how much food goes to waste between farm and fork—both nationally and internationally.

By reducing losses in our food systems, U.S. growers, processors, and others can enhance America's ability to feed itself and the world. By the same token, slashing waste may provide new opportunities to reduce costs along the entire supply chain and make better use of increasingly limited natural resources.

The U.S. Department of Agriculture's Economic Research Service (ERS) estimated—in 2008—that the amount of food lost annually at just the retail and consumer levels alone averaged 275 pounds per person, representing a total yearly national impact of $165 billion. Cutting our food losses by just 15 percent would provide enough extra food to feed more than 25 million Americans every year from existing crop, pasture, and rangelands.

Another ERS assessment found that most of the food loss in developed countries happens postharvest, that is, after food has left the farm gate, while in less developed countries, the bulk of the loss occurs before harvest.

In the United States, nonprofit organizations concerned with a stable and accessible food supply—and wise use of the resources that are needed to produce and deliver that food—have called on the federal government to conduct a comprehensive study of losses in our food systems and to set national goals for reducing this waste. Meanwhile, ARS scientists at laboratories throughout the country have, for some time, been conducting a range of studies to create new technologies or to newly apply existing ones to curb food waste.

Our ongoing work encompasses a wide variety of foods, from grains to grapes, meats to potatoes, and more.

STEPHEN AUSMUS (D832-1)

For example, we have developed an ozone-based treatment that growers of organic grapes can use—after harvest—to inhibit *Botrytis cinerea,* the microbe that causes gray mold. The research provides an alternative to sulfur dioxide, which organic growers cannot use.

We are investigating the combined use of refrigeration, improved packaging, and a natural compound that delays ripening to help perishables such as strawberries, blueberries, and tomatoes stay fresh longer during shipping and storage.

We are developing powdered fruit- and vegetable-based coatings to inhibit spoilage of fresh-cut produce.

We are experimenting with the use of cold plasma technology to ionize the atmosphere inside packages of raw chicken breasts to quickly, safely, and effectively extend the shelf life of this popular product.

We are inventing robots for in-orchard culling of apples, a high-tech approach that could help reduce the postharvest spread of insects or crop diseases from one apple to the next.

We are working to identify storage conditions that will minimize spoilage and losses in new food products such as "microgreens." These are greens—from daikon radish, buckwheat, or broccoli, for example—that are harvested when they are very young and very small.

We have designed a new package that reduces moisture loss and doubles the storage life of small fruits.

We are designing new and improved retail-display cases to help extend the shelf life of fresh and fresh-cut produce.

In collaboration with the U.S. Centers for Disease Control and Prevention and other cooperators, we are developing sophisticated near-infrared spectroscopy techniques to detect very low levels of insects, toxin-producing molds, and other contaminants that can ruin wheat and other grains during storage.

Some of our investigations target the needs of people in less-developed countries. For instance, we developed the technology for a superior instant corn-soy blend. Twenty metric tons of this ready-to-eat emergency-aid food were shipped to Haiti in 2011 to feed more than 3,000 malnourished children. The product's 1-year shelf life makes it ideally suited for tropical countries that lack adequate storage facilities.

What's more, the inexpensive, small-scale processing equipment that we developed has helped Haiti by cutting postharvest losses of locally grown peanuts by about 75 percent and speeding local production of a peanut-butter-based food that is important in preventing malnutrition.

In all, we are eagerly exploring a wide variety of approaches to reduce food waste, and we are continuing to form new partnerships with other researchers and producers in the United States and abroad who share our concern and sense of urgency. We are committed to resolving supply-chain challenges to improve the farm-to-fork flow of wholesome, nutritious food.

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Quality and Utilization
of Agricultural Products
Beltsville, Maryland

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Solving Problems for the Growing World

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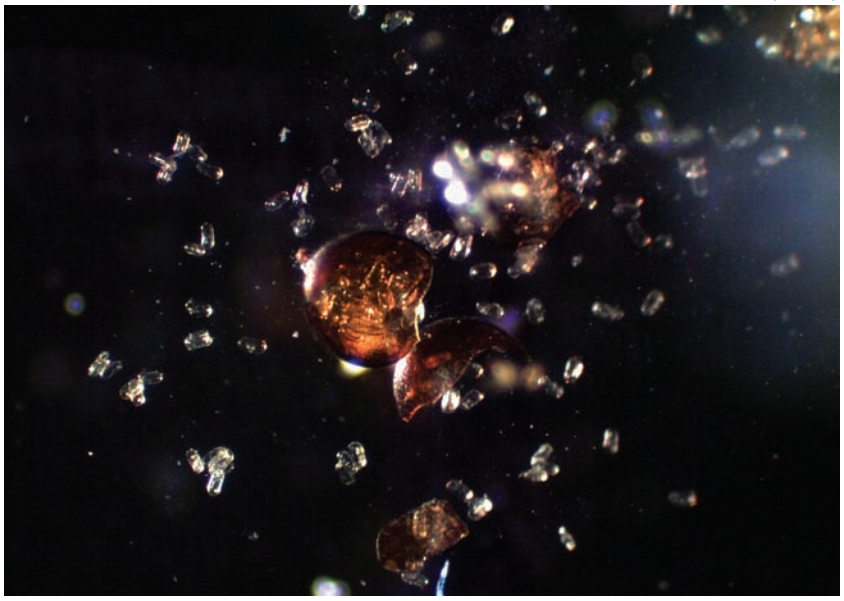
POTATO CYST NEMATODE RESEARCH GROUP (D2794-1)



Microscope image of potato nematode eggs spilling out of a ruptured cyst. ARS scientists are testing trap crops to find ones that can make the pest hatch from these cysts and then starve for lack of a host. See story, page 18.

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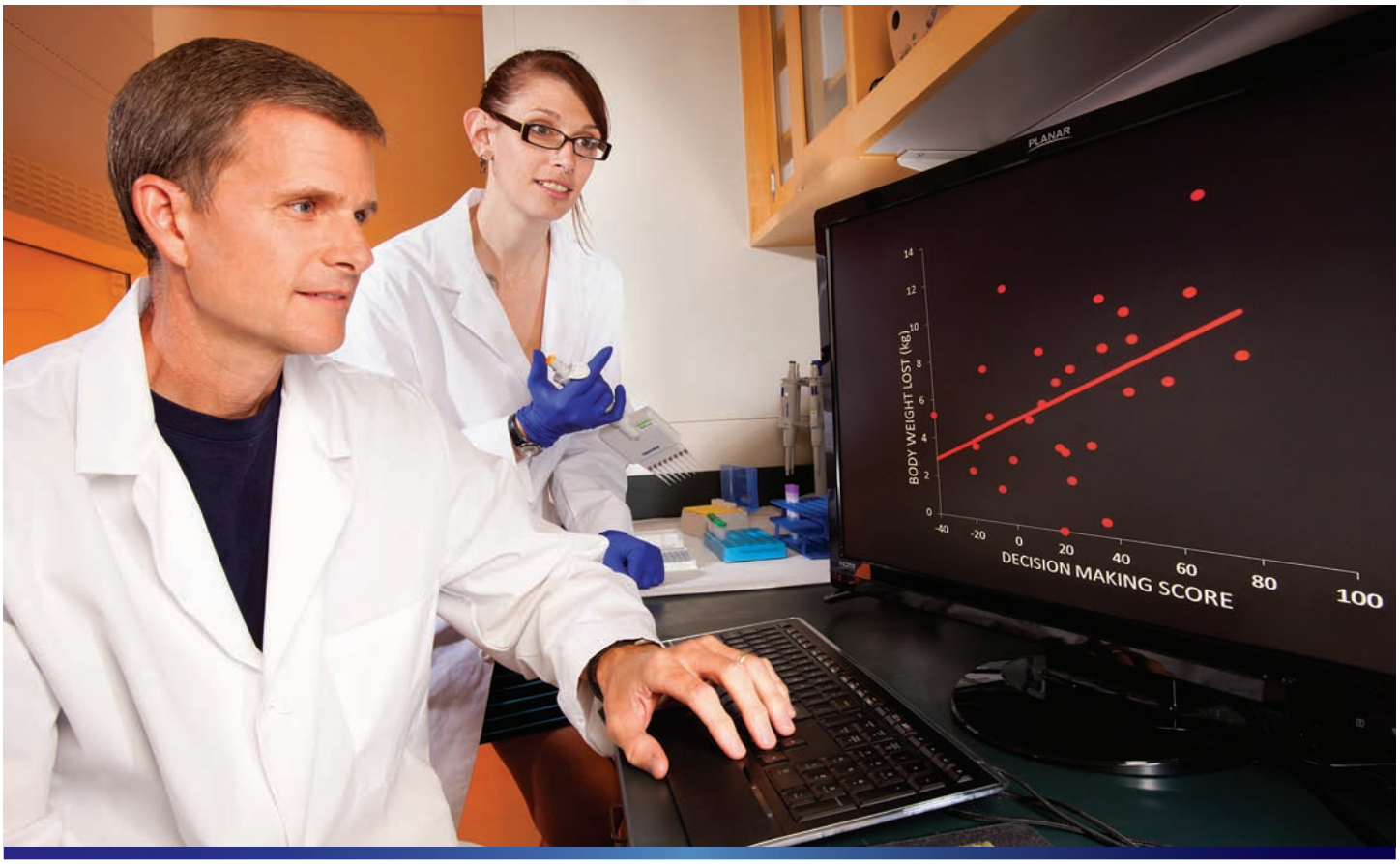
Cover: ARS scientists performed tests on low-fat yogurt to see how much oat fiber can be added without affecting key qualities of this popular dairy food. Story begins on page 8. Photo by Peggy Greb. (D1072-2)

Weight Loss, Cortisol, and Your Brain
Scientists Explore Connections



PEGGY GREB (D2802-1)

Nutrition scientist Kevin Laugero and biologist Rashel DeCant observe data that show a correlation between brain function and amount of weight lost.

Americans everywhere are struggling to lose weight—and to keep from putting those lost pounds right back on. For many, it's discouraging to have their best efforts fail while those of other dieters succeed.

Researchers at the Agricultural Research Service's Western Human Nutrition Research Center in Davis, California, are conducting studies that may provide new insights into the underlying causes of this disparity in dieting success.

Given America's obesity epidemic, such research is timely and relevant. The U.S. Centers for Disease Control and Prevention estimates that 35 percent of U.S. adults and 18 percent of kids and adolescents age 6 through 19 are overweight or obese. Both conditions are associated with increased risk of type 2 diabetes, cardiovascular disease, and other chronic disorders.

Chemist Nancy L. Keim, nutrition scientist Kevin D. Laugero, and their colleagues have looked at several factors that may affect weight-management success. Their analysis included assessing volunteers' patterns of decisionmaking and evaluating changes in their levels of cortisol—a stress-associated hormone.

The study volunteers, 29 obese but otherwise healthy women age 20 to 45, were asked to eat all their meals at the nutrition center, where their food was prepared for them.

The research began with a 3-week baseline phase, during which the intent was to stabilize the volunteers' weight. That was followed by a 12-week reduced-calorie regimen intended to help the volunteers shed pounds. During this weight-loss phase, meals provided 500 fewer daily calories than the total each volunteer would have needed if the goal had been to maintain her weight.

Two exceptions to this outline were built into the study: During each of the two study phases, volunteers had an "all you can eat" evening meal. These buffet dinners were provided for each volunteer to eat privately, to help rule out the effect that social pressure might have on what, and how much, the volunteer chose to eat.

Weight Loss Differs

The amount of weight lost and the amount lost as fat instead of lean (muscle or bone) varied widely among the volunteers. Says Keim, "The variation occurred even though volunteers were essentially provided the same foods and were each shorted

500 calories a day during the weight-loss phase—with the exception of the buffet dinner." Volunteers lost anywhere from 0 to 27 pounds.

This variation, along with findings from many other weight-management clinical trials conducted elsewhere, suggests that tomorrow's weight-loss strategies "may need to be even more individualized to be more successful," Keim says.

Dieting and Decisionmaking

For many people, dieting "involves an ongoing series of decisions," Keim notes. "We wanted to get a snapshot of volunteers' patterns of decisionmaking."

To do this, the researchers selected the Iowa Gambling Task, or IGT, a test that is widely used to evaluate what's known as "executive function." This umbrella term encompasses decisionmaking, differentiating good from bad, being cognizant of the potential future consequences of current actions, and resisting the temptation of short-term, immediate rewards in favor of longer term benefits.

These functions are thought be handled in a region of the brain known as the "prefrontal cortex."

During the IGT test, volunteers had a limited amount of time to choose cards from among four decks displayed face down on their computer screen. Each card offers, in "play" money, a monetary penalty and a monetary reward. As the test progresses, players can learn to distinguish a "good" from a "bad" deck in terms of the risks and rewards offered, and they can modify their future choices accordingly—or not.

"We found that the volunteers who lost the most weight had the highest IGT scores," Keim says. "To the best of our knowledge, this study is the first controlled-feeding weight-loss trial to report an association between diet-induced weight loss and performance on the IGT.

"The application of the IGT is really in its infancy in terms of decisionmaking about food—and eating in general. We intend to continue to use this test in studies that are designed to delve into how people make decisions about what they eat."

Cortisol Concentrations Increase

To learn more about volunteers' cortisol levels, the scientists collected saliva samples throughout the day on two test dates, one near the beginning of the weight-loss regimen and one near the end.

"Increases in cortisol concentration have long been regarded as a reliable indicator of psychological stress, even though those increases can also be caused by other factors," says Laugero. "Stress is considered to be a contributing factor to dieters' relapsing back to old eating habits and regaining weight.

"We found that our volunteers' cortisol concentrations generally increased from the beginning to the end of the reducing-diet phase of the study. Dieting may have been stressful for them. They were experiencing an element of outside control over what they ate, in that we asked them to eat only the foods that we offered them. Also, each dieter had to exercise restraint for 12 weeks, except perhaps during the buffet meal. That's a relatively long time.

"In addition to its association with stress, cortisol is thought to affect our eating habits and how our bodies metabolize fat," Laugero points out. "Some animal studies suggest that cortisol contributes to obesity, but the association remains unclear and controversial."

Cortisol Levels Compared to IGT Scores

In another analysis of the cortisol data, the scientists found that volunteers whose cortisol levels had increased the most were those with the lowest IGT scores.

"The IGT has been used in earlier research concerning eating disorders and obesity," Laugero says, "but our study is apparently the first weight-loss trial of its kind to report an association between cortisol concentrations and IGT scores." Says Laugero, stress is "already known to have a degrading effect on regions of the brain, including the prefrontal cortex, that are involved in decisionmaking."

Perhaps most interesting of all, the prefrontal cortex is also involved in releasing cortisol. "Some cross-talk that we don't fully understand may be taking place," says Laugero. "A better understanding of that communication may lead to successful, science-based strategies for reaching and maintaining a healthy weight."

Everyone, not just dieters, might benefit. Obesity adds an estimated $190 billion to the nation's annual healthcare costs.

Keim and Laugero, who are with the ARS Obesity and Metabolism Research Unit, collaborated in the study with unit physiologists Sean H. Adams and Marta D. Van Loan and postdoctoral researcher Megan G. Witbracht of the University of California-Davis Department of Nutrition.

The study was part of a larger investigation headed by Van Loan. A peer-reviewed article in *Physiology and Behavior* documents the investigation.—By **Marcia Wood,** ARS.

This research is part of Human Nutrition, an ARS national program (#107) described at www.nps.ars.usda.gov.

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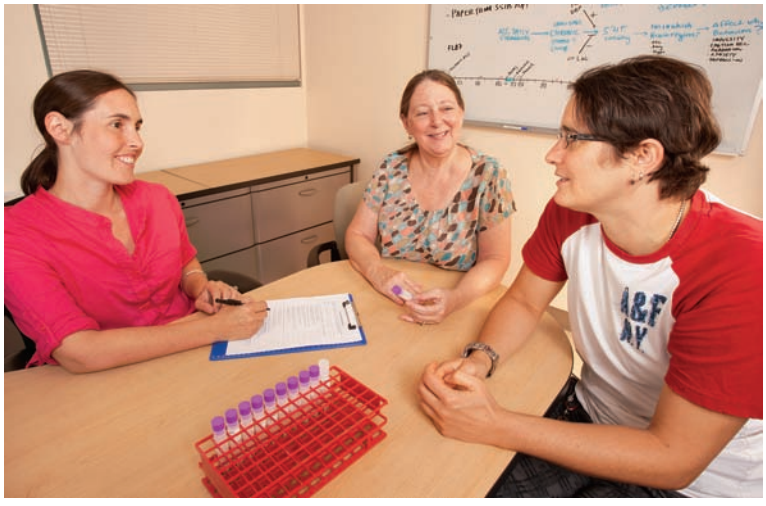


Postdoctoral researcher Megan Witbracht (left) instructs a study volunteer (right) on an end-of-study test of brain function while chemist Nancy Keim answers questions that come up.

PEGGY GREB (D2801-1)

How Does Mom's Nutrition Affect Her Children's Health?

FELICIA WEBB (D2737-1)

Seasonal fluctuations in food availability may affect what Gambian women eat before and during pregnancy. Scientists have shown that these dietary differences can affect the development of genes in the unborn children.

Epigenetics May Provide New Insights

In some rural villages of the tiny West African nation of The Gambia, food is generally less available during August and September—the peak of the rainy season—than during a typically dry March through May. Now, a study led by molecular geneticist Robert A. Waterland of the USDA-ARS Children's Nutrition Research Center in Houston, Texas, has shown that functioning of certain genes in kids conceived during the rainy season differs from that in children conceived during the dry season.

The difference may be explained by a relatively new science referred to as "epigenetics." The variation appears to be permanent, and in the case of two of the five genes in which it was detected, the variation may affect the kids' risk of certain diseases.

Waterland and coinvestigators have attributed the epigenetic variation to the dramatic seasonal differences in the kinds and amounts of foods available to soon-to-be moms in the days and weeks around the time of conception, or what's referred to as their "periconceptional nutrition."

The results of the study are of interest to healthcare professionals involved in improving the prenatal nutrition of these Gambian women, many of whom are, along with other family members, subsistence farmers living at or below the poverty level.

But Waterland's study is also of worldwide interest to geneticists, because it presents new, unique evidence of nutritional influences on the development of epigenetic mechanisms in humans.

What Is Epigenetics?

Epigenetics means "on or above genetics." Explains Waterland, "Epigenetic mechanisms don't change the DNA sequence of genes, but they do cause stable changes in the way genes function."

At one time highly controversial, epigenetics is now accepted as likely having a role in human disease, including cardiovascular disorders, type 2 diabetes, obesity, and certain kinds of cancer.

Waterland's research focused on DNA methylation, an epigenetic mechanism that plays a key role in the development of different cell types in the body. Earlier work with laboratory animals has already shown that establishment of DNA methylation can be influenced by mom's nutrition before and during pregnancy. Mice born to mothers (dams) fed a diet designed to increase DNA methylation "did in fact have higher DNA methylation levels at certain genes," Waterland says. Now, his Gambia investigation is the first to show that this influence can occur in humans, too.

DNA in Blood Samples Analyzed

For the Gambia study, small samples of blood from 50 healthy local kids were analyzed to detect differences in the level of DNA methylation at specific regions of certain genes. "Levels of DNA methylation can range from 0 to 100 percent," Waterland notes.

Using a screening procedure that Waterland developed earlier and improved for this study, the research team showed

STEPHEN AUSMUS (D2735-1)

Earlier studies in mice by ARS molecular geneticist Robert Waterland showed that the mother's diet before and during pregnancy affects DNA methylation in her offspring, leading to permanent changes in the function of certain genes.

that levels of DNA methylation of five specific genes were higher in kids who were conceived in the peak rainy season than the levels in the other children.

"DNA regions that show this kind of random, individual-to-individual variation in levels of DNA methylation that can be influenced by mom's nutrition are called 'metastable epialleles,'" says Waterland. "In our previous research, with mice, the effect of maternal nutrition on DNA methylation levels was permanent. Because we are seeing this effect in kids whom we tested when they were about 9 years old, we think that the epigenetic effect, established early in their development, will likewise be permanent."

Of the five genes at which the elevated levels of DNA methylation were observed, two in particular "warrant further study because they are associated with risk of disease," Waterland says. "Specifically, the *SLITRK1* gene is associated with Tourette's syndrome, and the *PAX8* gene is linked to hypothyroidism."

Farming in a Tropical Savannah

The three villages—Keneba, Kantung Kunda, and Maduar—that were the focus of the periconceptional nutrition research are situated in a tropical savannah ecosystem. "Farmers in these villages have no irrigation, so they must rely on the rains," says Waterland. "Staple crops like corn, rice, and millet are planted only at the beginning of the rainy season and harvested at the end. Understandably, they may be in very short supply, if not entirely gone, before the next harvest."

What's more, the hard labor involved in planting, tending, and harvesting the staple crops "burns a lot of calories, meaning that many villagers are expending more calories than they are taking in," he says.

"We thought that peak rainy season hunger would lower levels of DNA methylation in children conceived at that time, but we found exactly the opposite. We don't yet know why that happens, but we have more detailed studies under way that may give us the answer."

These new studies may also indicate precisely which foods—and nutrients in those foods—resulted in higher levels of DNA methylation in the rainy-season children.

"The best candidates include folate, vitamin B12, betaine, and choline, which were shown to affect DNA methylation in the earlier mouse studies," says Waterland. "Epigenetics research may help us determine more about the roles that these nutrients and others play in the health of not just these West African kids, but of children everywhere."

Waterland collaborated in the study with Richard Kellermayer, Eleonora Laritsky, Mark J. Manary, Lanlan Shen, Maria S. Torskaya, and Wenjuan Zhang—all with the Baylor College of Medicine in Houston, where Waterland is an associate professor of pediatrics and of molecular and human genetics; and R. Alan Harris of the college's department of molecular and human genetics.

Also collaborating were Pura Rayco-Solon and Andrew M. Prentice of the MRC International Nutrition Group, London (United Kingdom) School of Hygiene and Tropical Medicine; Michael Travisano of the Department of Ecology, Evolution, and Behavior at the University of Minnesota-St. Paul; and Jiexin Zhang of the Department of Biostatistics and Applied Biomathematics at the M.D. Anderson Cancer Center at the University of Texas-Houston.

The team's findings appear in a 2010 peer-reviewed article in *PLoS Genetics.*

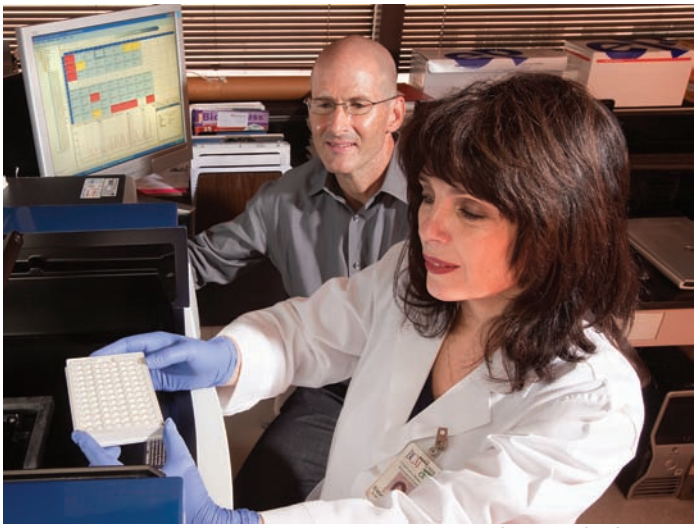
Funding for the study came from ARS and the United Kingdom Medical Research Council, and grants from the March of Dimes Foundation, the National Institutes of Health, and the Curtis and Doris K. Hankamer Foundation.

The Children's Nutrition Research Center is jointly operated by ARS, Baylor College of Medicine, and the Texas Children's Hospital.—By **Marcia Wood,** ARS.

This research is part of Human Nutrition, an ARS national program (#107) described at www.nps.ars.usda.gov.

Robert A. Waterland is with the USDA-ARS Children's Nutrition Research Center at Baylor College of Medicine, 1100 Bates St., Houston, TX 77030; (713) 798-0304, waterland@bcm.edu.

Robert Waterland and technician Eleonora Laritsky measure DNA methylation to determine how it changes the activity of genetically identical cells.



STEPHEN AUSMUS (D2734-1)

Enhancing Yogurt With Healthful Fiber From Oats

Adding about one-quarter teaspoon of a fiber-rich component of oats boosts the nutritional value of low-fat yogurt without noticeably affecting the taste or texture of this increasingly popular dairy food.

Oat fiber is of interest to foodmakers and nutritionists alike. Studies with volunteers have shown that it can lower serum cholesterol, which may help improve heart health.

Agricultural Research Service food technologist Mukti Singh, chemist Sanghoon Kim, and their colleagues experimented with adding fiber-containing oat beta-glucan to what's known in the dairy industry as "low-fat yogurt mix." It is made up of low-fat milk and a selection of common, safe-to-eat bacteria that ferment the milk. Best known bacteria include *Lactobacillus acidophilus* or various *Bifidobacterium* species.

Singh's intent was to see how much fiber she could add without altering key qualities of yogurt, including texture, viscosity, color, pH, and fermentation time.

In experiments at the ARS National Center for Agricultural Utilization Research in Peoria, Illinois, Singh's team added 0.1, 0.2, 0.3, 0.4, or 0.5 percent purified oat beta-glucan—a light, fine-textured, whitish powder—to low-fat yogurt mix and compared the results to yogurt mix with no oat fiber.

The idea of adding edible fiber to yogurt isn't new. But in studies such as this, Singh is filling in some of the gaps in our knowledge of how fiber may affect yogurt-mix qualities that are important to foodmakers and to yogurt fans.

In the oat beta-glucan work, the team determined that up to 0.3 percent highly purified (95 percent pure) oat beta-glucan, which translates to 0.3 grams of beta-glucan per 100 grams of yogurt mix, could be added without significantly altering key yogurt qualities. But adding 0.4 percent or higher changed the yogurt's color, contributed to unwanted hardening, and slowed fermentation.

The 0.3 percent level of fortification totals out at 0.75 grams of fiber per 8-ounce serving of yogurt. Most Americans don't get enough fiber, so even this small addition to a familiar dairy product helps.

A peer-reviewed article published in 2012 in the *Journal of Food Science* by Singh, Kim, and Sean X. Liu, research leader of the Functional Foods Research Unit at Peoria, documents the research.—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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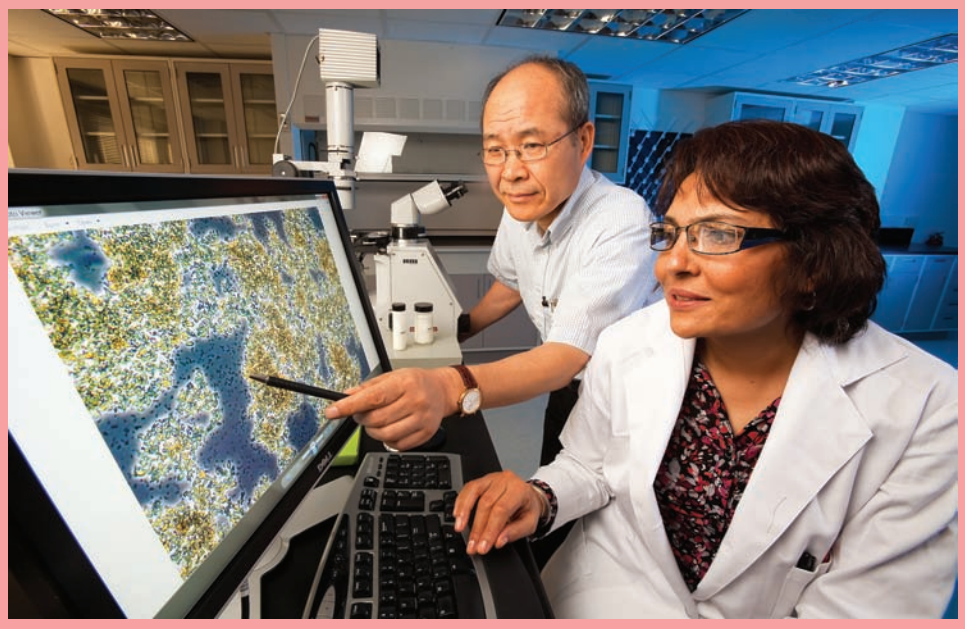
PEGGY GREB (D1073-2)

ARS scientists have added different levels of oat beta-glucan to low-fat yogurt mix to increase its fiber content.



At the ARS National Center for Agricultural Utilization Research in Peoria, Illinois, chemist Sanghoon Kim (left) and food technologist Mukti Singh review a microscope image showing the effects of oat beta-glucan during yogurt fermentation.

STEPHEN AUSMUS (D2763-1)

An Atlas for Guatemala, a Tool for Conserving World Crops

With exotic names like *ayote de caballo* (a wild squash), *friajolito* (a wild bean), and *teocinte* (a wild relative of corn), Guatemala's native plants seem very different from the agricultural bounty produced by farmers in the United States and other countries. But many of these native plants carry genes that may be vital to global food security. A new tool, developed by a team that includes Agricultural Research Service scientists, will make it easier to find and preserve these important plants. The tool is an interactive atlas designed to provide Guatemalan scientists and land managers with information on where these crop wild relatives grow, where they are relatively safe from habitat destruction, and which ones are rare and most at risk.

The genes these wild plants contain may prove useful in addressing threats posed by emerging diseases, insect pests, and temperature and rainfall extremes arising from a changing climate, says Karen Williams, a botanist with the ARS National Germplasm Resources Laboratory in Beltsville.

"Guatemala has many genetically diverse native plants closely related to some of our most important crops, including corn, beans, peppers, and potatoes. Some of these crop wild relatives are found only in Guatemala, and they have genes that equip them with survival mechanisms that may be useful to protect crops," Williams says.

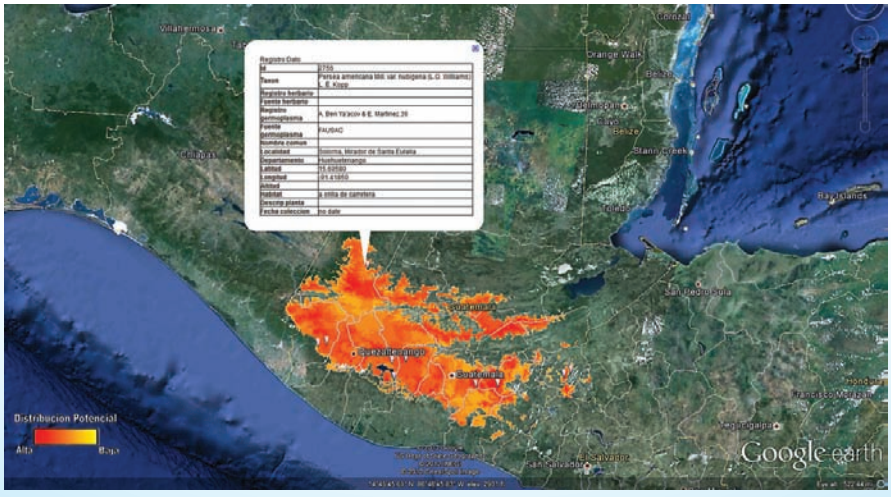
Williams worked on the atlas for almost 10 years with César Azurdia Pérez from the Agronomy Faculty at the University of San Carlos in Guatemala, David E. Williams and Veerle van Damme from Bioversity International, and Andrew Jarvis and Silvia Elena Castaño from the International Center for Tropical Agriculture.

Developing the database underlying the atlas required researchers to track down and compile some 2,600 records of scientific specimens, which included when and where the plants were found and descriptions of their appearance and native habitats. They consulted records from numerous germplasm collections, including the Agronomy Faculty at the University of San Carlos and the Institute of Agricultural Science and Technology in Guatemala, the ARS-managed National Plant Germplasm System, and the genebanks of the Consultative Group on International Agricultural Research. They also consulted collections of dried plant specimens preserved in the United States, Guatemala, Honduras, and Mexico.

Species of plants in the atlas are related to 29 crops, which were selected based on their importance to both world and Guatemalan agriculture. Of the 105 species included in the atlas, eight occur only in Guatemala.

The atlas, accessible to researchers and the public via a Google Earth interface, gives access to decades of data about a region that is rich in biodiversity. Users can zoom in on a satellite map of Guatemala and see icons showing exactly where the plants were found. When icons are clicked, pop-up boxes appear that give detailed descriptions of the plants.

KAREN WILLIAMS (D2805-1)



KAREN WILLIAMS (D2806-1)

The atlas also provides maps showing the projected range of each species based on its known climatic preference, the overlap of species' ranges with parks where they may be protected from habitat destruction, and the geographic regions with a high diversity of crop wild relatives. Scientists can consult the information to help determine which species are threatened and warrant conservation measures, plan future collection efforts, and identify areas where natural environments need to be preserved.

The atlas is currently available in Spanish only. Williams and her collaborators are translating it into English, and that translation is expected to be available this year.

The atlas and supporting data are available at www.ars.usda.gov/ba/atlascwrguatemala. A similar atlas is under construction for crop wild relatives in Paraguay.—By **Dennis O'Brien,** 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.

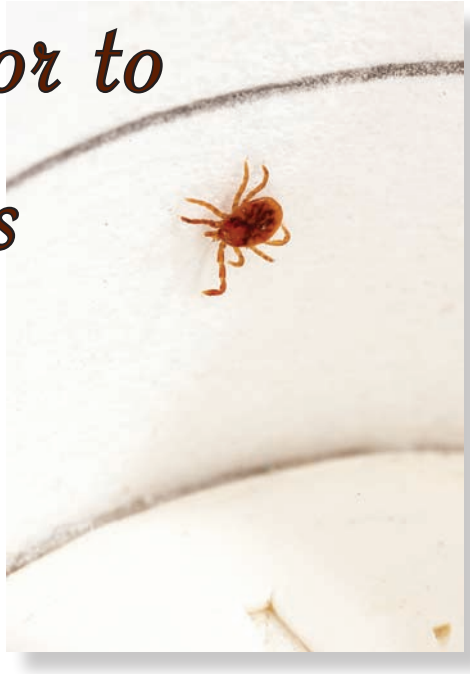
Karen Williams is with the USDA-ARS Plant Exchange Office, National Germplasm Resources Laboratory, 10300 Baltimore Ave., Beltsville, MD 20705-2350; (301) 504-5421, karen.williams@ars.usda.gov.

Top: A photo of one of the plants included in the atlas—a wild lima bean, *Phaseolus lunatus*.

Left: The interactive online atlas contains useful information about crop wild relatives growing in Guatemala.

Linking Animal Behavior to Useful Natural Repellents

STEPHEN AUSMUS (D2783-8)



In a lab test, this lone star tick nymph *(Amblyomma americanum)* was exposed to a citrus rind chemical, placed upside down inside an untreated filter paper cylinder, and observed to see whether it could right itself.

A little monkey business is revealing a few clues about natural remedies that animals use to protect themselves against biting insects and arthropods.

Certain species of animals, such as monkeys and birds, anoint themselves with citrus, other plants, and creatures like millipedes. To find out more about this behavior and to determine if any chemicals in the anointing substances effectively deter ticks and mosquitoes, scientists are examining responses to natural compounds.

Scientists at the Agricultural Research Service Henry A. Wallace Beltsville [Maryland] Agricultural Research Center (BARC) and the Smithsonian Conservation Biology Institute (SCBI) at the National Zoological Park in Front Royal, Virginia, compared the effects of citrus compounds on lone star ticks and yellowfever mosquitoes. They also investigated compounds found in millipedes.

Citing Citrus Effects

"We tested a number of components known to be abundant in all citrus extracts, not just lemons, limes, and oranges, but all the fruits that are used in anointing—including citrus leaves," says SCBI researcher Paul Weldon.

Of the more than 20 citrus compounds they evaluated, the scientists found that 10 deterred ticks and/or mosquitoes, and 9 impaired basic tick behavior.

Weldon used a feeding membrane module that he developed to test citrus compounds against mosquitoes. Some compounds were very effective. But the same compounds were not effective at all when mosquitoes were exposed to them in a wind tunnel module by chemist Ulrich "Uli" Bernier, in the Mosquito and Fly Unit at the ARS Center for Medical, Agricultural, and Veterinary Entomology in Gainesville, Florida.

"We viewed the results of the wind tunnel as being more authentic," Weldon says. "The compounds didn't affect mosquitoes that much, but mainly affected ticks. It was a step forward in pinpointing what we believe is the reason that animals anoint themselves with citrus substances."

Ticking Off Ticks

Mosquitoes, ticks, and other blood-feeding arthropods are attracted to certain chemicals, such as carbon dioxide in an animal's breath. One behavior of host-seeking ticks when a host draws near is to climb up a plant to reach the passing host and then find an attachment site on the host's body.

Entomologist John Carroll, of BARC's Invasive Insect Biocontrol and Behavior Laboratory, and colleagues conducted several experiments to evaluate citrus compound repellency against ticks. One test involved putting lemon rind exudates and various citrus chemicals on paper strips. When they sensed a host cue, the ticks

ARS entomologist John Carroll conducts tests to show the effects a 1-hour exposure to citrus rind chemicals has on ticks.

STEPHEN AUSMUS (D2782-9)

GREG ALLEN (D2799-1)

In Gainesville, Florida, ARS chemist Uli Bernier uses an olfactometer to evaluate the efficacy of a chemical to inhibit mosquitoes from being attracted to humans.

started climbing the paper. Information was recorded on whether a tick crossed a line into chemically treated zones, continued crawling, turned around, crawled back down, or fell off the paper. On average, 9 out of 10 ticks rushed to the top of the paper strip treated with acetone—the control. Stopping, retreating, and falling off the paper indicated repellency, Carroll says.

"In another experiment, we put ticks inside filter-paper packets treated with citrus chemicals," he says. "After an hour, ticks were removed from the packets, placed on their backs, and timed to see whether they could turn themselves right side up, walk, and climb out of a low enclosure."

Some of the chemicals that had repellency also had a big effect on tick behavior, but so did some of the nonrepellent ones, Carroll says. Some ticks did not crawl out and appeared uncoordinated. Of 24 ticks exposed to 1 chemical, only 1 tick righted itself. Of more than 20 chemicals tested, only 1 killed ticks exposed to it for an hour. Several other chemicals appeared potentially useful in deterring tick attachment.

Milling Millipedes

While some animals use citrus to ward off parasites, others roll on or rub themselves with crushed millipedes.

"Certain millipedes discharge chemicals to protect themselves," Carroll says. "If you pick up some species of millipedes, you'll notice the characteristic smell of cyanide."

Carroll and his colleagues tested the responses of lone star ticks to three benzoquinone chemicals found in millipedes and to permethrin, a commercial insecticide and repellent. Ticks were confined in filter-paper packets treated with each chemical for 1 hour.

Only one of the benzoquinone chemicals killed ticks, but it was not as toxic as permethrin, Carroll says. In the behavioral tests, all three benzoquinones inhibited righting and climbing. At higher concentrations, they impaired tick climbing for months.

"Some of the experimental methods that we used are kind of simple, but they can provide a lot of information," Carroll says. "In fact, one of the things that came out of the citrus chemical study was a much-needed method for statistically analyzing repeated behavior."

Measuring Multiple Behaviors

Although scientists had compiled data on many different host-seeking behaviors, they needed a simple method to determine how to assess repellency.

Based on data collected on the effects of five chemicals on lone star ticks, BARC statistician Matt Kramer devised a method to collapse several tick behaviors into one score when tested with different chemicals.

"The idea is to use the behavioral differences observed as ticks are tested on different compounds to find optimal weightings of these behaviors," Kramer says. "The sum of these weighted behaviors produces a single score for each tick." These scores are the best single numbers that could be used for discriminating among the compounds, he adds.

"We knew different compounds should produce different behaviors," Kramer says. "We just didn't know which behaviors were the most important to use in the score and how much weight each should get before summing them."

A technique called "canonical discriminate analysis" tells how much to weight each measure or behavior to best separate known groups—animals tested on different compounds, Kramer says. With some minor changes, this technique was used to create the composite scores.

The new method allows scientists to determine which chemicals are most effective in tests, greatly reduces the complexity of the analysis, and provides a valuable tool for measuring animal behaviors.

"It can be applied not only to other animals, but also to plants and in many situations where you have multiple measurements or dependent variables for a single individual," Kramer says.

Behavioral studies are valuable in understanding organisms that affect the health of animals, humans, and plants. With the new scoring system, scientists can obtain more accurate data that will benefit the producers of repellents and, ultimately, the people who use them.—By **Sandra Avant,** ARS.

This research is part of Veterinary, Medical, and Urban Entomology, an ARS national program (#104) described at www.nps.ars.usda.gov.

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Cultural Practices To Maintain Soil Quality and Address Climate Change

UPENDRA SAINJU (D2790-1)

For decades, farmers in Montana and the Dakotas have produced impressive yields of barley and wheat. But that bounty has come at a cost. Tilling the soil in the region's crop-fallow production systems has robbed the soil of nutrients and organic matter and reduced crop yields. In fact, the region's soils have lost up to 50 percent of their organic matter in the last 50 to 100 years, and scientists say that current practices are unsustainable.

Agriculture also contributes about 25 percent of the human-made carbon dioxide and 70 percent of the human-made nitrous oxide being released into the atmosphere. Tillage, crop-fallow management practices, cropping sequences, and the use of nitrogen fertilizers all play significant roles in those emission levels.

Agricultural Research Service scientists and their university partners are providing guidance to growers on ways to keep soils productive and reduce their climate change footprint by turning to some of agriculture's most tried-and-true practices.

At the ARS Agricultural Systems Research Unit in Sidney, Montana, Upendra Sainju and his colleagues have been studying how no-till systems, crop rotation, ecological (or alternative) cultural practices, nitrogen fertilization, and sheep grazing can improve soil quality, reduce greenhouse gas emissions, sustain crop yields, and reduce the amount of nitrogen polluting the air and water.

Growers have known for decades that no-till improves soil quality and that rotating crops reduces weeds, diseases, and pests. Grazing by livestock is also widely known to control weeds and pests and supply a natural fertilizer. The ARS studies in Montana and North Dakota are among the first to show how these systems are feasible alternatives that do not result in reduced yields. The research is also one of the first comprehensive efforts to examine the effects of irrigation and different crop management scenarios on greenhouse gas emissions in the northern Great Plains.

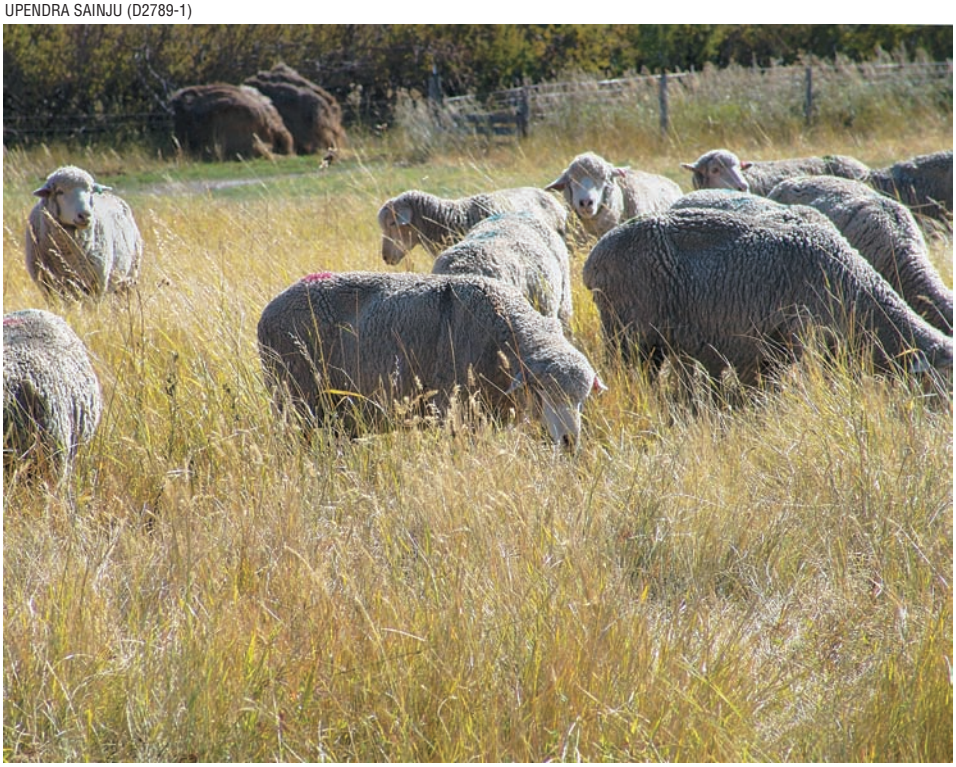
"These are issues that affect not only growers, but also the environment," Sainju says.

Grazing Sheep: A Viable Option

Grazing sheep and other livestock on cropland was common in the region before commercial fertilizers were introduced in the 1950s. Fertilizers have increased yields, but they also have increased nitrogen runoff and leaching, made soils more acidic, and contributed to greenhouse gas emissions. Some growers looking for alternatives, particularly those with organic operations, have turned to grazing sheep during seasons when fields are left fallow. The trend in Montana and North Dakota prompted Sainju and his colleagues to study the effects of grazing on crop quality, soil chemistry, and amounts of nutrients in the soil, each of which can have long-term effects on yields.

Sainju and his colleagues set up three cropping systems (continuous spring wheat, spring wheat-fallow, and winter wheat-fallow) in southwestern Montana and compared soil qualities on plots

UPENDRA SAINJU (D2789-1)



Left: Winter wheat residue (left) and spring wheat (right) at an experimental site in southwestern Montana. In the fenced plots (far), sheep are allowed to graze on crop residue and weeds. ARS scientists are looking at different crop management techniques to improve soils, such as grazing, crop tillage, and no-till. Above: White-faced sheep grazing on crop residue and weeds at the experimental site.

where, during the fallow season, sheep were grazed, herbicides were used, or the soil was tilled for weed control.

Over 4 years, sheep were grazed at rates of up to 153 sheep per hectare, glyphosate was applied at standard rates, and soils were tilled to a standard 15 centimeters depth. Soil samples from varying depths were analyzed for organic matter, nutrients, pH, and electrical conductivity.

Results showed that tillage returned more of the beneficial wheat residue to the soil than either grazing or the herbicide treatments, resulting in higher levels of calcium, sulfur, and electrical conductivity in the soil.

The different cropping sequences had mixed effects. The spring wheat-fallow sequence returned the least amount of residue to the soil, and the continuous spring wheat produced higher annualized yields than the spring wheat-fallow system.

Grazing sheep returned some of the phosphorus and potassium in the wheat residue to the soil by way of feces and urine, but weed growth between grazing bouts reduced available concentrations of those nutrients. Grazing increased soil levels of magnesium and sodium, possibly because the urine and feces contained higher levels of them.

In general, the results showed that grazing had no negative effects on soil organic matter and crop yields and that growers could offset the reduced levels of phosphorus and potassium by limiting the amount of grazing or fertilizing fields with those nutrients. The results were detailed in papers published in *Agronomy Journal* in 2010 and *Soil Science Society of America Journal* in 2011.

Promoting a Novel Management Practice

Sainju and his colleagues also evaluated the effects of different management practices in eastern Montana, where irrigation is rarely available for most crops. They grew spring wheat in some areas and in alternative plots rotated it with hay barley, corn, and peas over a 4-year rotation cycle. The researchers tilled some plots, left others untilled, and used two different cultural practices to control weeds and apply nitrogen fertilizer.

In some plots they used traditional cultural practices that included conventional seeding rates and planting dates and broadcast systems to apply fertilizer. In others, they delayed planting for 2 to 3 weeks and seeded plots in arrangements specifically

ARS technician Joy Barsotti collects greenhouse gas samples from a static chamber at an experimental site in eastern Montana. ARS scientists are helping growers reduce their climate change footprint.

UPENDRA SAINJU (D2791-1)

designed to minimize weed competition. In those areas, they placed fertilizer directly into the soil rather than broadcasting it, and they left taller postharvest stubble on the ground. Delayed planting allows growers to terminate weeds with herbicides at a stage when the weeds are more fully developed, which reduces their threat to the crop later in the growing season. Placing nitrogen fertilizer directly in the soil reduces nitrogen runoff, and leaving tall stubble also means fields capture more snow in the winter, increasing soil moisture and boosting crop yields.

The researchers say their no-till, 4-year rotation cycle also offers numerous advantages. No-till conserves soil water, reduces soil erosion, and increases organic matter compared to conventional tillage. Including hay barley and pea in the rotation with cereal crops uses less soil water, resulting in more water available for succeeding crops. Peas also supply nitrogen to the soil and reduce the need for nitrogen fertilizer.

"It's a system that uses soil water and nitrogen more efficiently, increases soil organic matter, reduces the risk of crop failure from drought, and uses less nitrogen fertilizer, up to 20 pounds less per acre," Sainju says.

UPENDRA SAINJU (D2791-2)

Close-up of a static chamber in a field of malt barley. The chamber is used to collect greenhouse gas samples coming off this tiny section of the plot.

The researchers published three papers based on the field work. In one, they evaluated the effects of the different management practices on crop residue and soil organic matter levels. In another, they examined carbon sequestered in the soil and labile carbon fractions by analyzing levels of soil surface residue, microbial biomass and activity critical to soil health, and other factors. In the third study, they looked at levels of nitrogen in the soil being "cycled" into the crops. Nitrogen cycling is a critical environmental issue because crops need to take up nitrogen to grow, but if too much nitrogen is in the soil it can be released in the air as nitrous oxide or leach into waterways.

Together, the results of the studies showed that no-till with the traditional cultural practices increased soil organic matter, led to higher carbon sequestration rates, optimal nitrogen cycling, and higher levels of the kinds of microbial biomass and activity important for soil health. Conventional till to control weeds with diversified crop rotation also increased nitrogen mineralization and availability.

The soil organic matter study results were published in *Plant and Soil* (2011). The carbon fractions study was published in the *Open Journal of Soil Science,* and the nitrogen cycling study appeared in *Nutrient Cycling in Agroecosystems,* both in 2012.

Fewer Emissions With Crop Rotation and Reduced Nitrogen Fertilization

In another experiment, the researchers evaluated the effects of irrigation, tillage, cropping systems, and nitrogen fertilization on greenhouse gas emissions from five cropping systems in sandy loam soil in western North Dakota, where growers can irrigate fields. They also studied three cropping systems under dryland conditions in loam soil in eastern Montana. For 4 years, they raised conventionally tilled malt barley with and without nitrogen fertilizer, no-till malt barley with and without nitrogen fertilizer, and a no-till malt barley-pea rotation with and without nitrogen fertilizer. Some systems were irrigated and others were not, and the researchers tracked soil temperatures and soil water content; measured plant biomass; and used static, vented chambers to measure greenhouse gases.

Results, described in the *Journal of Environmental Quality* (2010) and in the *Soil Science Society of America Journal* (2012), showed that regardless of whether the field was irrigated, the no-till malt barley-pea rotation with reduced rate of nitrogen fertilization was the most effective system for reducing greenhouse gas emissions and sustaining crop yields. They also found that the no-till barley-pea rotation reduces the need for nitrogen fertilizer with no effect on yields.

Getting the Word Out

The studies are prompting growers in Montana and the Dakotas to graze sheep more readily, adopt no-till systems, rotate crops, and use less nitrogen fertilizer. Growers are seeing how no-till crops can be grown every year instead of leaving the land fallow for a year, a common practice in the region. Rotating legumes like peas with nonlegumes also reduces the need for nitrogen fertilizers and the likelihood that nitrogen will flow into water supplies and air as greenhouse gas.

"The benefits are apparent. To some extent, it's just a matter of getting the word out," Sainju says.—By **Dennis O'Brien,** ARS.

The research is part of Agricultural System Competitiveness and Sustainability (#216) and Water Availability and Watershed Management (#211), two ARS national programs described at www.nps.ars.usda.gov.

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A Desert Shrub's Crystallized Protein Sheds Light on Photosynthesis

MIKE SALVUCCI (D2781-2)

Right: Three-dimensional view (via X-ray crystallography) of rubisco activase from creosote bush.

Plants use an enzyme known as "rubisco" to capture carbon dioxide from the atmosphere and, with energy from the sun and nutrients from the soil, build up the shoots, leaves, and stems that make up the plant itself. Scientists have known that for years. They also have known that temperatures are important. When it gets too hot, a rubisco helper protein called "rubisco activase" shuts down, photosynthesis stops, and the plant stops growing. Heat literally unravels the activase protein, and when it does, the result is a less bountiful harvest. Different plants shut down photosynthesis at different temperatures, and the process of unraveling the activase protein is known as "denaturation."

Michael E. Salvucci, an Agricultural Research Service plant physiologist with the U.S. Arid-Land Agricultural Research Center, has teamed with Rebekka Wachter, associate professor of chemistry and biochemistry at Arizona State University, and Nathan Henderson, her postdoctoral research associate, to crystallize rubisco activase.

Crystallization will allow researchers to study the activase protein more closely, to visualize its structure, and possibly to manipulate its sequence so that it doesn't unravel at higher temperatures. The findings could help in the search for genes that cue plants to synthesize more heat-stable versions of the protein. Crops with such enhanced proteins could thrive at higher temperatures.

With climate change expected to alter landscapes and growing cycles, the work is considered all the more relevant.

The work builds on previous research by William L. Ogren and Archie R. Portis, Jr., two retired ARS scientists who were based in Urbana, Illinois, and Salvucci, who worked with them as a postdoctoral researcher in the 1980s. The team discovered the existence of rubisco activase in 1985 and proved that it activates rubisco. For this and other accomplishments in the field of photosynthesis, Ogren was awarded the coveted International Alexander Von Humboldt Foundation Award. He was also named to the ARS Hall of Fame and to the National Academy of Sciences.

Scientific teams around the world have been trying to crystallize rubisco activase ever since. "You need to know what the protein looks like to understand how it works," Salvucci says. For proteins, the tougher and more rigid a structure, the easier it is to crystallize. But the problem has been that most plant activase proteins do not have rigid or even regular structures.

Wachter, Salvucci, and Henderson managed to crystallize the activase protein from the creosote bush, a shrub abundant in the Arizona desert. (The plant has no connection to the tarlike preservative found in many wood products.) They wanted to find the most temperature-tolerant activase possible, and they chose creosote because it can survive and photosynthesize at relatively high temperatures. Wachter's research is funded by a grant from the U.S. Department of Energy.

The researchers suspected creosote's activase proteins would remain relatively stable under most conditions. They cloned the plant's activase proteins and reproduced parts of them that were stable enough that crystals could be produced from them.

The results were published in the *Journal of Biological Chemistry*.—By **Dennis O'Brien,** ARS.

NATHAN HENDERSON (D2780-1)

In Maricopa, Arizona, ARS plant physiologist Mike Salvucci and professor Rebekka Wachter from Arizona State University discuss strategies for isolating the enzyme rubisco activase from creosote bush, a heat-tolerant desert shrub.

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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KOSSI NOUWAKPO (2757-1)

Measuring and Managing Impacts of Manure Spills

KOSSI NOUWAKPO (D2753-8)

Manure spills happen for a range of reasons—a manure spreader rolls over, a hose breaks, a storage pond overflows after a relentless downpour. Whatever the cause, these events are such a threat to the environment that states have emergency teams to deal with the hazard.

Typically, the responders build dams to contain the spill and then pump out the contaminated water. Although cleanup efforts start as quickly as possible, a fish kill in a nearby stream is often the first evidence that a spill has taken place.

Another problem is that sediments in the contaminated water channel can capture phosphorus from the manure and release the nutrient back into the water—sometimes for months on end—at levels exceeding U.S. Environmental Protection Agency (EPA) criteria. But there were few details available about the links between manure spills and phosphorus until Agricultural Research Service soil scientist Doug Smith and doctoral candidate Shalamar Armstrong began to study the issue.

Smith, who works at the ARS National Soil Erosion Research Laboratory in West Lafayette, Indiana, was Armstrong's technical advisor throughout the study. ARS soil scientist Chi-hua Huang, also in West Lafayette, and soil scientist April Leytem, who works at the ARS Northwest Irrigation and Soils Research Laboratory in Kimberly, Idaho, were also part of the team.

STEPHEN AUSMUS (D2753-13)

Soil scientist Doug Smith and technician Katelin Fisher collect water and sediment samples to evaluate the nutrient concentrations in them.

Sizing Up Sediments

Armstrong collected sediments from two drainage ditches in the Cedar Creek subwatershed of the St. Joseph River Watershed in northeast Indiana. The land surrounding each ditch was primarily used for row cropping.

Three sampling locations were selected so that the study would include sediments from drainage areas that ranged from 768 acres to 10,625 acres. This methodology also ensured that the scientists would be able to assess the effects of different particle size distributions and physiochemical properties on phosphorus absorption.

The West Lafayette team added the sediments to an artificial water channel called a "fluvarium" and used swine manure minimally diluted with water to create their

Far left: In West Lafayette, Indiana, researcher Shalamar Armstrong applies chemical lime/alum sulfate during testing of sediment and water samples from drainage ditches in northeast Indiana. Left: Soil scientist Doug Smith prepares a sample for nutrient analysis.

own worst-case manure "spill." Then, after 24 hours, they cleaned it up using standard operating protocols for remediating contaminated spill sites.

The researchers found the spill simulation initially resulted in an average water column dissolved phosphorus concentration of 5.57 milligrams per liter. The concentrations dropped to between 0.19 and 0.21 milligrams per liter 24 hours later, but they still exceeded EPA standards for rivers, streams, and drainage ditches in the Cedar Creek subwatershed.

The scientists also documented that after the spill, the channel sediments were able to capture significant amounts of phosphorus from the water, with adsorption rates ranging from 8.9 to 16.7 milligrams per square meter of sediment per hour. The finest clay loam sediments from the upstream channel sites adsorbed the greatest levels.

"These clay loam sediments have a larger surface area available for the chemical reactions that bind the phosphorus to the sediments," Smith explains. "These sediments also have the highest levels of iron, aluminum, and organic carbon, all of which enhance the ability of the sediments to bind phosphorus."

However, after the simulated spill cleanup, all the sediments released phosphorus back into the water at rates that caused the phosphorus level in the ditch water to exceed EPA's maximum level by at least 67 percent. Even though the fine-textured clay loam sediments adsorbed the highest levels of phosphorus, the course-textured sandy sediments from the largest drainage areas released the most phosphorus back into the water after cleanup was complete.

"These results strongly suggested that the current approaches to remediating manure spills need improvement," Smith says.

Shalamar Armstrong collects drainage ditch sediment that will be used in laboratory testing of worst-case manure spill scenarios.

An Answer in Alum

Fortunately, the team had some ideas about where to start looking for improvements. Earlier studies showed that adding alum to poultry litter, swine manure, and other agricultural byproducts substantially mitigates phosphorus release. So they ran a series of tests to see how well alum amendments could stop, or at least slow, the release of phosphorus deposited in channel sediments after manure spills.

The researchers added different levels of an alum-calcium carbonate mix to the same sediments they tested in the first study. The calcium carbonate was included to prevent the acidic alum from significantly increasing the water's acidity.

They observed that amending the contaminated sediments with 1.6 milligrams of alum-calcium carbonate per gram of sediment suppressed phosphorus release by 92 percent in sandy sediments and by 72 percent in clay loam and loamy sand sediments. Higher amendment levels suppressed phosphorus release in all three soil types by up to 100 percent.

In general, greater rates of alum were needed to suppress phosphorus release from the clay loam sediments than from either the loamy sand or the sandy sediments. On average, clay loam sediments required 54 percent more alum to mitigate the release of phosphorus than sediments containing at least 60 percent sand.

Adding calcium carbonate to the alum did not completely protect the water column from increased acidification. But water flowing over sediments amended with the alum-calcium carbonate mix was less acidic than water flowing over sediments amended solely with alum. Data from the study was used to develop models to predict the rate of alum application that would be needed to mitigate phosphorus release from contaminated sediments, based on sediment properties.

"Our results demonstrated that alum can help sediments retain phosphorus after a manure spill," says Armstrong, who is now an assistant professor at Illinois State University. "We think it has potential for enhancing current manure spill remediation methods." Findings from both studies were published in the *Journal of Environmental Quality* in 2009 and the *Journal of Environmental Monitoring* in 2012.

"These are the first studies that have examined in detail how manure spills affect in-stream phosphorus fate," adds Smith. "Farmers are focusing on finding ways to contain phosphorus loss from their farms, and this information could help."—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.

To reach scientists mentioned in this story, contact Ann Perry, USDA-ARS Information Staff, 5601 Sunnyside Ave., Beltsville, MD 20705-5129; (301) 504-1628, ann.perry@ars.usda.gov.

KOSSI NOUWAKPO (D2755-1)

Trickery and Other Methods Explored To Vanquish Potato Cyst Nematodes

The pale cyst nematode, *Globodera pallida,* is one bad roundworm.

Unchecked, it invades the roots of potato and other host crops to feed, obstructing the free flow of nutrients and causing stunted growth, wilted leaves, and other symptoms that can eventually kill the plant. Severe infestations in potato fields can cause yield losses of up to 80 percent.

To make matters worse, female *G. pallida* nematodes form hard, round cysts that safeguard their eggs from predators and parasites, inhospitable conditions, or a scarcity of food. As many as 30 years may pass before the eggs hatch (cued by a signal from their plant host) to spawn a new generation of nematodes to restart the cycle of destruction.

POTATO CYST NEMATODE RESEARCH GROUP (D2798-1)

Microscope image of a juvenile pale cyst nematode (right) emerging from an egg.

Now, however, a team of ARS and university researchers is working to exploit those plant signals to help counter the emerging threat this pest poses to America's $3.4 billion tuber crop.

The signals are chemicals—called "egg-hatching factors"—secreted from the roots of potato and some other solanaceous plants into the soil. There, "they penetrate the cysts, stimulating the eggs inside to hatch," explains Roy Navarre, an Agricultural Research Service plant geneticist with the Vegetable and Forage Crops Research Laboratory in Prosser, Washington. The scientists aim to use the chemicals to trick the eggs into hatching when no potato plants are present, leaving the hatchling nematodes with no host and thus no way to survive.

Leader of the Potato Cyst Nematode Pack

G. pallida, a nonnative species, was first detected in eastern Idaho in April 2006. To

ARS scientists are growing potato plants hydroponically to generate root secretions that cause pale cyst nematodes to hatch. The secreted chemicals could be used in biocontrol efforts against these potato pests.

ROY NAVARRE (D2795-1)

STEPHEN AUSMUS (D857-1)

Geneticists Chuck Brown (left) and Roy Navarre examine diverse potato lines. One of several ways to battle the pale cyst nematode that can infest potatoes is to find genes conferring resistance to the pest.

date, the species has been found in—and confined to—a 5-mile radius comprising 1,916 total acres in Bingham and Bonneville counties.

G. pallida isn't the first cyst nematode species to be detected in the United States on potato, though. That distinction goes to the golden nematode, *G. rostochiensis,* which was first reported in 1941 in New York State and is confined today to eight counties there. A third species of unknown origin, initially dubbed "atypical *Globodera"* and now known as *G. ellingtonae,* was found in small pockets on an Oregon State University (OSU) research farm near Powell Butte.

Despite *G. pallida's* limited geographic distribution, its U.S. presence has had far-reaching impact: closed or limited export markets, devalued farmland, regulatory restrictions, and other economic hardships. Ornamental plant nurseries in Idaho were also adversely affected immediately after the pest's 2006 detection.

"This nematode species is really bad news," says Navarre, whose collaborators include Chuck Brown and Rick Boydston, both with ARS at Prosser; Inga Zasada at the ARS Horticultural Crops Research Unit in Corvallis, Oregon; Mike Thornton and Louise-Marie Dandurand of the University of Idaho; and Russ Ingham, with OSU.

G. pallida has been labeled a quarantine pest and targeted for eradication. Eradication efforts have involved fumigating infested fields about twice a year with one of two chemical pesticides: methyl bromide or Telone II. One problem, though, is that "the cysts are somewhat resistant to fumigation," Navarre says. "Additional methods of control that can complement fumigation efforts would facilitate eradication" and reduce costs of implementing it on a large scale.

Use of egg-hatching factors could be one such method.

Formulating a Plan of Attack

Two approaches are being explored to force the nematode eggs to hatch: The first is to use "trap crops" as the vehicle to deliver hatching factors. A trap crop would make the hatching factors and secrete them into the soil just like the host crop does, but the trap crop would be resistant to the nematode and not allow it to reproduce.

In Europe, sticky nightshade, *Solanum sisymbriifolium,* is being used as a trap crop. Navarre's group was the first to establish that it stimulates eggs of the Idaho nematode population to hatch. His team also didn't observe any reproduction of the pest. The researchers are now interested in ways of making a superior trap crop and have produced sticky nightshade with greater root mass. This will allow them to determine whether such plants secrete greater amounts of hatching factors, cover greater soil area, or secrete hatching factors deeper into the soil.

Since sticky nightshade is covered in thorns, ARS plant geneticist/breeder Chuck Brown has produced lines with fewer thorns to make the plant easier to work with. The researchers are also searching for other potential trap crops that could provide an economic return to growers or not present a potential weed threat.

The second approach being explored is to use hatching factors directly, either as a soil amendment or through chemical irrigation.

"At least 10 compounds are involved," says Navarre, citing the results of chromatography analysis, but a few key compounds might suffice for direct field application. The researchers are also exploring methods to produce large amounts of a mix of partially purified hatching factors that could be used on a commercial scale.

"We are focusing on *G. pallida* now, but we expect the strategy would also work on *G. rostochiensis* and *G. ellingtonae*." he adds.

There are lower costs associated with planting trap crops, but there is greater flexibility in using purified or partially purified egg-hatch chemicals.

Other strategies under investigation include:

• biological control, including a soil fungus Dandurand is studying that ensnares the nematode in a web of filaments and consumes its innards

• surveys by Boydston of weedy hosts—the identification and management of which could help deprive the nematode of places to hide and reproduce

• examinations by Brown of existing potato germplasm collections for genes conferring resistance

• basic studies of the pest's biology and life cycle for weaknesses that could be exploited, especially proteins enabling it to infiltrate host roots, and

• use of so-called green manures, including arugula, that could be worked into the soil to reduce nematode populations before planting.

"What will likely emerge from all this is a response to eradicating the nematode that uses these methods in concert," says Navarre.—By **Jan Suszkiw,** 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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MATT MYERS (D2784-1)

Measuring the Potential of Switchgrass Pellets

President Barack Obama wants U.S. scientists to pursue an "all-of-the-above" strategy in developing new sources of domestic energy. Agricultural Research Service agronomist Paul Adler is providing complete cost-benefit breakdowns for using switchgrass pellets instead of fuel oil to heat homes and businesses in the Northeast.

"There have been a lot of studies on bioenergy potential," says Adler, who works at the ARS Pasture Systems and Watershed Management Research Unit in University Park, Pennsylvania. "Most of them are focusing on transportation, but we still need a viable, commercial, biobased fuel substitute for petroleum. In the meantime, our studies suggest that we already have opportunities to use homegrown feedstocks for producing heat, and that we can save money, reduce petroleum use, and cut greenhouse gas production in the process."

Adler and others conducted a life-cycle assessment comparing costs of energy generation from coal, natural gas, fuel oil, and switchgrass in the form of energy-dense cubes, briquettes, and pellets. His research partners included ARS technician Fred McNeal, Pennsylvania State University graduate student Tom Wilson, Wilson's advisor David Abler, and Drexel University assistant professor Sabrina Spatari.

The researchers calculated the economic outlays associated with switchgrass pro-

Denny Bookhamer assesses switchgrass stand density in January prior to harvest near Chestertown, Maryland. Switchgrass has potential as a biomass fuel to replace fuel oil.

MATT MYERS (D2807-1)

This greenhouse full of orchids is heated by a biomass boiler system. Here, ARS technician Denny Bookhamer (left) and president of Plainview Growers Arie Van Vugt discuss the use of biomass instead of fuel oil and the potential carbon footprint from each.

duction throughout the supply chain and the amounts of greenhouse gases—carbon dioxide, nitrous oxide, and methane—emitted during switchgrass production, densification, and conversion to heat and power. This included the first life-cycle inventory of switchgrass seed production and the greenhouse gas emissions associated with it, which the team developed using real-world information from a Pennsylvania producer.

The analysis indicated that 192 pounds of "carbon dioxide equivalent," or CO_2e, were emitted for every ton of switchgrass dry matter that was grown, harvested, and delivered to densification plants for processing into pellets. CO_2e is a measurement used to compare the emissions from various greenhouse gases based on their global-warming potential.

More than 54 percent of these emissions were from nitrous oxide resulting from nitrogen fertilizer application, while farm equipment operation also produced substantial levels of greenhouse gases. Processing each ton of dry matter into pellets generated another 287 pounds of CO_2e; 78 percent of these emissions stemmed from grinding and pelletizing processes, with the remainder coming from the drum dryer.

Feel the Heat

With these findings in hand, the researchers calculated that using switchgrass pellets instead of petroleum fuel oil to generate one gigajoule of heat in residences would reduce greenhouse gas emissions by 146 pounds of CO_2e. Using switchgrass pellets instead of natural gas to produce one gigajoule of heat in residences would reduce greenhouse gas emissions by 158 pounds of CO_2e.

Substituting switchgrass pellets for fuel oil for home heating would also save money. Totaling all costs associated with installing an appropriate residential heating system and fuel consumption, Adler's team concluded that each gigajoule of heat produced using switchgrass pellets would cost $21.36. Using fuel oil to produce the same amount of heat would cost $28.22. The savings would be less in a commercial facility, because capital costs for a commercial biomass boiler, storage, and fuel-handling equipment are five times greater than the costs for components that use fuel oil.

According to the team's calculations, heating with switchgrass pellets would continue to be less expensive even if switchgrass production costs rose 200 percent and the price of fuel oil dropped 70 percent. These findings are based on the average heating-oil price from the 2010-2011 heating season, which was $0.90 per liter. But even if fuel-oil prices dropped to their 10-year average of $0.62, it would still cost less to generate a gigajoule of heat using switchgrass pellets.

Coal is a somewhat different story. Although substituting biomass for coal in electric generation substantially reduced greenhouse gas emissions, it would come at a high cost to domestic consumers. Using coal, it would cost $31.03 to generate each megawatt of electricity, but using switchgrass briquettes would cost $154.62, and switchgrass cubes would cost $156.52. (Briquettes and cubes were used in this series of life-cycle analyses because of their lower energy intensity relative to pellets.) So even though greenhouse gas emissions would drop dramatically by using switchgrass to generate power, these reductions are achieved at a high cost relative to coal—an outcome called "positive abatement costs" that policymakers would like to avoid.

A die extrudes pellets at the pellet mill of Plainview Growers in Allamuchy, New Jersey, as a feedstock for heating greenhouses.

MATT MYERS (D2786-1)

Biomass pellets produced from the die shown at left. They can be burned as a renewable fuel source to heat greenhouses and other buildings.

MATT MYERS (D2786-2)

Biomass pellets burning inside the boiler furnace chamber supply radiant heat for all 8 acres of greenhouses at Plainview Growers.

MATT MYERS (D2785-1)

Using projections from the U.S. Department of Energy's "Billion Ton Report," the scientists concluded that by 2022 there would be enough sustainably harvested biomass available in the northeastern United States to offset the entire regional demand for heating oil. This would save consumers between $2.3 and $3.9 billion per year in fuel costs.

It would also reduce greenhouse gas emissions in the Northeast—currently around 885 million tons of CO_2e every year—by 5 percent. Many renewable-fuel projects are tasked with finding cost-effective strategies for generating electricity with biomass instead of coal, but replacing fuel oil with switchgrass pellets in home heating systems could become just as beneficial.

Replacing fuel oil with switchgrass pellets in home heating systems could save consumers billions of dollars.

Partners in Pellets

Adler is now working with Plainview Growers president Arie Van Vugt to determine the carbon footprint of using biomass rather than fuel oil to heat the nursery's greenhouses and how much it costs to reduce that carbon footprint using various fossil fuel alternatives. Plainview Growers has two production locations in New Jersey and sells more than 160 million nursery plants produced from seeds every year.

Van Vugt, who also started a company called "Pequest Energy" with the goal of using locally grown and sustainable sources of biofuel for energy production, already burns pellets made from locally grown warm-season grasses to heat some of his greenhouses.

PEGGY GREB (D2808-1)

Switchgrass can be formed into pellets, cubes, and round briquettes that can be used to heat homes and businesses instead of fuel oil.

The scientists have published their results in *Environmental Science & Technology*. Wilson, who conducted the work as part of his master's program, was the lead author. Adler notes that this research—which is the first published life-cycle analysis of the costs and benefits of using switchgrass-derived fuel for U.S. thermal generation—demonstrates that the energy contained in switchgrass pellets compares favorably with that contained in petroleum-based fuels.

"We can use a ton of pellets made from dried switchgrass to replace 116 gallons of fuel oil that contains 17.2 megajoules of energy. Or we can use a ton of switchgrass pellets to replace 50 gallons of gasoline that contains 6.2 megajoules of energy. So using biomass to replace fuel oil displaces more than twice as much petroleum as using biomass to replace gasoline," says Adler. "If we use the switchgrass to replace fuel oil instead of the coal used to generate electricity, we also substantially reduce greenhouse gas emissions at a much lower cost to consumers—and help meet our long-term goals for domestic energy production from alternative fuels."—By **Ann Perry,** ARS.

This research is part of Bioenergy, an ARS national program (#213) described at www.nps.ars.usda.gov.

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The Agricultural Research Service has about 100 labs all over the country.

Locations Featured in This Magazine Issue

Locations listed west to east.

Map courtesy of Tom Patterson, U.S. National Park Service

Davis, California
3 research units ■ 117 employees

Corvallis, Oregon
3 research units ■ 127 employees

Vegetable and Forage Crops Research Unit, Prosser, Washington
1 research unit ■ 35 employees

Northwest Irrigation and Soils Research Laboratory, Kimberly, Idaho
1 research unit ■ 34 employees

U.S. Arid-Land Agricultural Research Center, Maricopa, Arizona
3 research units ■ 80 employees

Northern Plains Agricultural Research Laboratory, Sidney, Montana
2 research units ■ 59 employees

Children's Nutrition Research Center, Houston, Texas
1 research unit ■ 8 employees

National Center for Agricultural Utilization Research, Peoria, Illinois
7 research units ■ 201 employees

West Lafayette, Indiana
3 research units ■ 71 employees

Center for Medical, Agricultural, and Veterinary Entomology, Gainesville, Florida
4 research units ■ 134 employees

University Park, Pennsylvania
1 research unit ■ 40 employees

Henry A. Wallace Beltsville Agricultural Research Center, Beltsville, Maryland
30 research units ■ 707 employees

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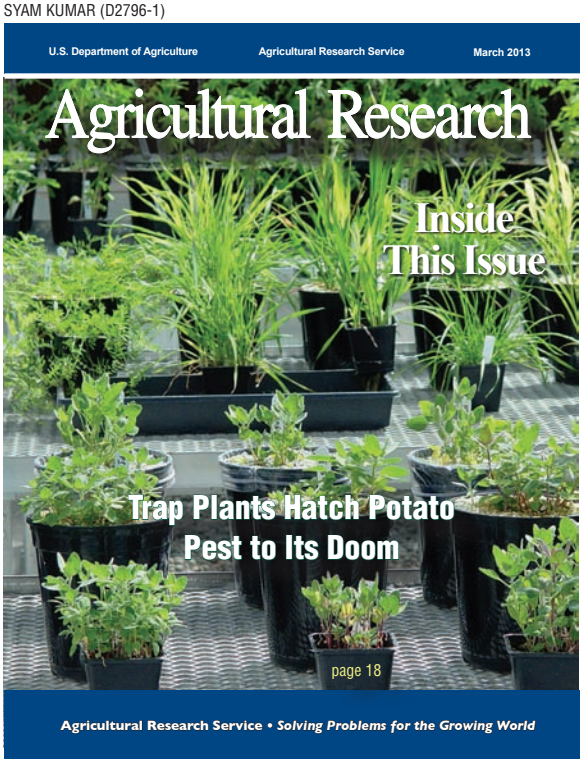

STEPHEN AUSMUS (D2813-8)